Clinical Nutrition ESPEN 72 (2026) 102973

Contents lists available at ScienceDirect

Clinical Nutrition ESPEN

journal homepage: http://www.clinicalnutritionespen.com

Original article

Dietary intake distribution patterns in post-intensive care patients

Michelle C. Paulus [a,b], Tommaso X. Verhoog [a], Rianne Slingerland-Boot [a,b], Arthur R.H. van Zanten [a,b], Imre W.K. Kouw [a,b,*]

[a] Department of Intensive Care Medicine & Research, Gelderse Vallei Hospital, Ede, the Netherlands
[b] Division of Human Nutrition and Health, Nutritional Biology, Wageningen University & Research, Wageningen, the Netherlands

ARTICLE INFO

Article history:
Received 21 January 2026
Accepted 9 February 2026

Keywords:
Critical care
ICU survivors
Nutrition support
Energy
Protein

SUMMARY

Background & aims: Adequate oral food intake remains a challenge in Intensive Care Unit (ICU) survivors on the general hospital ward, with evidence suggesting that daily energy and protein intake from oral food intake are inadequate during recovery from critical illness. Currently, limited evidence is available regarding meal intake distribution patterns and the impact of prolonged enteral tube feeding on oral intake in survivors of critical illness. This study aimed to: (1) investigate daily distribution of energy and protein intake patterns of oral meals; and (2) evaluate the impact of enteral tube feeding on oral food intake, including potential differences across mealtimes, in post-ICU patients during the first 14 days of recovery after critical illness on the ward.

Methods: This was a pre-post comparison of two prospective observational cohorts (PROSPECT-I and II) conducted at Hospital Gelderse Vallei (the Netherlands) before and after the implementation of a tailored nutrition protocol in post-ICU patients during recovery on the general hospital ward. Adult ICU survivors who stayed ≥72 h in the ICU and were receiving enteral tube feeding at ICU discharge were included. Daily energy and protein content from oral food consumption during the first 14 days post-ICU were analysed. Ordered and consumed intake data were pooled by mealtime (breakfast, lunch, and dinner) and intake distributions across mealtimes (within-group comparisons) were compared using the Kruskal–Wallis test, with Dunn's post-hoc test applied in case of significant differences.

Results: Oral food consumption data from 90 participants ($n = 24$ pre-implementation and $n = 66$ post-implementation) with a median hospital stay of 10 days post-ICU discharge were analysed. For all ordered meals, median oral energy content ranged from approximately 481 to 555 kcal across main meals, and median oral protein content ranged from 22.1 g to 28.2 g. However, median energy intake from consumed meals ranged from 302 to 354 kcal, with no differences between specific meal moments (all $p > 0.05$). Absolute protein intake did not differ across meals ($p = 0.423$), with median values ranging from 14.5 to 15.0 g per mealtime. Following implementation of the tailored nutrition protocol, patients received enteral tube feeding for a longer duration (median 5 vs. 3 days, $p = 0.002$). Patients had lower energy and protein intake from oral food intake (both $p < 0.001$). The tailored nutrition intervention resulted in higher total daily energy (2115 vs. 1816 kcal, $p < 0.001$) and protein intake levels (108.1 vs. 91.5 g, $p < 0.001$).

Conclusions: Post-ICU patients showed an even distribution of energy and protein intake from oral food consumption throughout the day, suggesting a per-meal intake threshold. The introduction of a tailored nutrition protocol resulted in prolonged enteral tube feeding post-ICU, increased energy and protein adequacy, but reduced oral meal consumption.

Abbreviations: ABW, Actual body weight; APACHE, Acute Physiology and Chronic Health Evaluation; BMI, Body Mass Index; ICU, Intensive Care Unit; NICE, National Intensive Care Evaluation (The Netherlands); mNUTRIC, Modified Nutrition Risk in the Critically Ill; ONS, Oral nutritional supplements; SOFA, Sequential Organ Failure Assessment.

* Corresponding author. Division of Human Nutrition and Health, Chair Group Nutritional Biology, Wageningen University & Research, Stippeneng 4, 6708 WE Wageningen, and Intensive Care & Research, Gelderse Vallei Hospital, Willy Brandtlaan 10, 6716 RP Ede, the Netherlands.
E-mail address: imre.kouw@wur.nl (I.W.K. Kouw).

https://doi.org/10.1016/j.clnesp.2026.102973

1. Introduction

Inadequate oral food intake is a common issue among Intensive Care Unit (ICU) survivors following transfer to the general ward, with studies indicating persistent deficits in energy and protein consumption during recovery from critical illness, both during the initial phase of hospital recovery and up to a year after discharge [1–4]. Patients who rely solely on an oral diet represent the group at highest risk for insufficient nutritional intake following ICU discharge, consuming only 55–75 % of their energy and 27–74 % of their protein needs during the early stages of ward-based recovery [2]. Because patients receiving enteral nutrition typically achieve greater nutritional adequacy, premature removal of feeding tubes is often identified as a significant barrier to meeting nutritional goals [1,2].

Several patient-related factors may contribute to inadequate nutritional intake, including diminished appetite, altered smell and taste, as well as physical and psychosocial challenges commonly experienced after critical illness [5–9]. A recent review highlights that while early satiety and reduced appetite often improve within three months post-ICU, appetite dysregulation can persist longer and is linked to long-term low mood [10]. Moreover, fatigue is one of the most frequently reported symptoms post-ICU discharge, with up to 90 % of patients reporting that it impacts dietary intake [11–13]. In addition to patient-related barriers, clinician and system-related factors, such as transition of care, removal of feeding tubes, and the availability of food assistance, also play a role in limiting nutritional intake [7,8].

vRecent studies have implemented intensive monitoring and nutrition protocols that promote individualised enteral and parenteral tube feeding, as well as nutritional supplements during the post-ICU phase, showing increased energy and protein adequacy [14–16]. However, the impact of these strategies on patients' oral food intake remains unclear, and it is unknown whether enteral tube feeding, often administered in addition to voluntary oral food consumption throughout the day, affects specific mealtimes more than others [17]. This may be particularly relevant, as large differences have been observed between ordered and consumed meals in patients during the post-ICU phase, suggesting a potential ceiling effect on patients' oral intake [15]. Despite this, there is limited evidence on meal-level distribution of food intake in post-ICU populations. Understanding the timing and distribution of food intake could be of relevance for muscle mass preservation, as it has been shown that a more even protein distribution can optimise whole-body protein net balance compared to a skewed intake [18,19]. Moreover, timing of nutrition plays an important role in circadian health, which is drastically disturbed during critical illness [20]. As such, examining post-ICU intake distribution patterns is an essential first step in understanding nutritional intake behaviour during recovery from critical illness. Given the persistent anabolic resistance and delayed functional recovery commonly observed in ICU patients [21,22], optimising the distribution of protein intake across meals could be an important strategy to minimise muscle loss during recovery. In this context, understanding meal intake patterns is essential for designing effective nutritional support strategies.

Therefore, the present study aims to determine the distribution of energy and protein intake from oral food consumption in post-ICU patients during the first 14 days of recovery on the ward. Additionally, we aimed to investigate the impact of enteral tube feeding during recovery after ICU stay on oral food intake.

2. Methods

2.1. Study design and participants

This cross-sectional, pre-post study is based on data from two prospective, observational, monocentre cohort studies conducted at Gelderse Vallei Hospital, Ede, the Netherlands: the PROSPECT-I and PROSPECT-II [15]. The PROSPECT-I study, conducted from May 2019 to March 2020, investigated energy and protein intake in patients during recovery in the post-ICU hospitalisation period by analysing digital photographs of leftover meals. The PROSPECT-II study, conducted from September 2023 to November 2024, investigated the implementation of an individually tailored, stepwise nutrition protocol that gradually reduced enteral tube feeding based on the proportion of actual oral intake, aiming to achieve at least 90 % of the daily prescribed energy and protein targets. Since daily nutritional intake and meal timing were recorded in both studies, data from the two cohorts were combined for this analysis.

For the pre- and post-implementation comparison, data were used from patients enrolled in the PROSPECT-I (pre-implementation) and PROSPECT-II (post-implementation) studies who had complete food intake data for the 14 days following ICU discharge. Both studies included critically ill adults ($\geq$18 years) with an ICU stay of at least 72 h. Exclusion criteria were discharge to another facility (e.g., another ICU, hospital, or nursing home) and an expected life expectancy of $\leq$48 h. In the post-implementation cohort, additional exclusions were the absence of enteral tube feeding at ICU discharge, participation in another post-ICU nutrition study, or anticipated incomplete post-ICU nutrition (e.g., due to refeeding syndrome or a protein-restricted diet). For the present comparison, only patients receiving enteral tube feeding at ICU discharge were included to ensure cohort comparability, and patients were excluded if under a strict fasting order during the entire 14-days follow-up period. The PROSPECT-I and PROSPECT-II studies were approved by the Gelderse Vallei Hospital Medical Ethical Committee in Ede, the Netherlands (study protocol numbers 1810-181 and 2305-026).

2.2. Data collection

Unprocessed data from the PROSPECT-I and PROSPECT-II cohorts were used for analysis. Baseline characteristics, including age, sex, actual body weight, body mass index (BMI) at ICU admission, and reason for ICU admission, were extracted from the original study datasets. Clinical parameters collected at ICU admission included Acute Physiology and Chronic Health Evaluation (APACHE) II and IV scores; Barthel Index; Sequential Organ Failure Assessment (SOFA) score; and modified Nutrition Risk in the Critically Ill (mNUTRIC) score. Additional information regarding the ICU stay was collected, including the length of stay and the duration of invasive mechanical ventilation. In both cohorts, nutritional targets were available upon ICU discharge, as determined by the treating dietitian, including total energy and protein goals, both absolute and relative (per kg of actual body weight).

For the current analysis, food intake data from the first 14 days on the hospital ward - each corresponding to a full calendar day - were included. This approach was based on the original study data to ensure that each intake day had data from a sufficient number of

patients. The number of patients with available measurements for each study day is shown in Supplementary Table 1. In both studies, photographs of daily meal trays were taken by patients, nursing staff, or food service assistants before and after eating to estimate food consumption, using either a digital photo camera (PROSPECT-I) or a tablet (PROSPECT-II). Food intake from photos was categorised by using a semi-quantitative scale: 0 (nothing consumed), 0.25, 0.375, 0.5, 0.625, 0.875, or 1.0 (entire meal consumed). In both studies, patients could order their preferred meals through the hospital meal service system, which delivered them to their bedsides within 45 min. Patients were also instructed to document any food or drinks brought from outside the hospital using a bedside form. If photographs were unavailable, food intake was assessed using food record charts, medical records, or, for the post-implementation cohort only, patient recall. If none of these sources were available, the data were marked as missing. Digital photography and food record charts have both been shown to be reliable tools for nursing staff to estimate nutritional intake [23]. The hospital's food service software automatically logged all ordered meals, including detailed nutritional information (energy and protein content), and categorised snacks and oral nutritional supplements (ONS) under the corresponding main mealtimes, breakfast, lunch, or dinner. Intake scores for each food item were converted to energy (kcal) and protein (g) values, and summed per meal to calculate the total ordered and consumed energy and protein for each main mealtime. Data on the type of enteral feeding formula, start and end times, and feeding rates of the administered (par)enteral nutrition were extracted from the study databases and medical records, allowing for the calculation of each patient's daily energy and protein intake from enteral tube feeding.

Follow-up data during hospitalisation were obtained from electronic medical records: NeoZis (MI-Consultancy, Katwijk, the Netherlands) for the pre-implementation cohort and Nexus (Nexus Netherlands, Vianen, the Netherlands) for the post-implementation cohort. Data included the number of days patients remained hospitalised after ICU discharge and any medically indicated dietary restrictions (e.g., nil by mouth or preoperative fasting), which were excluded from the analysis.

2.3. Data analysis

Continuous data were reported as mean and standard deviation (SD): mean (SD). Skewed data were reported as median and interquartile range (IQR): median [IQR]. Normality of the data was assessed visually using Q–Q plots and statistically with the Shapiro–Wilk test; a p-value >0.05 indicates no significant deviation from normality. Discrete data were displayed as proportions, such as frequencies (n) and percentages (%). Baseline characteristics were presented for the overall cohort and compared between the pre- and post-implementation periods. For continuous variables, p-values were calculated using the independent samples t-test or, for non-normally distributed data, the Mann–Whitney U test. Categorical variables were analysed using the Chi-square test. When expected cell counts were less than 5, the Fisher's Exact test was applied.

To analyse the primary outcome, the distribution of daily energy and protein intake across mealtimes following ICU discharge, analyses were conducted using all available individual meal observations, including both ordered and consumed intake, pooled by mealtime. Differences in intake distributions across mealtimes within cohorts were assessed using the Kruskal–Wallis test, with Dunn's post-hoc tests applied where appropriate. As a complementary approach accounting for repeated measurements within patients and over time, model-based analyses were performed using generalised additive mixed models, which appropriately handle the unequal number of days of intake data available for each patient. Intake was modelled separately for mealtime and intake route (oral, enteral and total), with cohort (pre-vs post-implementation) included as a fixed effect, time since ICU discharge (day) modelled as a smooth term, and a random intercept for individual patient.

For the secondary outcome, differences in energy and protein intake before and after implementation of the nutrition protocol, analyses were likewise primarily conducted at the level of individual meal observations. Daily totals for oral, enteral, and combined (oral plus enteral) intake were calculated from days with complete intake data for all mealtimes and enteral nutrition where applicable, and compared between the pre- and post-implementation groups. Model-based analyses using the same mixed modelling framework were additionally applied to estimate differences in daily intake and goal attainment relative to prescribed patient targets. Where multiple comparisons were performed, p values were adjusted using the Bonferroni method. All statistical analyses were performed using R version 4.5.1 (RStudio, PBC, Boston, MA, USA), and figures were generated in R or GraphPad Prism version 10 (GraphPad Software, USA). A two-sided p value < 0.05 was considered statistically significant.

3. Results

Oral food consumption data from 90 participants ($n = 24$ pre-implementation and $n = 66$ post-implementation) were included for analysis (Fig. 1). Baseline characteristics are presented in Table 1 and Supplementary Table 2. Participants had a median age of 69 [60–75] years, 48.9 % were male, and had a median BMI of 26.7 [23.6–30.3] kg/m^2. The median length of hospital stay after ICU discharge was 10 [7–14] days. Patients in the post-implementation cohort were more frequently admitted with a medical rather than a surgical diagnosis (81.8 % vs. 58.3 % medical and 18.2 % vs. 41.7 % surgical, $p = 0.004$) and had higher baseline APACHE II scores (24 [18–31] vs. 18 [15–27], $p = 0.012$) and SOFA scores (8 ± 4 vs. 7 ± 3, $p = 0.018$).

Complete nutritional intake data (before and after consumption) were available for 80.9 % of all meals during follow-up for energy intake (1698 out of 2100 total meals) and 80.7 % for protein intake (1695 out of 2100 meals). Of the missing data, ~75 % (300 out of about 400 missing orders) could be attributed to medical reasons, including nothing-by-mouth orders.

3.1. Distribution of energy and protein intake across mealtimes

Based on individual meal observations, the median ordered energy intake ranged from 481 to 555 kcal, and the median protein intake ranged from 22.1 to 28.2 g across mealtimes (Supplementary Table 3A). Energy and protein content varied between mealtimes (both $p < 0.001$), with higher values at dinner compared to breakfast and lunch (Fig. 2, Supplementary Table 3B). There were no differences in energy ($p = 1.000$) or protein ($p = 0.407$) content between breakfast and lunch. For consumed meals, median energy intake ranged from 302 to 354 kcal, and median protein intake ranged from 14.5 to 15.0 g. Energy intake differed across mealtimes ($p = 0.049$), but protein intake did not ($p = 0.423$). Post-hoc comparisons showed no significant pairwise differences in consumed energy between mealtimes (all $p > 0.05$). The proportion of the ordered meal that was consumed differed between mealtimes for both energy and protein ($p < 0.001$), with the highest consumption at breakfast and the lowest at dinner (Supplementary Table 3A–B).

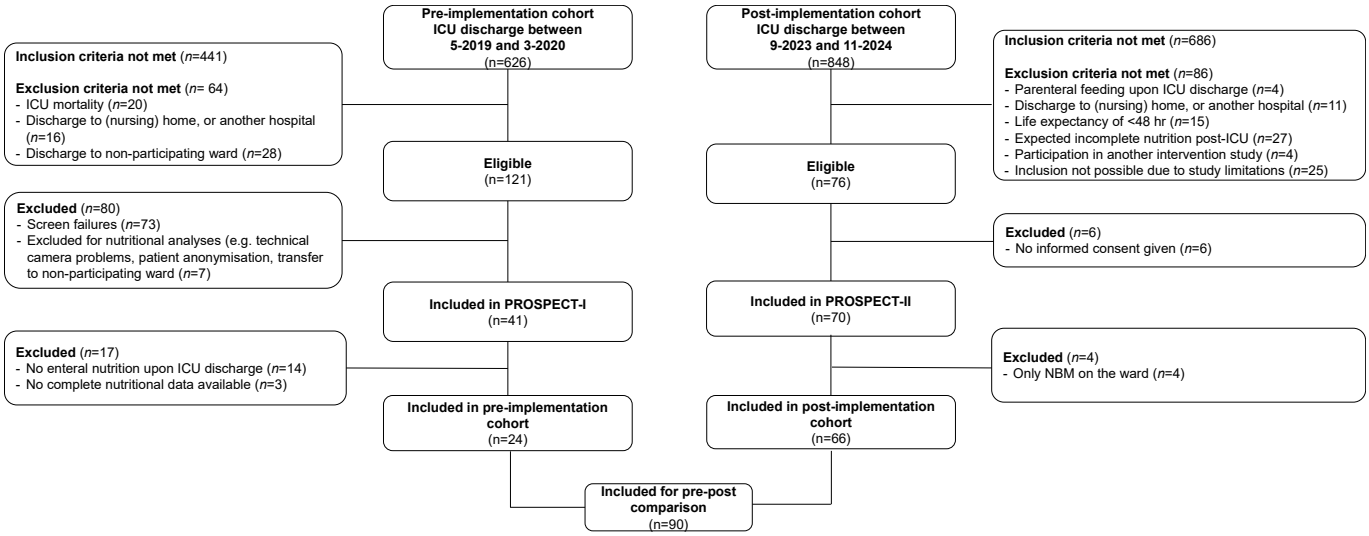

Fig. 1. Study flow diagram. Study flow diagram of 90 patients included in the analysis of food intake data from 14 days post-ICU hospitalisation during pre- and post-implementation of a nutrition protocol. Legend: ICU = Intensive Care Unit, NBM = Nothing by Mouth.

Table 1
Baseline characteristics.

ICU admission			(*n* = 90)
Age (y)	Median [IQR]		69 [60–75]
Sex (male)	*n* (%)		44 (48.9)
ABW (kg)	Mean (SD)		82.2 ± 20.5
BMI (kg/m^2)	Median [IQR]		26.7 [23.6–30.3]
ICU NICE admission type	*n* (%)		
Medical			68 (75.6)
Elective surgery			17 (18.9)
Emergency surgery			5 (5.6)
Barthel score[a]	Median [IQR]	*n* = 86	20 [19–20]
APACHE II score[b]	Median [IQR]		22 [17–29]
APACHE IV score[c]	Median [IQR]	*n* = 89	85 [67–102]
SOFA score[d]	Mean (SD)		7.7 ± 3.4
mNUTRIC score[e]	Median [IQR]		5 [4–6]
During ICU stay			
Invasive mechanical ventilation	*n* (%)		67 (74.4)
ICU length of stay, days	Median [IQR]		9 [6–17]
ICU discharge			
Energy target, kcal/day	Mean (SD)		2055 ± 324
Energy target, kcal/ABW	Mean (SD)		25.8 ± 3.9
Protein target, g/day	Median [IQR]		101 [93–117]
Protein target, g/ABW	Mean (SD)		1.3 ± 0.2

Patient demographics of 90 patients included in the analysis of food intake data from 14 days post-ICU hospitalisation during pre- and post-implementation of a nutrition protocol. Baseline data were obtained at the time of ICU discharge. Legend: ABW = Actual Body Weight; APACHE = Acute Physiology And Chronic Health Evaluation; BMI = Body Mass Index; ICU = Intensive Care Unit; m-NUTRIC = modified Nutrition Risk in Critically Ill; NICE = National Intensive Care Evaluation; SOFA = Sequential Organ Failure Assessment.

[a] Barthel score: assesses activities of daily living, with scores ranging from 0 (indicating dependence) to 20 (indicating independence).

[b] APACHE II score: ranges from 0 to 71, with higher scores indicating greater disease severity and an increased risk of mortality.

[c] APACHE IV score: ranges from 0 to 179, with higher scores indicating greater disease severity and an increased risk of mortality.

[d] SOFA score: ranges from 0 to 20, with higher scores indicating more severe organ failure.

[e] mNUTRIC score: ranges from 0 to 9, measures the risk of adverse events in critically ill patients that can be modified by aggressive nutritional therapy, with higher scores indicating a greater risk.

Mixed-effects modelling confirmed that ordered dinner meals contained more energy than breakfast meals (β = +69.5 kcal, $p < 0.001$), while ordered lunch meals did not differ from breakfast ($p = 0.851$). Ordered protein content was higher at dinner compared to breakfast (β = +6.0 g, $p < 0.001$), with a smaller difference between lunch and breakfast (β = +1.7 g, $p = 0.021$) (Supplementary Table 4, Supplementary Fig. 1). For consumed meals, no differences in energy intake were observed between mealtimes. Consumed protein intake was higher at dinner compared to breakfast (β = +1.8 g, $p = 0.003$), while lunch did not differ from breakfast ($p = 0.839$). Despite statistical significance, absolute differences in consumed protein were small (16.2–16.8 g). Modelling of relative intake (% of ordered consumed) showed lower consumption at lunch (β = −0.84, $p < 0.001$) and dinner (β = −1.37, $p < 0.001$) compared to breakfast. Relative intake did not differ between energy and protein, and no nutrient-by-meal interactions were observed (all $p > 0.05$). Over time, consumption rankings remained consistent (breakfast > lunch > dinner), with non-linear changes observed for all meals. The energy-to-protein ratio was nearly constant across all mealtimes (Supplementary Fig. 2).

Before implementation of the nutrition protocol, no differences in ordered energy or protein intake across mealtimes were observed (Supplementary Table 5A–B). After implementation, however, ordered energy and protein intake differed between meals, with higher amounts ordered at dinner compared with breakfast and lunch (all $p < 0.001$). Energy and protein consumption did not differ between mealtimes in either cohort (all $p > 0.05$). In contrast, the proportion of ordered intake that was consumed (relative intake) differed consistently across meals in both cohorts, being highest at breakfast, intermediate at lunch, and lowest at dinner (all $p < 0.05$), except for protein intake between lunch and dinner after implementation ($p = 0.068$). Generalised additive mixed models yielded results consistent with the descriptive analyses, showing no evidence of cohort-by-meal interactions for ordered or consumed energy and protein (all interaction $p > 0.05$). Before implementation, relative intake did not differ between breakfast, lunch, and dinner for either energy or protein (all $p > 0.05$). After implementation, relative intake was significantly higher at breakfast than at lunch and dinner for both energy and protein (all $p < 0.001$), while no significant differences were observed between lunch and dinner ($p > 0.05$) (Supplementary Table 6).

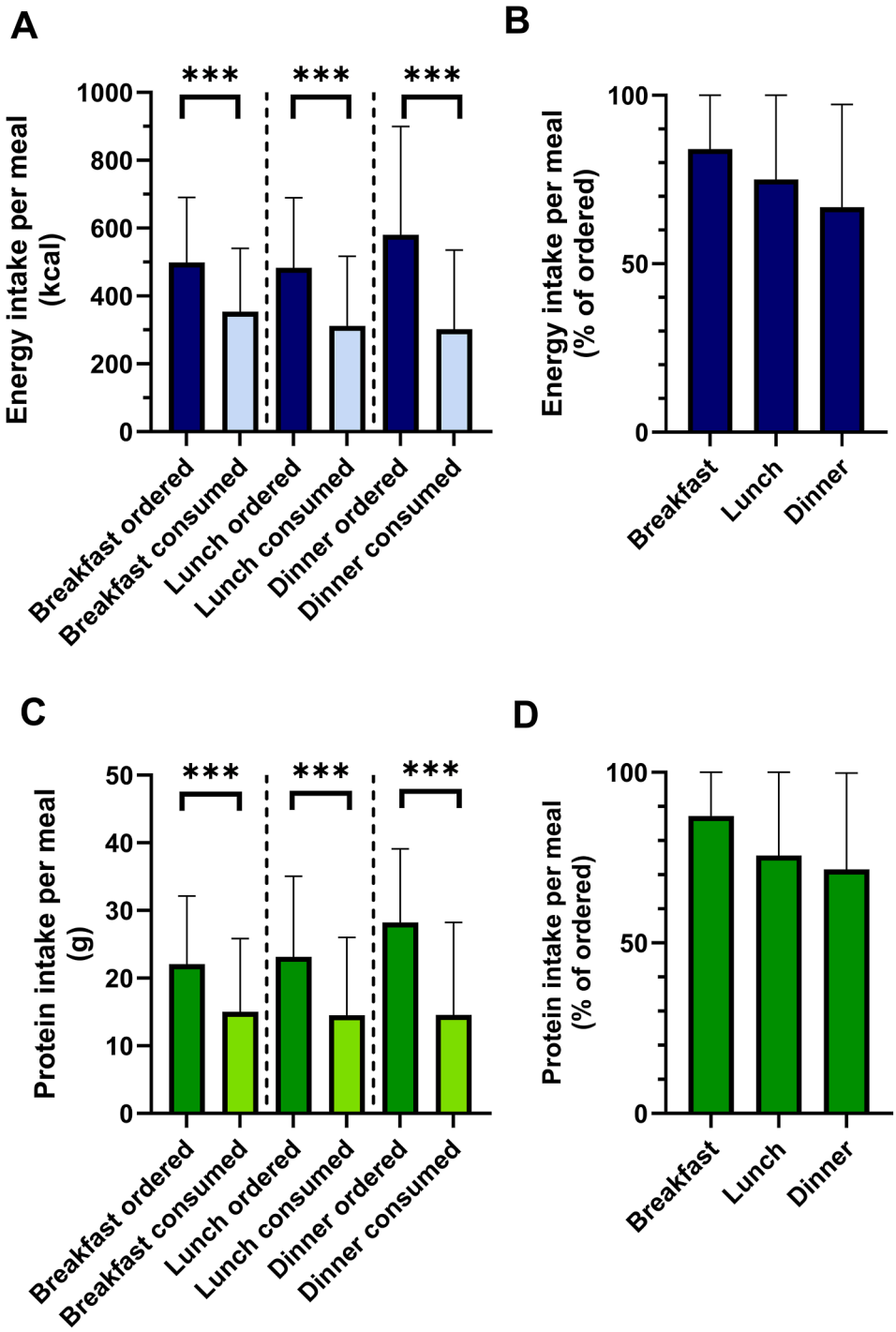

Fig. 2. Distribution of Oral Energy and Protein Intake Across Mealtimes. Energy and protein intake from oral food intake per mealtime in 90 post-ICU patients during the first 14 days of recovery after ICU discharge. Intake is shown as both ordered and consumed amounts of energy and protein across different mealtimes. A) Energy intake ordered and consumed per mealtime (kcal); B) Energy consumption as % of ordered amount); C) Protein intake ordered and consumed per mealtime (g); D) Protein consumption as % of ordered amount. *p < 0.05; **p < 0.01; ***p < 0.001.

3.2. Intake from oral food and enteral tube feeding

Based on individual days with complete dietary data, the median total daily energy intake in the total cohort was 2050 kcal [1618–2549] and median protein intake was 105.0 g [78.5–132.0]. Following implementation of the nutrition protocol, median oral energy intake was lower than in the pre-implementation period (energy: 900 kcal [500–1450] vs. 1330 kcal [969–1713]; protein: 44.1 g [21.1–71.6] vs. 63.4 g [41.6–91.3]; both p < 0.001), whereas enteral intake was significantly higher (energy: 1249 kcal [0–1807] vs. 0 kcal [8–810]; protein: 64.1 g [9.5–95.8] vs. 0 g [0–41.2]; both p < 0.001). Consequently, median total daily energy intake was higher after implementation (energy: 2115 kcal [1707–2581] vs. 1816 kcal [1419–2207]; protein: 108.1 g [82.5–135.0] vs. 91.5 g [69.1–114.2]; both p < 0.001; Fig. 3, Supplementary Table 7A).

These results were corroborated by model-based analyses accounting for repeated measurements within patients and time after ICU discharge (Supplementary Table 7B). Estimated marginal means showed lower oral energy intake after implementation (1059 vs. 1386 kcal) alongside higher enteral energy intake (1094 vs. 361 kcal), resulting in a higher total energy intake in the post-implementation group (2134 vs. 1786 kcal; difference +348 kcal, $p < 0.001$). Protein intake followed the same pattern, with lower oral intake (−15.8 g, $p = 0.006$) and increased enteral intake (+39.3 g, $p < 0.001$), leading to a higher total protein intake after implementation (+19.7 g, $p < 0.001$).

When intake was evaluated relative to prescribed patient targets, implementation of the nutrition protocol was associated with a redistribution from oral to enteral nutrition (Fig. 4). Based on individual days with complete data, the proportion of targets ordered and consumed via oral meals was lower in the post-implementation group across all mealtimes (all $p < 0.05$), whereas enteral nutrition contributed a greater proportion of both energy and protein targets (both $p < 0.001$) (Supplementary Table 8A). As a result, total daily intake adequacy (oral plus enteral) was higher after implementation, with median energy intake increasing from 94.5 % [70.4–120.6 %] to 103.2 % [83.4–120.7 %] ($p = 0.016$) and protein intake from 93.4 % [65.9–121.1 %] to 102.8 % [82.0–119.9 %] ($p = 0.038$) In contrast, model-based analyses confirmed significantly higher enteral target attainment after implementation but showed no differences

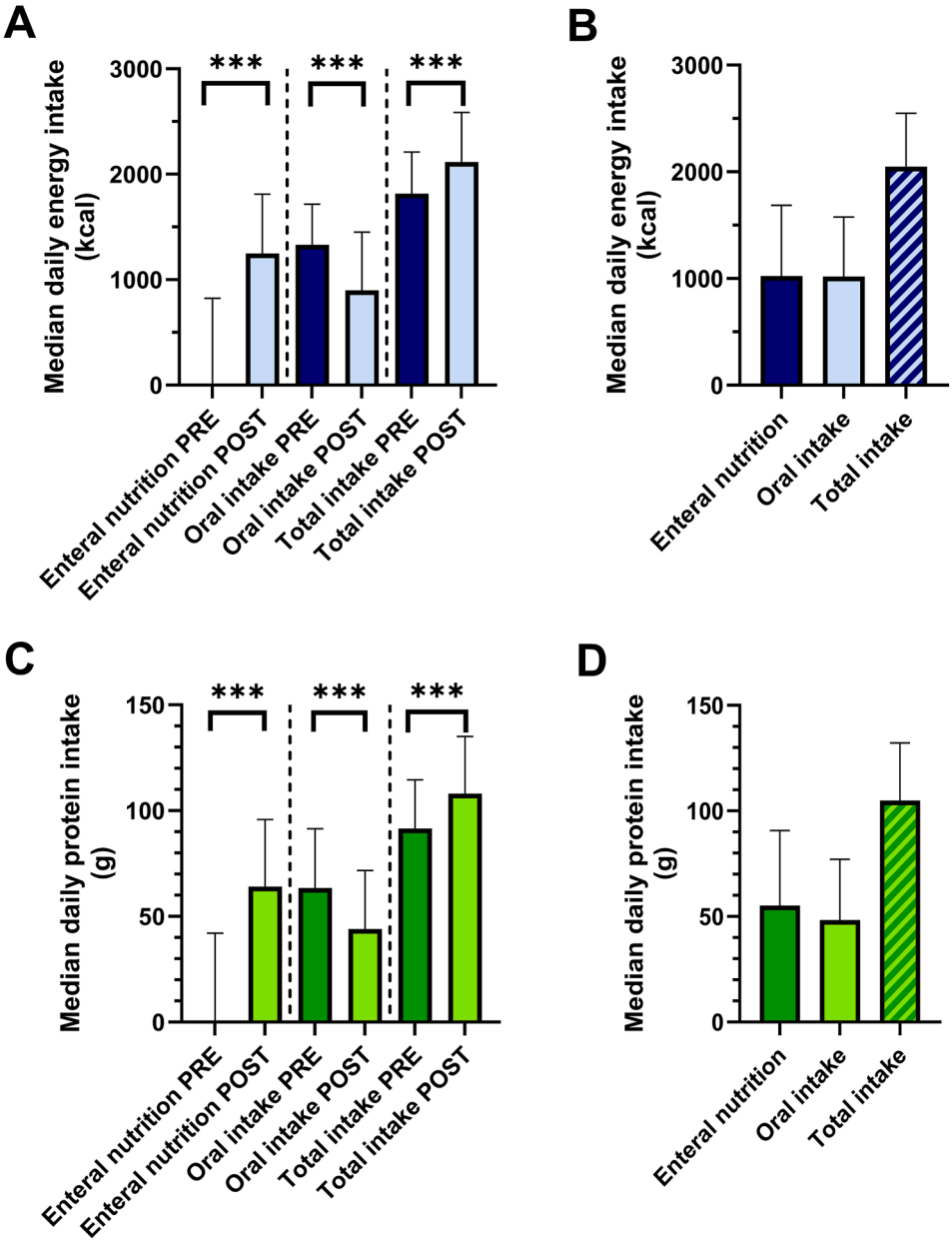

Fig. 3. Daily energy and protein intake. Total daily energy and protein intake in post-ICU patients pre- ($n = 24$) and post- ($n = 66$) implementation of a nutrition protocol during the first 14 days of recovery after ICU discharge. Data from 90 patients followed after ICU discharge to assess daily nutritional intake, including intake via oral and enteral (tube feeding) routes. A) Total median daily energy intake (kcal/day) pre- and post-implementation; B) Median total energy intake (kcal/day) for the entire study population; C) Total median daily protein intake (g/day) pre- and post-implementation; D) Median total protein intake (g/day) for the entire study population. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

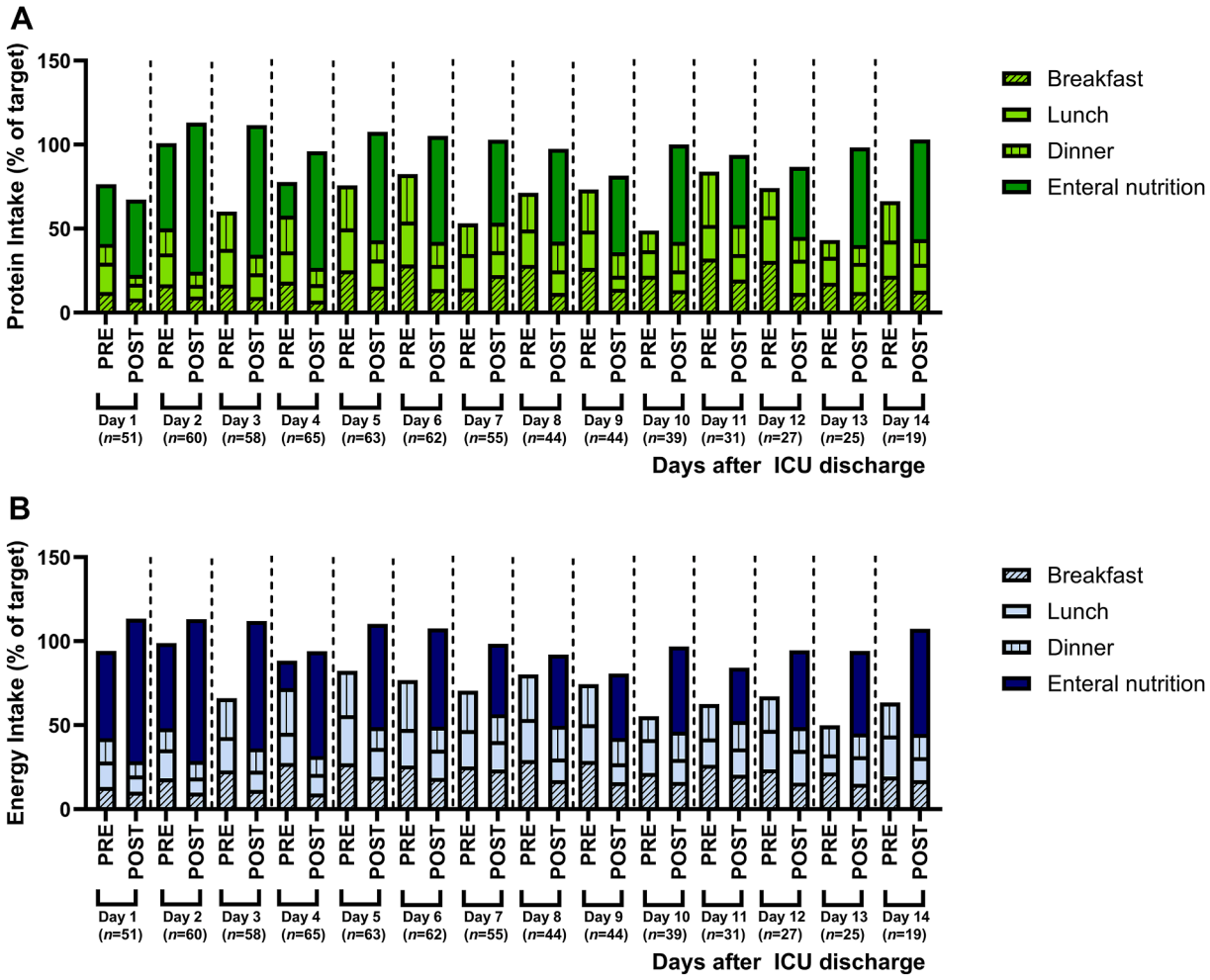

Fig. 4. Daily distribution of energy and protein intake per mealtime (breakfast, lunch, and dinner) and daily enteral nutrition as a percentage of target in the pre- and postimplementation cohorts. This figure shows the daily median energy and protein intake from both oral food and enteral nutrition at each mealtime, expressed as a percentage of the prescribed nutritional target. Data are presented for 90 post-ICU patients during the first 14 days of recovery following ICU discharge, comparing the period before (pre) and after (post) the implementation of a nutrition protocol. Oral intake includes only those mealtimes with complete intake records.

in total daily energy or protein adequacy relative to targets between cohorts after adjustment for multiple comparisons (Supplementary Table 8B).

4. Discussion

The present study examined distribution intake patterns from oral food intake and enteral nutrition during the critical transition from the ICU to the general ward. Over the first 14 days of recovery, post-ICU patients exhibited an even distribution of energy and protein intake across main meals. A consistent per-meal intake amount was observed across all mealtimes, indicating a possible physiological or behavioural limit to food intake at a single eating occasion, regardless of meal size or composition. After implementation of an individualised, tailored nutrition protocol, energy and protein intake from oral food intake was lower than before protocol implementation, while total energy and protein intake was increased as a result of more intensive enteral tube feeding support.

Providing adequate nutritional support post-ICU is suggested to improve recovery in patients at nutritional risk and to prevent energy and protein deficits observed during the transition from the ICU to the hospital ward [1,2]. Currently, there are no specific nutritional recommendations for post-ICU regarding the amount and timing of macronutrients. Increased energy and protein intake compared to during the ICU stay have been suggested [24]. However, many patients continue to experience prolonged deficits in both energy and protein intake following critical illness, evident not only during the early stages of hospital-based recovery but also persisting for up to a year after discharge [1–3]. Patients who depend solely on oral intake are particularly at risk, as they typically meet only 55–75 % of their energy needs and 27–74 % of their protein requirements during the early stages of recovery after ICU discharge [2]. This inadequate intake has been attributed to several patient-specific and/or critical illness-related factors, including reduced appetite, disturbances in taste and smell, early satiety, and various physical and psychological challenges commonly encountered after intensive care [5–13]. Beyond individual factors, system- and clinician-related barriers also contribute, including incomplete handovers during transitions of care, early removal of enteral feeding tubes, and limited access to nursing support for nutritional management [7,8].

Regarding the timing of meal intake throughout the day, we observed significant differences in the content of the ordered meals across different mealtimes. However, no differences in actual intake was observed at these mealtimes. In contrast, a

previous study in older adults showed differences in food consumption across mealtimes, with the lowest protein consumption at breakfast and the highest at dinner [25]. In our study, we observed lower energy intake at breakfast in the post-implementation group only. A possible explanation for this difference could be that patients in the post-implementation cohort had an overall higher total intake, leading to earlier satiety which is known to decline throughout the day [26]. While our data suggest that the amount consumed per meal has a ceiling, we lack subjective or objective physiological measurements to pinpoint the underlying mechanism. Appetite- and satiety-regulating mechanisms likely underlie the reduced food intake observed in patients during recovery from critical illness, which has been suggested to result from multiple clinical and physiological factors during critical illness [11–13,27,28].

In the present study, post-ICU patients consumed an overall energy intake of ~25 kcal/kg/day and a protein intake of ~1.3 g/kg/day throughout the first 14 days of recovery on the hospital ward after ICU discharge (Supplementary Fig. 2). These intakes are higher compared to those reported in previous post-ICU studies, such as those included in reviews by Moisey et al. and Rosseel et al. [1,2]. One possible explanation is that our study population included patients discharged from the ICU with ongoing enteral nutrition prescription. In contrast, in routine practice, many patients are discharged without a structured or comprehensive nutritional plan [29]. This aligns with findings from Rosseel et al. and Slingerland-Boot et al., who showed that post-ICU patients receiving (partial) enteral tube feeding achieve the highest levels of nutritional adequacy [1,30], likely reflecting more intensive nutrition support through enteral tube feeding combined with more frequent dietetics counselling. Previous research has shown that oral food intake drastically decreases after removal of the feeding tube [1,30]. In the present study, we demonstrate that later removal of the feeding tube resulted in higher daily energy and protein intake than before the nutrition protocol was implemented. This observation is consistent with recent findings from the INTENT trial, which also demonstrated that a tailored nutrition intervention can improve energy delivery [14]. Similarly, a pre- and post-implementation study of critically and post-critically ill patients showed that, compared with standard care, energy- and protein-dense foods, ONS, and nutritional screening improved protein and energy intake [31].

However, in the present pre-post implementation comparison, we showed that prolonged enteral tube feeding reduced oral food intake. Patients consumed around 13 g protein and 260–310 kcal from oral foods per meal after implementation of the nutrition protocol, before implementation, protein intake averaged 20 g and energy intake ranged from 370 to 470 kcal. In another study involving post-critically ill patients ($n = 19$), no difference in oral intake was observed between those who did and did not receive enteral nutrition; however, the enteral nutrition group had higher overall nutritional intake [32]. The study by Ridley et al. also showed that, in post-critically ill patients, the highest intake was achieved with a combination of enteral and oral nutrition [33]. In our study, we also observed that overall intake was higher after the nutrition protocol was implemented, both in the early days following ICU discharge and throughout the entire 14-day recovery period. These observations further confirm that while intensified enteral/parenteral tube feeding support might impact oral food intake, overall nutritional adequacy is improved [34].

4.1. Strengths and limitations

This study combines detailed meal-level data from two prospective cohorts of 90 ICU survivors, encompassing nearly 1700 individual meals. By quantifying both the content of ordered and consumed meals, it provides consistent evidence of a 20–30 % intake gap and identifies a clear per-meal intake ceiling limiting recovery of oral food intake. The comparison of similar cohorts before and after implementation of a new intensively monitored nutrition protocol, further enabled assessment of how structured, prolonged enteral feeding affects oral intake behaviour in patients during recovery on the hospital ward. These findings fill a major evidence gap in post-ICU nutrition and offer a foundation for designing targeted, personalised feeding strategies after critical illness.

This study has several limitations. First, it was conducted in a single nutrition-focused hospital, which may limit generalisability to centres with different feeding practices or cultural meal patterns. Second, the pre- and post-implementation cohorts were not matched for sample size or baseline characteristics, which may have introduced confounding despite consistent inclusion criteria. Approximately 20 % of meal-level data were missing, mostly due to medical fasting orders; the remaining ~5 % missing data were randomly distributed and unlikely to have affected the outcomes. Additionally, no functional or clinical measures were analysed in this study, as it primarily focused on mechanistic aspects, such as intake patterns, rather than patient outcomes. Furthermore, the population studied predominantly consisted of longer-stay ICU patients who were receiving enteral tube feeding at ICU discharge, which represents a specific and more complex subset of post-ICU patients. Therefore, the findings should be restricted to this group and may not be generalisable to other ICU populations or those with different feeding regimens. Finally, food intake was estimated from digital photographs and food record charts rather than weighed food records, although these methods are validated and reliable for assessing hospital meal consumption [23].

4.2. Future directions and recommendations

Future research should further investigate the role of in-between snacks, including high-energy, protein-rich items and ONS, as these may reduce intake during main mealtimes [35]. Understanding the distribution of protein intake throughout the day is crucial, since protein metabolism has shown to be impaired during critical illness and anabolic resistance (e.g. a reduced anabolic response to protein intake) has been observed to lower amounts of protein in ICU patients compared to healthy individuals [36,37]. Future studies should explore whether optimising protein distribution across meals can enhance recovery after critical illness. Currently, it remains unclear whether changes such as increased nutritional adequacy directly improve patient-centred outcomes. While the INTENT trial demonstrated improvements in energy delivery, it did not impact clinical outcomes such as hospital stay duration, ventilator-free days, or bloodstream infection rates [14]. The challenges of monitoring post-ICU patients throughout recovery with the assessment of more patient-centred outcomes are compounded by the complexities of post-intensive care syndrome [38]. Given these issues, further research on the impact of nutritional interventions on clinical and patient-centred outcomes is needed to further establish the clinical benefits for ICU survivors. In addition to these nutritional aspects, further work should examine underlying patient-related and contextual factors that influence meal distribution patterns, such as illness severity, appetite regulation, and clinician- or system-related barriers [5–13]. Moreover, the role of delirium, sleep disturbances, and disrupted circadian rhythms, common in ICU survivors, deserves attention, as these may affect appetite patterns and meal timing [39], particularly while meals are typically provided at the exact times as for other hospitalised patients.

Approximately 20–30 % of self-selected meals remained unconsumed, consistent with data from hospitalised older adults at risk of malnutrition showing that 30–40 % of provided meals and supplements are routinely not consumed [40]. Although potentially time-consuming, validated methods such as digital photography and food record charting can reliably estimate actual nutritional intake and should be implemented in clinical practice to guide personalised post-ICU nutrition strategies [23].

5. Conclusion

In this study, conducted during the first 14 days of post-ICU recovery in patients discharged with enteral tube feeding from the ICU, energy and protein intake were evenly distributed across meals, but patients consistently consumed only 70–80 % of what was ordered, revealing a per-meal intake ceiling that limits oral food intake recovery. Implementation of an intensive, individualised enteral tube feeding protocol substantially improved total energy and protein adequacy, yet further suppressed oral food intake. These findings demonstrate that while extended enteral tube feeding is essential to achieve nutritional targets early after ICU discharge, it must be carefully tapered and combined with personalised strategies that stimulate appetite and restore oral intake capacity.

Author contributions

Michelle Paulus: Conceptualisation, investigation, formal analysis, data curation, writing – Original Draft, writing – Review & Editing. Tommaso Verhoog: data curation, writing – Review. Rianne Slingerland-Boot: data curation, investigation, writing – Review. Arthur van Zanten: Conceptualisation, funding acquisition, writing – Review & Editing. Imre Kouw: Conceptualisation, data curation, writing – Review & Editing.

Funding statement

PROSPECT-I and PROSPECT-II were supported by Danone Research and Innovation (restricted research grant), which provided the enteral nutrition formulas (Nutrison Protein Advance, Nutrison Protein Plus Multifiber) and ONS (Nutridrink Compact Protein) (Nutricia, Zoetermeer, The Netherlands), but did not play a pivotal role in the design and conduct of the trial, nor did they have access to the data or influence the publication's content.

Conflict of interest

ARHvZ reported receiving honoraria for advisory board meetings, lectures, research, and travel expenses from AOP Pharma, Abbott, Baxter, Cardinal Health, Dutch Medical Food, Fresenius Kabi, GE Healthcare, InBody, Nutricia-Danone, PAION, and Rousselot. IWKK holds an NWO/ZonMW Veni Fellowship (2023) for a research program focused on improving nutrition support in (post)-ICU patients. The other authors have nothing to declare.

Acknowledgements

We extend our gratitude to all researchers, nurses, nutrition assistants, and dieticians involved in data collection for both study cohorts.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnesp.2026.102973.

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