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ORIGINAL ARTICLE

An algorithm for balanced protein/energy provision in critically ill mechanically ventilated patients

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Summary

Background & aims: Optimal nutritional therapy for energy and protein in critically ill, mechanically ventilated patients can be defined as: providing calories matched with the measured energy expenditure and delivery of protein in an amount of 1.2–1.5 g/kg pre-admission weight/day. Several enteral nutritional products are available with different energy/protein proportions. We developed an algorithm to choose the nutritional formula that combines optimal energy and protein supply for individual patients.

Methods: The energy and protein values of three nutritional formulas were used together with an aimed provision of 1.2–1.5 g protein/kg/day to construct a nomogram. From that, an algorithm followed, which was tested retrospectively in 203 mechanically ventilated patients with a normal BMI and known values for energy expenditure and weight.

Results: In the nomogram cut-off points for energy/weight ratios were: 19.0–23.8 for a normal energy/high protein formula, 23.8–29.8 for a high energy/high protein formula and 30–37.5 for the normal energy/normal protein formula. The algorithm uses energy expenditure/body weight ratio of the patients to choose one of the three formulas. This resulted in an adequate provision of protein in 93% of the patients.

Conclusion: The algorithm leads to provision of adequate amounts of protein and energy in the majority of critically ill, mechanically ventilated patients.

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Introduction

The goal of nutritional therapy is to conserve or restore the normal body composition. To achieve this goal, adequate amounts of energy, protein, minerals and trace elements must be provided, tailored towards the individual needs of our patients. For patients who are fully dependent on artificial nutrition, the composition of the nutritional formula is important as it determines the relationship between energy and protein that is provided. Nutritional formulas have a fixed energy/protein ratio, e.g. 1000 calories and 40g protein/L. Thus, the patient who is fed according to his caloric needs, will have a protein provision that results from the composition of the formula used. As argued below, nutritional goals must be defined for energy and protein separately. As a consequence, the use of nutritional formulas with different energy/protein ratios are necessary to meet the individual patients' needs. In this article we report a mathematical model that clarifies the characteristics of different nutritional formulas with regard to energy and protein per kg body weight delivery. As energy expenditure varies widely between patients and also the weights of the patients differ considerably, we tested the mathematical model in a group of 203 critically ill, mechanically ventilated patients of whom weight and energy expenditure by indirect calorimetric measurements were available. With this validated model we offer the reader an algorithm for choosing a formula providing optimal nutritional treatment.

In a foreword to one of the handbooks in clinical nutrition¹ Sir David P. Cuthbertson stressed the responsibility of the therapist as follows: "It is obvious that the power of the therapist is so complete in enteral and parenteral nutrition that it is extremely important to be well informed and to exercise it to the best available criteria. One of the most important criteria for establishing the appropriate amounts of carbohydrate, fat, and protein that should be given is the quantitative effect of each of these nutrients on maintenance of the body's cell mass, usually as measured by N balance."

In this article, we focus only on energy and protein delivery. The specific sort of protein provided and the supply of minerals, vitamins and trace elements is beyond the scope of our discussion.

In the first part of this article we will try to determine how optimal energy and protein nutrition is defined. In the second part a model is presented which leads to cut-off points in energy/weight ratio for choosing an enteral nutritional formula that meets the energetic and protein needs of an individual patient.

Energy requirements in critically ill patients

The gold standard for determining resting energy expenditure (REE) in critically ill, mechanically ventilated patients is indirect calorimetry. Measurement of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) allows for an accurate, bedside method to calculate the energetic needs of our patients. To establish total energy expenditure (TEE), 10% is added to the REE value.²

REE measurements allow prescribing nutritional regimens tailored to patients' energy needs; in addition the measure-

ments allow determination of substrate utilization when urinary nitrogen values are concomitantly measured.³

Protein requirements

Although in nutritional terms the word protein delivery is used, actually the gut breaks down protein into amino acids or very short amino peptides that are absorbed. In the body these are re-synthesized and become proteins again. The capacity to synthesize protein is limited. The maximum capacity of the human body to synthesize protein is reached when 1.5–1.7g protein/kg/day is administered, indicating that supply of amino acids above this value is useless.^{4,5} In addition to data on stimulation of protein synthesis, data on changes in whole body protein mass should be considered too. The gold standard for measurement of whole body protein is in vivo neutron activation analysis. At this moment we are aware of only two studies that have used this technique. One study was done in surgical patients after major abdominal surgery. The chosen amount of protein was either 0.8 or 1.9g protein/kg/day.⁶ In those patients, provision of 0.8g protein/kg/day proved to be insufficient to maintain body protein mass, whereas body protein mass was conserved if 1.9g protein/kg/day was given. The other study was carried out in probably mechanically ventilated and fully immobilized intensive care patients, given, respectively, 1.1, 1.5 and 1.9g of protein/kg fat free mass/day during 14 days.⁷ Provision of 1.5g protein/kg fat free mass/day proved the optimal amount to preserve protein mass; 1.5g per kilogram FFM/day equals 1.2g protein/kg pre-admission weight/day.

Optimal support in terms of energy and protein in critically ill, mechanically ventilated patients in the ICU can therefore be defined as: energy delivery of measured REE+10% (= TEE) and provision of 1.2–1.5g protein/kg pre-admission body weight/day (for extensive discussion see Sauerwein et al.⁸).

Materials and methods

Development of the nomogram to define characteristics of nutritional formulas

Three types of enteral nutrition, that we also use in daily clinical practice, were included in the analysis. We used a normal energy/normal protein solution (Nutrison standard; Nutricia, Zoetermeer, the Netherlands), containing 1000 kcal and 40g protein/L, a high-energy/high-protein solution (Nutrison protein plus; Nutricia, Zoetermeer, the Netherlands), containing 1250kcal and 63g protein/L, and a normal energy/high-protein solution (Promote; Abbott Nutrition, Hoofddorp, the Netherlands), containing 1000kcal and 62.5g protein/L.

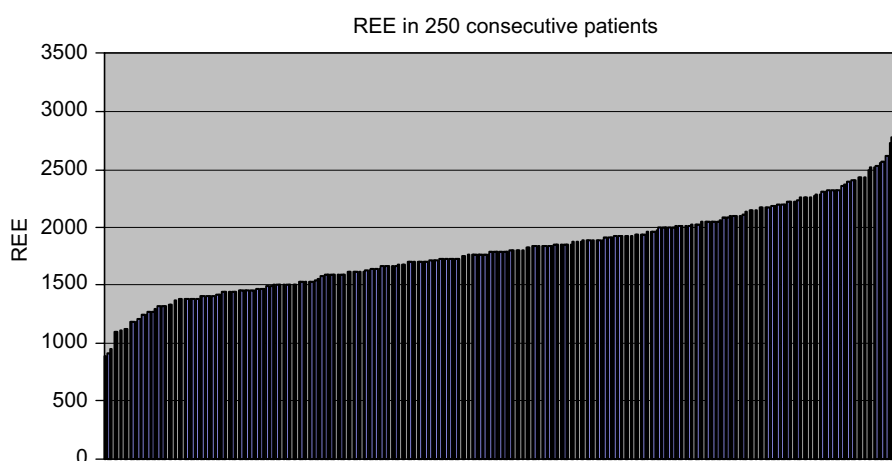
Nutritional formulas have a fixed energy/protein ratio. The target provision of protein for patients is a protein/weight ratio. Multiplying energy/protein from the nutritional formula by the targeted protein/weight ratio for the patient results in an energy/weight ratio. As the lower limit for protein provision is set at 1.2g/kg and the upper limit is 1.5g/kg, the cut-off points for adequate caloric and protein provision are determined by the energy/protein

Table 1 Calculations for cut-off points derived from energy/protein ratios of nutritional formulas and target protein provision.

	kcal/L	P/L	kcal/p ratio	Target P/kg low	kcal/kg low cut-off point	Target P/kg high	kcal/kg high cut-off point
Normal E/high P	1000	63*	15.9*	1.2	19.0*	1.5	23.8*
High E/high P	1250	63	19.8*	1.2	23.8*	1.5	29.8*
Normal E/normal P	1000	40	25	1.2	30.0	1.5	37.5

Characteristics of the three nutritional formulas: kcal/L, P/L = protein/litre and kcal/protein ratio per formula. Target P/kg is the set limit, low and high for the aimed amount of protein/kg body weight. Cut-off points for energy/weight ratios (kcal/kg) are calculated by multiplying Kcal/p ratio by target P/kg.

*Numbers are rounded.

**Figure 1** Distribution of resting energy expenditure values measured by indirect calorimetry in 250 consecutive ICU patients.

ratio of the nutritional formula multiplied by 1.2 and 1.5, respectively, and expressed as energy/weight. Table 1 shows the characteristics and calculations for the different formulas.

As energy expenditure and weight are known from patients, also for each patient an energy expenditure/body weight ratio can be calculated. So, both the characteristics of the nutritional formula, combined with the target protein/kg values, and the characteristics of the patient can be expressed as energy/weight ratios. We hypothesized that the energy/weight ratio derived from the nutritional formula in combination with the target protein provision for the patient would match the energy expenditure/body weight ratio of the patients.

Description of patient population and methods

For the analysis, we retrospectively used a database of 250 consecutive patients in whom indirect calorimetry was performed, recorded over a period of nearly 2 years. The database contains data from critically ill, mechanically ventilated patients in a 28-bed tertiary mixed medical/surgical ICU in a university hospital.

Indirect calorimetry is used on a routine basis. Indications for performing indirect calorimetry are according to the AARC guideline.³ Measurements are done in rest, after calibration of the calorimeter (Datex DeltatracTM MBM 100 metabolic monitor, Datex-Engstrom Division, Instrumentation Corp. Helsinki Finland), for a period of 1–1.5 h. The calorimetric data are then entered in our patient data management system (MetavisionTM, IMD-soft) in a special nutritional/metabolic section. TEE (in these fully immobilized patients) is defined as REE+10%. Pre-admission weight and height of the patients are retrieved from the pre-assessment out clinic, from earlier measurements done during admissions or from data obtained in other health care settings. If we cannot find actual measurements, the patient or the family is asked to provide these data. Only if no source of further information was found, we estimated height and weight of the patient. Height and weight could be retrieved in 60% of cases; in 40% estimations were used.

Only the first measurement (if multiple determinations of indirect calorimetry were done) of individual patients was used. Energy expenditure values are shown in Fig. 1.

Undernourished and obese patients, defined as having a BMI of <18.5 ($n = 15$) or a BMI over 30 kg/m² ($n = 26$) were

excluded from the simulation, as for these patients tailored nutritional support should be provided, based on estimated lean body mass and repeated indirect calorimetric measurements. So the simulation analysis was done for 203 patients with a BMI between 18.5 and 30 kg/m². Patient characteristics are given in Table 2.

In the simulation, for each individual patient the energy expenditure/body weight ratio was calculated. According to the cut-off points of the energy/weight calculations in the nomogram, a nutritional formula was chosen. The amount of nutrition to be provided was calculated from the patient's energy expenditure by dividing TEE by caloric value of the chosen nutritional formula per millilitre. From that amount, and the protein content/millilitre of the formula, the amount of protein/kg/day was calculated.

The results were plotted against TEE and weight with the corresponding nutritional formula and placed in a graph according to the energy/weight ratio's. Furthermore, the number of patients per optimal nutritional formula was calculated.

Results

Table 1 shows the calculated cut-off points for energy/weight ratios: 19.0–23.8 for the normal energy/high protein formula, 23.8–29.8 for the high-energy/high protein formula and 30.0–37.5 for the normal energy/normal protein solution. For the three formulas that we used, the cut-off points are corresponding: the upper limit of two enteral formulas are equal or very close to the lower limits of another formula. Therefore, the three chosen nutritional formulas offer a continuous spectrum without gaps for all energy expenditure/body weight ratios between 19.0 and 37.5.

In the simulation model, where the energy expenditure/body weight ratio guided the choice of the nutritional formula, all patients received 100% of their caloric goal and

92.6% reached a protein provision between 1.2 and 1.5 g/kg body weight. The distribution of weights, TEE and nutritional formula are shown in Fig. 2.

For 9 patients (4.4%) with a low TEE and a normal body weight even the high protein formula was insufficient to reach 1.2 g protein/kg body weight. Six patients (3%) with a low body weight and a high TEE would be receiving more than 1.5 g protein/kg body weight (Fig. 3).

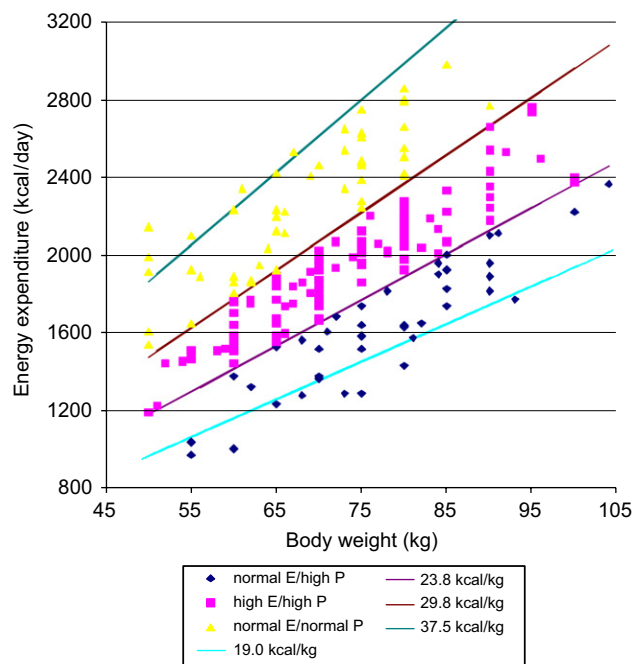


Figure 2 The distribution of weights, TEE and nutritional formula by applying the algorithm to achieve provision of required TEE and a protein delivery of 1.2–1.5 g/kg pre-admission body weight.

Table 2 Demographic and clinical data of 203 patients with 18.5 ≤ BMI ≤ 30.

	N	Median	Mean (range)	SD
No. of patients				
Total	203			
Female	87			
Male	116			
Age (yrs)		69	63.6 (15–91)	18.32
Height (cm)		173	172.6 (150–203)	9.58
Weight (kg)		73	72.4 (50–104)	11.50
BMI		24.25	24.26 (18.5–29.7)	2.72
APACHE II score		20	20.79 (4–46)	7.5
TEE (calorimetry)		1899	1943 (1400–3033)	312.7
Outcome parameters				
Length of stay (ICU) (days)		18	24.45 (2–209)	23.28
Length of Ventilation (days)		16	21.78 (1–181)	20.91
Died				
At ICU	35 (17.2%)			
In hospital	63 (30.9%)			

BMI = body mass index, APACHE = acute physiology and chronic health evaluation score, TEE = total energy expenditure.

In our patient group, with a BMI between 18.5 and 30 kg/m², more than half of the patients had an energy expenditure/body weight ratio between 23.8 and 29.8. The frequency of distribution of the ratios and the resulting choice for a specific nutritional formula are given in Table 3.

If the standard solution (normal energy/normal protein) was chosen for all patients to meet the energetic needs, protein supply was adequate in 24% of the cases.

Discussion

This study shows that the use of an algorithm that uses energy expenditure/weight ratios of patients combined with a nomogram that contains energy/protein ratios of three different nutritional formulas with upper and lower targets for protein provision per kilogram results in optimal provision of both energy and protein in critically ill, mechanically ventilated patients in 92.6% of cases, when the BMI is between 18.5 and 30 kg/m².

For products that have a different composition from the ones we used, Table 1 will easily allow calculating different cut-off points. Also for patient groups, where a different target for protein provision/kg body weight is warranted, changing the target protein values in the table will allow calculation of the resulting cut-off points.

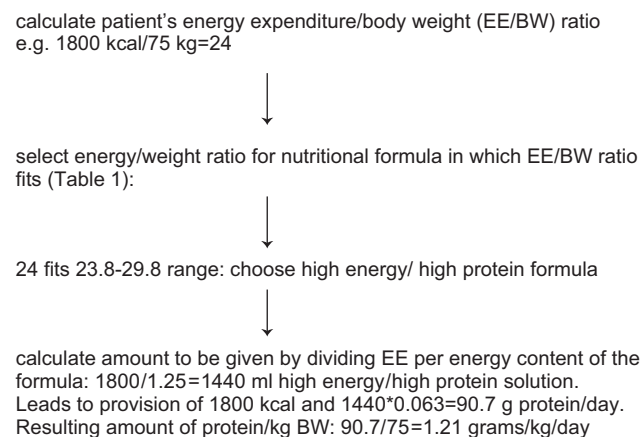


Figure 3 Algorithm for choosing an optimal nutritional formula.

From our data it is also clear that the use of only one nutritional formula for all patients will not provide adequate nutrition. The use of a normal energy/normal protein product, called “standard” by the manufacturer, will provide adequate amounts of protein in only 24% of cases if energy is taken as a starting point for the calculation. Fifty-two percent of the patients can be adequately fed with a high-energy/high protein formula. High energy consuming normal weight patients will have their metabolic needs fulfilled with a normal energy/normal protein formula, and obese patients with a low-energy expenditure are best fed with a normal energy/high protein formula.

If indirect calorimetry is not available, energy requirements in critically ill patients can be estimated with different formulas, but indirect calorimetry remains the method of choice to determine energy expenditure, especially in patients with a prolonged ICU stay.⁹ Applying the algorithm with an estimated TEE will lead to an adequate provision of protein as the body weight is leading for protein administration, but caloric needs may be under- or oversupplied.

The algorithm is easily applicable in the clinical situation, either manually by dividing energy expenditure by the weight of the patient and looking up the correct interval for the found value in Table 1, or through the use of a computer where the algorithm can simply be entered and that can also calculate the amount of nutrition to be given. If the intensive care unit uses a decision support system, patients can be checked on a routine basis to detect appropriateness of nutritional therapy. If height, weight, TEE and nutritional formula that is provided are available from the patient data management system, comparison of the actually given amount and sort of enteral nutrition with optimal nutritional therapy according to the algorithm is possible and allows for automatic identification of patients that deviate from the norm of optimal nutritional therapy. Both strategies have been implemented in our unit using the MetavisionTM system from IMD-soft.

In conclusion, the proposed algorithm offers the clinician and nutritional therapist a simple tool to make a choice for a formula that provides optimal protein delivery for a certain amount of energy and body weight. Optimal nutritional support requires determination of individual energy expenditure and the use of different enteral nutrition formulas. Choosing the optimal mixture of energy and protein will bring the realization of Sir Cuthbertson’s encouragement closer to daily practice.

Table 3 Distribution of number of patients for the different energy/weight ranges and the resulting choice for the nutritional formula.

Energy–weight ratio (kcal/kg)	Number of patients	Percentage	Nutritional formula
<19.0	9	4	No fitting formula; outside range
19.0–23.8	34	17	Normal energy-high protein
23.8–29.8	105	52	High energy-high protein
30.0–37.5	49	24	Normal energy-normal protein
>37.5	6	3	No fitting formula; outside range
Total	203	100	

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RS: thought of the concept to link nutritional formulas' characteristics to patients energy/weight ratios; has done part of the indirect calorimetric measurements; has prepared the manuscript.

PW: developed [Table 1](#); was responsible of analysis of data; has revised the manuscript.

HS: defined optimal nutrition as used in this article gave valuable feedback on earlier drafts of the manuscript.

SdG: found the nutritional formulas that give continuous cut-off points; contributed to drafts of the manuscript.

AB: has done part of the indirect calorimetric measurements; helped draft the manuscript.

AG: gave valuable advice and suggestions to improve the text of the manuscript to its final form.

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