



Energy Expenditure and Nutritional Therapy in Critically ill Patients

Elisabeth De Waele, MD, PhD
SIZ Award 2016

REVIEW

Open Access

Metabolic and nutritional support of critically ill patients: consensus and controversies

Jean-Charles Preiser^{1*}, Arthur RH van Zanten², Mette M Berger³, Gianni Biolo⁴, Michael P Casaer⁵, Gordon S Doig⁶, Richard D Griffiths⁷, Daren K Heyland⁸, Michael Hiesmayr⁹, Gaetano Iapichino¹⁰, Alessandro Laviano¹¹, Claude Pichard¹², Pierre Singer¹³, Greet Van den Berghe⁵, Jan Wernerman¹⁴, Paul Wischmeyer¹⁵ and Jean-Louis Vincent¹

Consequences of inappropriate feeding

Underfeeding

Observational studies have shown the association between negative energy balance and poor outcome

Overfeeding

Provision of macronutrients in excess of metabolic demand is deleterious.

- To optimize nutritional therapy
- To improve bedside techniques

The Scientific World Journal
Volume 2015, Issue 01, 4 pages
doi:10.58987/2015.0104

The Scientific World JOURNAL

Research Article
Bedside Calculation of Energy Expenditure Does Not Guarantee Adequate Caloric Prescription in Long-Term Mechanically Ventilated Critically Ill Patients: A Quality Control Study

Elisabeth De Waele¹, Herbert Spapen¹, P. M. Honore¹, Sabrina Mattens¹, Thomas Rose¹, and Luc Hooghebaert¹

¹Department of Intensive Care Medicine, University Hospital, Vrije Universiteit Brussel
²Department of Dentistry, University Hospital, Vrije Universiteit Brussel, 1089 Brussels

Correspondence should be addressed to Elisabeth De Waele, elisabeth.dewaele@vub.ac.be

Received 21 January 2015; Accepted 4 February 2015

Academic Editors: J. Carona, Y. C. Huang, and C. Weissen

Copyright © 2015 Elisabeth De Waele et al. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Nutrition is essential in critically ill patients, but translating caloric prescriptions to bedside practice is challenging. Indirect calorimetry (IC) is the gold standard for measuring energy expenditure, but bedside IC is not available in most intensive care units. We performed a quality control study to assess the accuracy of bedside IC in long-term mechanically ventilated patients. Energy expenditure was measured by IC in 16 patients. Caloric needs were calculated by bedside IC and compared to the actual caloric intake. Caloric needs were underestimated in 10.6% of patients, 27.4% being severely malnourished. Caloric needs were overestimated in 14.3% of patients, 10.0% being severely malnourished. Caloric needs were underestimated in 10.6% of patients, 27.4% being severely malnourished. Caloric needs were overestimated in 14.3% of patients, 10.0% being severely malnourished. Caloric needs were underestimated in 10.6% of patients, 27.4% being severely malnourished. Caloric needs were overestimated in 14.3% of patients, 10.0% being severely malnourished.

1. Background

Delivering a correct amount of calories to critically ill patients is considered to be of cardinal importance [1, 2]. Indeed, inadequate nutrition (i.e., under- or overfeeding) in this population has distinct effects on immune-inflammatory pathways, is associated with increased morbidity, and may impact survival [3, 4]. Underfeeding disrupts the regeneration of respiratory epithelium and causes respiratory muscle dysfunction [5] which may prolong ventilator dependence [6]. Even when present underfeeding, it is responsible for reduced superficial and deep wound healing [7]. Also, failure to provide more than 25% of recommended calories significantly increases the risk of bloodstream infection [8].

In contrast, overfeeding (i.e., under- or overfeeding) in this population has distinct effects on immune-inflammatory pathways, is associated with increased morbidity, and may impact survival [3, 4]. Underfeeding disrupts the regeneration of respiratory epithelium and causes respiratory muscle dysfunction [5] which may prolong ventilator dependence [6]. Even when present underfeeding, it is responsible for reduced superficial and deep wound healing [7]. Also, failure to provide more than 25% of recommended calories significantly increases the risk of bloodstream infection [8].

Blood Purification

Nutritional and Metabolic Alterations During Continuous Renal Replacement Therapy

Patrick M. Honore¹, Elisabeth De Waele¹, Ritta Jacobs¹, Sabrina Mattens¹, Thomas Rose¹, Olivier Joannes-Boyau², Jouke De Regt¹, Lies Verfallie¹, Viola Van Gorp¹, Willem Boer¹, Vincent Collin¹, Herbert D. Spapen¹

¹Intensive Care Department, Universiteit Ziekenhuis Brussel, Vrije Universiteit Brussel, and ²Chimique de l'Eau, Site St Michel, Brussels, and ³Department of Anaesthesiology and Critical Care Medicine, Ziekenhuis Oost Limburg, Genk, Belgium; ⁴Haut Levreque University Hospital of Bordeaux, University of Bordeaux 2, France, France

Key Words

Continuous renal replacement therapy; Nutrition; Indirect calorimetry; Acute kidney injury; Calorie intake; Glutamine; Macronutrients; Micronutrients; Blood purification; Dialysis; Hemofiltration; Sepsis; Systemic inflammatory response syndrome; Dialyzer trauma; Continuous renal replacement therapy; Trauma

Abstract

Adequate feeding of critically ill patients under continuous renal replacement therapy (CRRT) remains a challenging issue. We performed a systematic search of the literature published between 1992 and 2012 using the quorum guidelines regarding nutrition in intensive care unit patients treated with CRRT. Daily recommended energy requirements during CRRT are between 25 and 35 kcal/kg with carbohydrates and lipids accounting for 60–70% and 30–40% of calorie intake, respectively. Daily protein needs range from 1.5 to 1.8 g/kg. Indirect calorimetry corrected for CRRT-induced CO₂ diversion should be used to more correctly match calorie intake to the real needs. This type of tool is not yet available but hopefully soon. Electrolyte deficit as well as overload have been described during CRRT but, in general, can be easily

controlled. Although not strongly evidenced, consensus exists to supplement important micronutrients such as amino acids (glutamine), water-soluble vitamins and trace elements.

Introduction

Feeding patients with acute kidney injury (AKI), especially when treated with continuous renal replacement therapy (CRRT), remains a delicate yet challenging task for intensive care unit (ICU) clinicians. Indeed, the AKI process itself is accompanied by inherent metabolic and physiological disturbances necessitating careful implementation of ICU feeding protocols. CRRT allows volume removal and permits quasi-unrestricted feeding. On the other hand, CRRT may cause considerable modifications in the nutritional “household” by inducing substantial and incompletely quantified losses of macro- and micronutrients [1, 2]. CRRT allowing clearance of low-molecular-weight water-soluble substances implies significant loss of glucose, amino acids, low-molecular-weight proteins, trace elements, and water-soluble vitamins. Nonetheless,

Journal of Critical Care (2015) 28, 84–88

ELSEVIER

Introducing a new generation indirect calorimeter for estimating energy requirements in adult intensive care unit patients

Practical considerations for indirect calorimetry in adult intensive care unit patients

Japen MD, PhD^a, Patrick M. MD^a, Marc Diltoro MD^a, Luc Hooghebaert MD^a, Vincent Collin MD^a, Vincent Boer MD^a, Vincent Boer MD^a, Vincent Boer MD^a

^aIntensive Care Department, Universiteit Ziekenhuis Brussel, Vrije Universiteit Brussel, Belgium

Indirect calorimetry (IC) is increasingly advocated for adults, but questions remain regarding its practice. In subjects considered unable to meet energy requirements (ME) was compared with calculated (cal) values were performed in 265 patients (age, 64.8 ± 14.8 years; 144 M; 121 F). A total of 27 of 265 (10.2%) patients were excluded from the study because of technical problems. In the remaining 238 patients, IC was indicated. Practical considerations for the use of IC in the intensive care unit are discussed. Indirect calorimetry is increasingly advocated for adults, but questions remain regarding its practice. In subjects considered unable to meet energy requirements (ME) was compared with calculated (cal) values were performed in 265 patients (age, 64.8 ± 14.8 years; 144 M; 121 F). A total of 27 of 265 (10.2%) patients were excluded from the study because of technical problems. In the remaining 238 patients, IC was indicated. Practical considerations for the use of IC in the intensive care unit are discussed. Indirect calorimetry is increasingly advocated for adults, but questions remain regarding its practice. In subjects considered unable to meet energy requirements (ME) was compared with calculated (cal) values were performed in 265 patients (age, 64.8 ± 14.8 years; 144 M; 121 F). A total of 27 of 265 (10.2%) patients were excluded from the study because of technical problems. In the remaining 238 patients, IC was indicated. Practical considerations for the use of IC in the intensive care unit are discussed.

Copyright © 2015, Elsevier B.V. All rights reserved.

Copyright © 2015, Elsevier B.V. All rights reserved.

Journal of Critical Care (2015) 28, 84–88

ELSEVIER

Introducing a new generation indirect calorimeter for estimating energy requirements in adult intensive care unit patients

Measuring resting energy expenditure during extracorporeal membrane oxygenation: preliminary clinical experience with a proposed theoretical model

E. De Waele¹, K. van Zwaan¹, S. Mattens¹, K. Staessens¹, M. Diltoro¹, P. M. Honore¹, J. Caapla¹, J. Nijp¹, M. La Motte¹, L. Hooghebaert¹ and H. Spapen¹

¹Intensive Care Department, Universiteit Ziekenhuis Brussel (UZ Brussel), Vrije Universiteit Brussel (VUB), Brussels, Belgium; ²Department of Cardiac Surgery, Universiteit Ziekenhuis Brussel (UZ Brussel), Brussels, Belgium

Background: Extracorporeal membrane oxygenation (ECMO) is increasingly used in patients with severe respiratory failure. Indirect calorimetry (IC) is a safe and non-invasive method for measuring resting energy expenditure (REE). No data exist on the use of IC in ECMO-treated patients as oxygen uptake and carbon dioxide elimination are divided between mechanical ventilation and the artificial lung. We report our preliminary clinical experience with a theoretical model that derives REE from IC measurements obtained separately on the ventilator and on the artificial lung. Methods: A patient undergoing veno-venous ECMO for acute respiratory failure due to bilateral pneumonia was studied. The calorimeter was first connected to the ventilator and oxygen consumption (VO₂) and carbon dioxide transport (VCO₂) were measured until steady state was reached. Subsequently, the IC was connected to the membrane oxygenator and similar gas analysis was performed. VO₂ and VCO₂ values at the native and artificial lung were summed and incorporated in the Weir equation to obtain a REE_{ECMO} equation. Results: At the ventilator level, VO₂ and VCO₂ were 29.5 ml/min and 16 ml/min. VO₂ and VCO₂ at the artificial lung level were 113 ml/min and 127 ml/min. Based on these values, a REE_{ECMO} of 1703 kcal/day was obtained. The Faigó-Fajón and Harris-Benedict equations calculated a REE of 1373 and 1563 kcal/day. Conclusion: We present IC-acquired gas analysis in ECMO patients. We propose to insert individually obtained IC measurements at the native and the artificial lung in the Weir equation for retrieving a measured REE_{ECMO}.

Copyright © 2015, Elsevier B.V. All rights reserved.

Copyright © 2015, Elsevier B.V. All rights reserved.

COPYRIGHT © 2015 EDIZIONI MINERVA MEDICA

ORIGINAL ARTICLE

Measured versus calculated resting energy expenditure in critically ill adult patients. Do mathematics match the gold standard?

JORÉ S. M. DILTORO¹, S. MATTENS¹, H. SPAPEN¹

¹Intensive Care Department, Universiteit Ziekenhuis Brussel (UZ Brussel), Vrije Universiteit Brussel (VUB), Brussels, Belgium

Background: Extracorporeal membrane oxygenation (ECMO) is increasingly used in patients with severe respiratory failure. Indirect calorimetry (IC) is a safe and non-invasive method for measuring resting energy expenditure (REE). No data exist on the use of IC in ECMO-treated patients as oxygen uptake and carbon dioxide elimination are divided between mechanical ventilation and the artificial lung. We report our preliminary clinical experience with a theoretical model that derives REE from IC measurements obtained separately on the ventilator and on the artificial lung. Methods: A patient undergoing veno-venous ECMO for acute respiratory failure due to bilateral pneumonia was studied. The calorimeter was first connected to the ventilator and oxygen consumption (VO₂) and carbon dioxide transport (VCO₂) were measured until steady state was reached. Subsequently, the IC was connected to the membrane oxygenator and similar gas analysis was performed. VO₂ and VCO₂ values at the native and artificial lung were summed and incorporated in the Weir equation to obtain a REE_{ECMO} equation. Results: At the ventilator level, VO₂ and VCO₂ were 29.5 ml/min and 16 ml/min. VO₂ and VCO₂ at the artificial lung level were 113 ml/min and 127 ml/min. Based on these values, a REE_{ECMO} of 1703 kcal/day was obtained. The Faigó-Fajón and Harris-Benedict equations calculated a REE of 1373 and 1563 kcal/day. Conclusion: We present IC-acquired gas analysis in ECMO patients. We propose to insert individually obtained IC measurements at the native and the artificial lung in the Weir equation for retrieving a measured REE_{ECMO}.

Copyright © 2015, Elsevier B.V. All rights reserved.

Copyright © 2015, Elsevier B.V. All rights reserved.

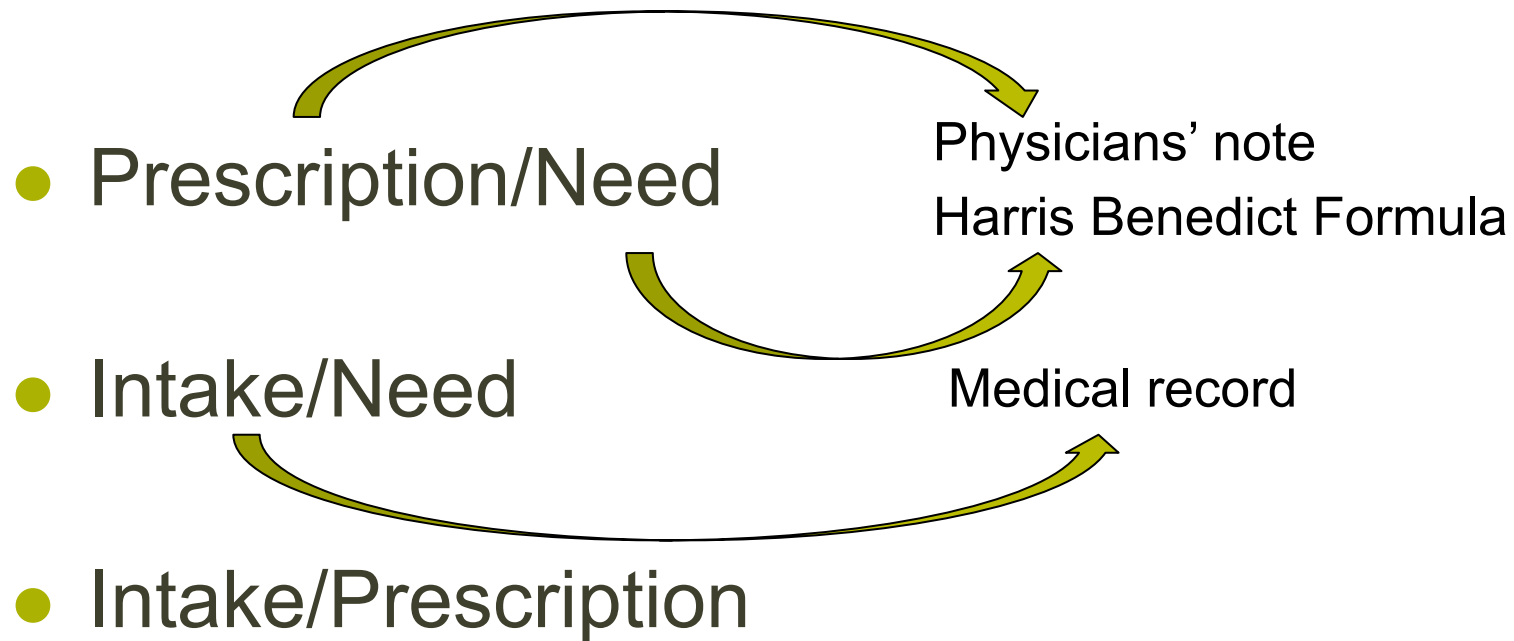


1. Quality control study

Methods

- Prospective non-interventional design
- Adult critically ill patients
- Intubation and mechanical ventilation for 7 days
- n=50

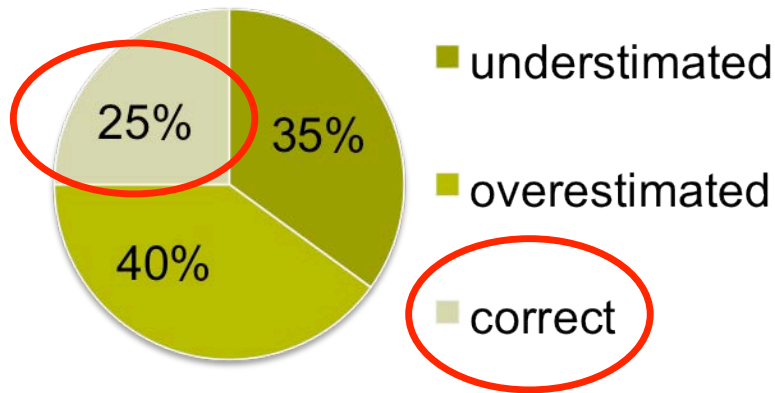
Protocol



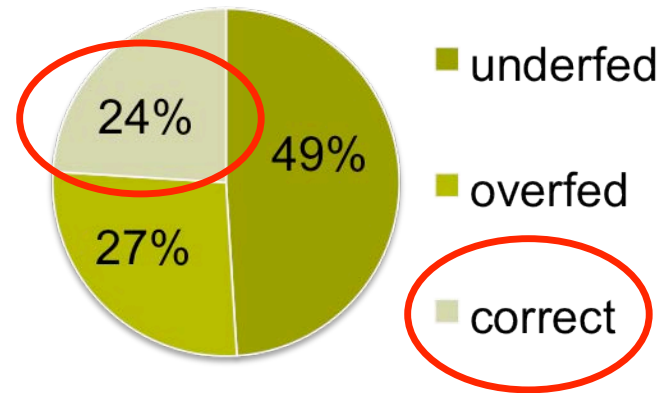
Observation days	350
Mechanical ventilation	7 days
Number of patients	50

Results: Adequacy

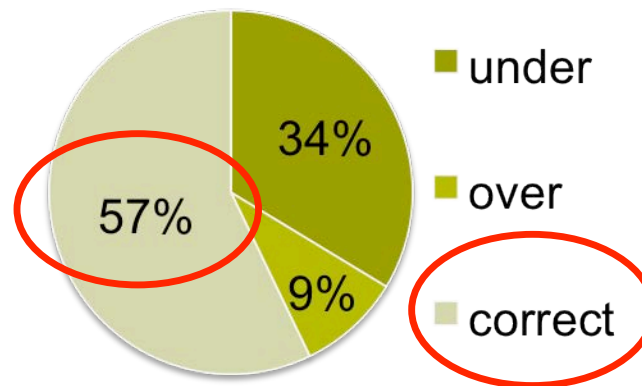
Prescriptions



Intake



Translation





2. Feasibility of Indirect Calorimetry to determine Energy Expenditure

Optimal nutrition = use of Indirect Calorimetry

Research

Open Access

Optimal nutrition during the period of mechanical ventilation decreases mortality in critically ill, long-term acute female patients: a prospective observational cohort study

Rob JM Strack van Schijndel¹, Peter JM Weijs², Rixt H Koopmans¹, Hans P Sauerwein³, Albertus Beishuizen¹ and Armand RJ Girbes¹

- Energy determined by indirect calorimetry
- Protein at least 1.2 g/kg/d

Indirect Calorimetry

Principle:

- Oxygen consumption
 - Carbon dioxide production
- Metabolism

Abbreviated Weir Equation:

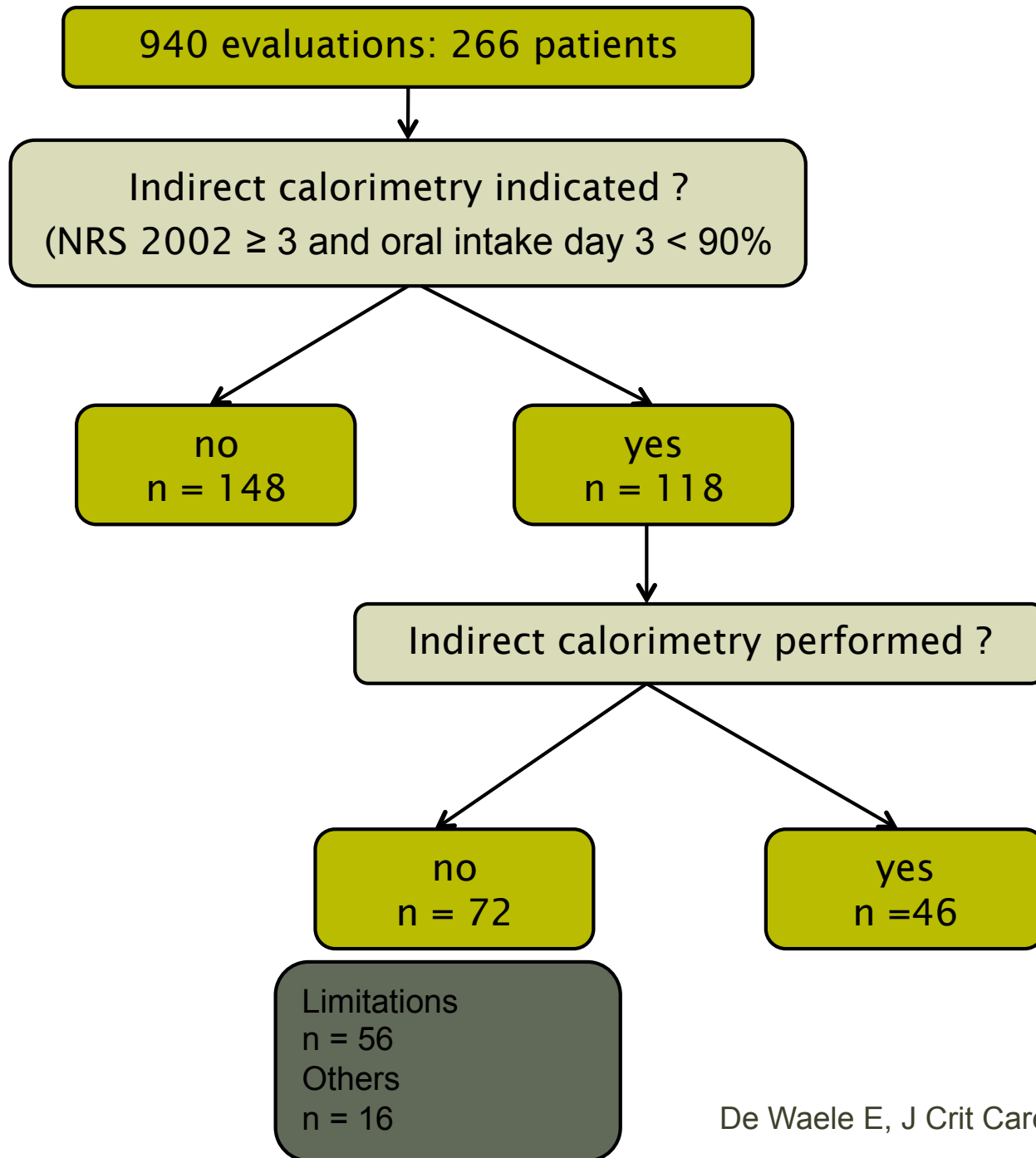
$$REE = [3.9 (VO_2) + 1.1 (VCO_2)] 1.44$$

VO₂ = oxygen uptake (ml/min)

VCO₂ = carbon dioxide output (ml/min)

$$\text{Respiratory quotient (RQ)} = VCO_2/VO_2$$







3. Correlation between IC measured and equation-generated Energy Expenditure

Energy Expenditure - Calculated

	Formula		
Harris Benedict 1919	♂: $66.4730 + (13.7516 \times W) + (5.0033 \times H) - (6.7550 \times A)$ ♀: $655.0955 + (9.5634 \times W) + (1.8496 \times H) - (4.6756 \times A)$		
Harris Benedict 1984	♂: $88.362 + (13.397 \times W) + (4.799 \times H) - (5.677 \times A)$ ♀: $447.593 + (9.247 \times W) + (3.098 \times H) - (4.33 \times A)$		
Faisy-Fagon	$(8 \times W) + (14 \times H) + (32 \times Vm) + (94 \times T) - 4834$		
Ireton-Jones 1992	$1925 - (10 \times A) + (5 \times W) + (281 \text{ if } \text{♂}) + (292 \text{ if trauma present}) + (851 \text{ if burns present})$		
Ireton-Jones 1997	$1784 - (11 \times A) + (5 \times W) + (244 \text{ if } \text{♂}) + (239 \text{ if trauma present}) + (840 \text{ if burns present})$		
Penn State 1998	$(1.1 \times \text{value of HBE}) + (140 \times T_{\max}) + (32 \times V_E) - 5340$		
Penn State 2003	$(0.85 \times \text{value of HBE}) + (175 \times T_{\max}) + (33 \times V_E) - 6433$		
Penn State 2003b	Mifflin (0.96) + Tmax (167) + Ve (31) - 6212	Mifflin: Men: $10(W) + 6.25(H) - 5(A) + 5$	
Penn State 2010	Mifflin (0.71) + VE (64) + Tmax (85) - 3085	Women: $10(W) + 6.25(H) - 5(A) - 16$	
Swinamer	$(945 \times BSA) - (6.4 \times A) + (108 \times T) + (24.2 \times RR) + (817 \times V_T) - 4349$		
American College of Chest Physicians (ACCP) recommendation	$25 \times W$ - if BMI 16-25 kg/m ² use usual body W - if BMI > 25 kg/m ² use ideal body W - if BMI < 16 kg/m ² use existing body W for the first 7-10 days. then use IBW		
ESICM '98 statement	Caloric target = caloric need × corrected IBW	Corrected IBW	
	Formula for calculating IBW	If BMI < 18.5	$(IBW + \text{actual body W}) / 2$
	♂: $50 + [0.91 \times (H - 152.4)]$	If BMI 18.5 – 27	IBW
	♀: $45.5 + [0.91 \times (H - 152.4)]$	If BMI > 27	$IBW \times 1.2$
		Caloric need (kcal/kg/day)	
		♀	♂
	A ≤ 60 years	30	36
	A > 60 years	24	30

♂: male; ♀: female; W: weight (kg); H: height (cm); A: age (years); Vm: minute ventilation (L/min); T: body temperature (°C); BSA: body surface area (m²); HBE: Harris Benedict equation; T_{max}: maximum body temperature in the past 24 h (°C); RR: respiratory rate (breaths/min); IBW: ideal body weight (kg); BMI: body mass index (kg/m²); V_E: minute volume (L/min); V_T: tidal volume (L).

Equations for calculating resting energy expenditure (kcal/day)

Degree of correlation between measured and calculated REE

Equation	R ²	Intercept	slope
Harris Benedict 1919	0.43	670,72	0,5403
Harris Benedict 1984	0.44	681,25	0,5420
Ireton-Jones 1992	0.30	1271,66	0,3791
Ireton-Jones 1997	0.28	1073,25	0,3587
Penn-State 1998	0.49	786,78	0,7628
Penn-State 2003	0.47	839,44	0,6377
Faisy-Fagon	0.49	1150,81	0,5358
Swinamer	0.51	1024,30	0,5856
ACCP recommendations	0.24	1171,05	0,2894
ESICM '98 statement	0.41	658,32	0,9168

R² = correlation coefficient

Correlation study

- Poor correlation between IC measurements and equation-derived energy calculations
- In the post-acute phase of critical illness we obtained a mean REE of 21 kcal/kg/day
- Clinical: Nutritional targets may be missed when using calculations



4. Nutrition of patients under continuous renal replacement therapy



Renal Replacement Therapy

Loss of nutritional substrates

Activation of protein catabolism

Increase in lipid peroxidation (bioincompatibility)

Methods

- Systematic review literature 1992-2012
- Nutrition in critically ill patients treated with CRRT
- QUORUM guidelines
- Provide recommendations for daily nutrition management in CRRT practice

Recommendations (summary)

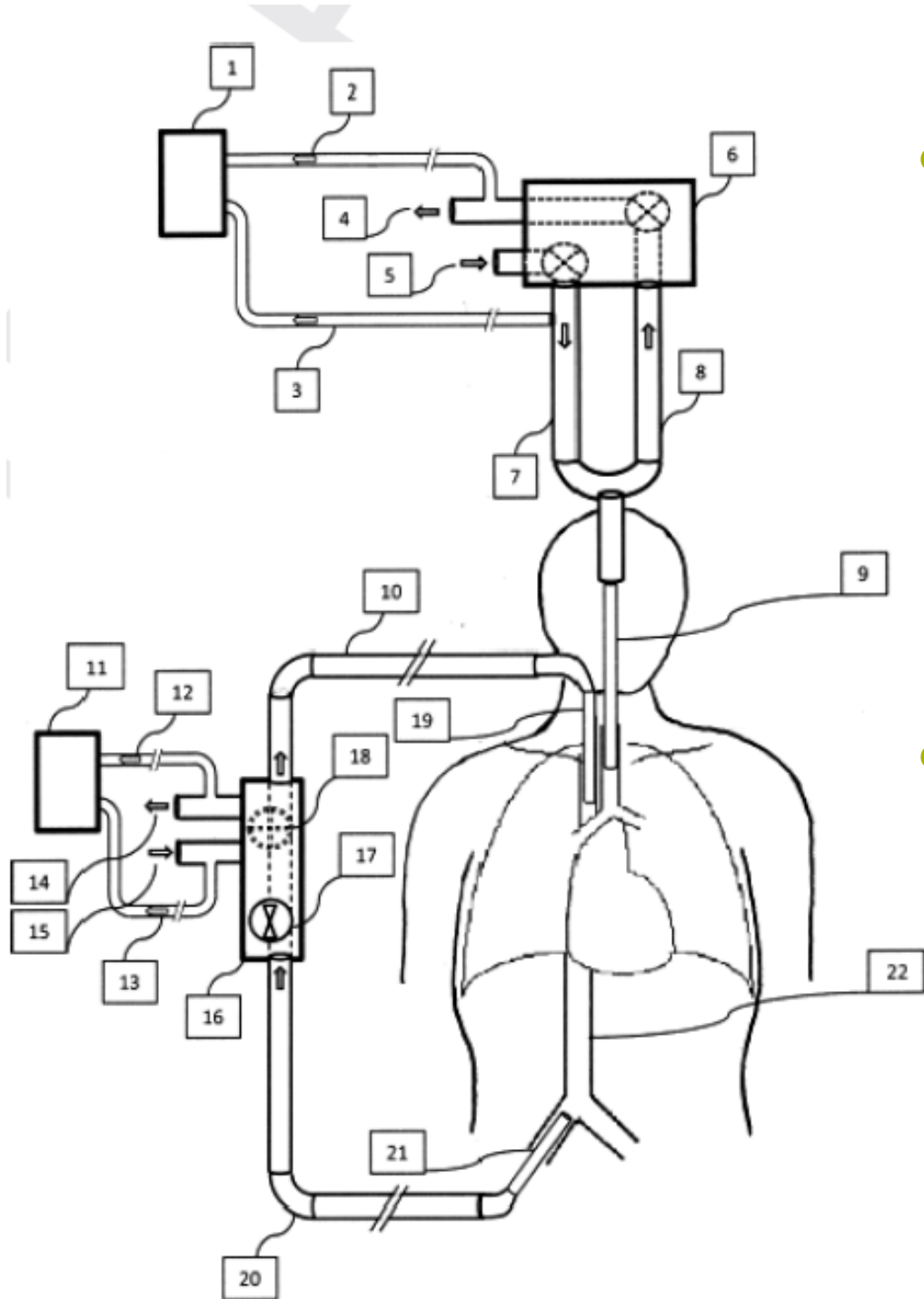
Energy	Indirect calorimetry 25–35 kcal/kg body weight/day	60–70% carbohydrates 30–40% lipids
Protein	1.5–1.8 g/kg body weight/day	
Electrolytes		
K	serum level >4 mEq/l	i.v. supplements K-rich replacement fluid K-rich substitution fluid
P		i.v. supplements substitution fluid
Mg		enteral supplements i.v. bolus 2–4 g/day
Glucose		strict glycemia control
Amino acid	+0.2–2.5 g/kg body weight/day glutamine (alanyl-glutamine dipeptide) 0.3–0.6 g/kg body weight/day	
Lipids		close triglyceride monitoring
Vitamins		
Water-soluble	vitamin B ₁ : 100 mg/day vitamin B ₂ : 2 mg/day vitamin B ₃ : 20 mg/day vitamin B ₅ : 10 mg/day vitamin B ₆ : 100 mg/day	vitamin B ₇ (biotin): 200 mg/day vitamin B ₉ (folic acid): 1 mg/day vitamin B ₁₂ : 4 µg/day vitamin C: 250 mg/day
Fat-soluble	vitamin E: 10 IU/day vitamin K: 4 mg/week	vitamin A: reduce supplementation
Trace elements	selenium: +100 µg/day zinc: 50 mg/day copper: 5 mg/day	triple dose of i.v. trace elements-containing solutions
Body temperature	>37°C	



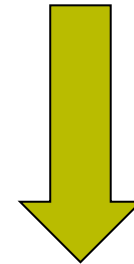
5. Indirect Calorimetry during Extra-Corporeal Membrane Oxygenation

Nutrition implications and challenges of the transplant patient undergoing extracorporeal membrane oxygenation therapy.

- Provision of adequate nutrition support challenging
- Clinical guidelines are available for the nutrition support of neonates
- No guidelines for the adult population
- Guidelines for nutrition support therapy in the adult critically ill provide best guidance.



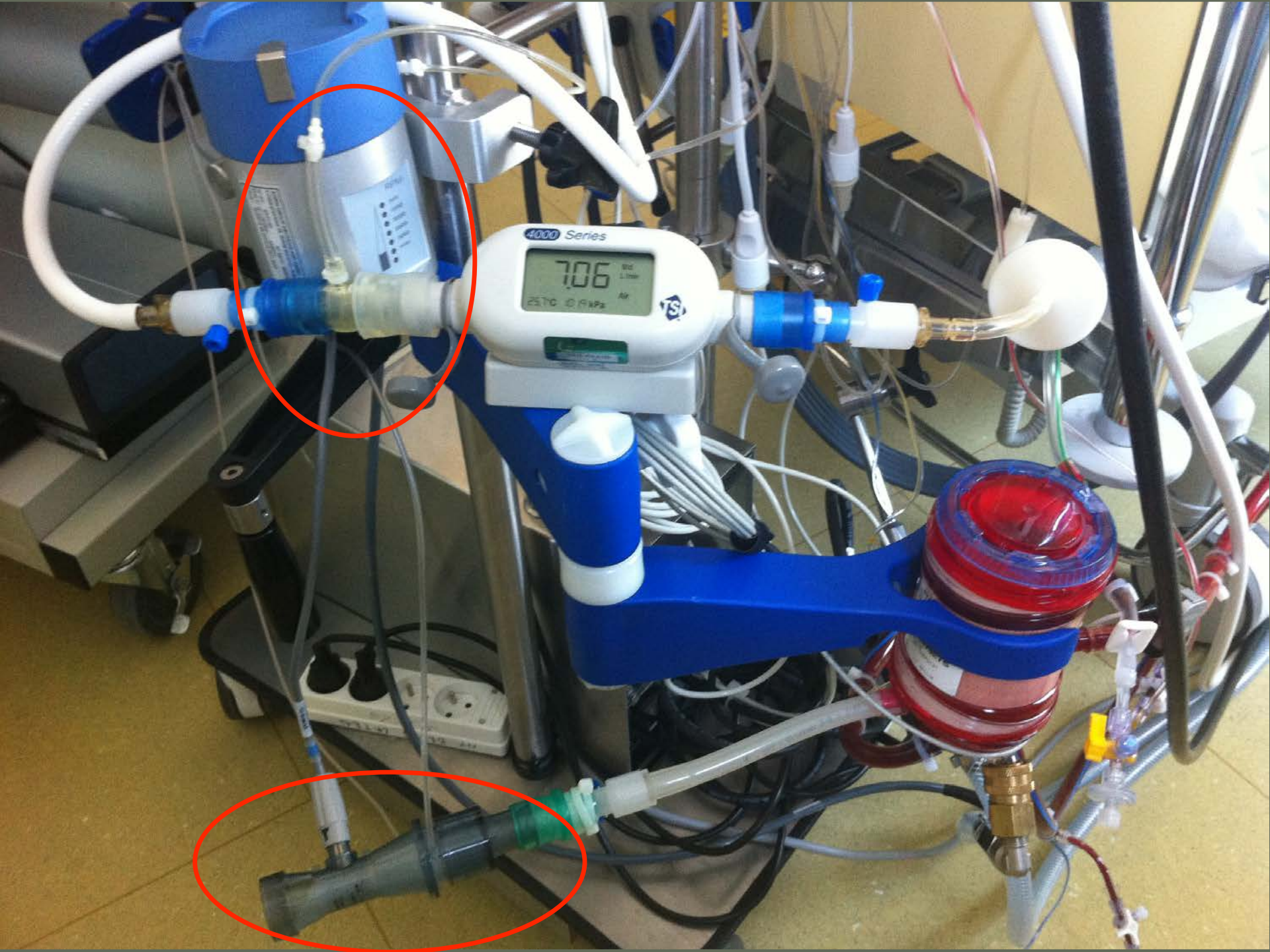
- 30 minutes indirect calorimeter connected to the ventilator



- 30 minutes indirect calorimeter connected to the oxygenator







Calculation case

- Weir: heat output total kg.cal. = (3.9 x L O₂ used + 1.1 x L CO₂ produced)
- Weir abbr REE kcal = {(3.94 x VO₂) + (1.1 x VCO₂)} x 1440
- Weir ECMO: REE = {(3.94 x VO₂ total) + (1.11 x VCO₂ total)} x 1440

$$\text{Weir}_{\text{ECMO}}: \text{REE} = \{(3.94 \times 0.243 \text{ L/min}) + (1.11 \times 0.203 \text{ L/min})\} \times 1440 \text{ min/24h}$$

$$\text{REE} = (0.957 + 0.225) \times 1440 = 1.182 \text{ L/min} \times 1440 \text{ min/24h} = 1703 \text{ kcal/day}$$

$$\text{VO}_2 \text{ total} = \text{VO}_2 \text{ native lung} + \text{VO}_2 \text{ ECMO}$$

$$\text{VO}_2 \text{ total} = 29.5 \text{ ml/min} + 213 \text{ ml/min} = 243 \text{ ml/min}$$

$$\text{VCO}_2 \text{ total} = \text{VCO}_2 \text{ native lung} + \text{VCO}_2 \text{ ECMO}$$

$$\text{VCO}_2 \text{ total} = 16 \text{ ml/min} + 187 \text{ ml/min} = 203 \text{ ml/min}$$

- $\text{VO}_2 \text{ ECMO} = (\text{FiO}_2 \text{ ECMO} \times \text{VI}_{\text{ECMO}}) - (\text{FeO}_2 \text{ ECMO} \times \text{VE}_{\text{ECMO}})$

$$\text{VO}_2 \text{ ECMO} = (0.950 \times 3.5 \text{ L/min}) - (0.889 \times 3.5 \text{ L/min})$$

$$= 3.325 \text{ L/min} - 3.112 \text{ L/min} = 0.213 \text{ L/min} = 213 \text{ ml/min}$$

- $\text{VCO}_2 \text{ ECMO} = (\text{FECO}_2 \text{ ECMO} \times \text{VE}_{\text{ECMO}}) - (\text{FiCO}_2 \text{ ECMO} \times \text{VI}_{\text{ECMO}})$

$$\text{VCO}_2 \text{ ECMO} = (0.0539 \times 3.5 \text{ L/min}) - (0.00053 \times 3.5 \text{ L/min})$$

$$= 0.189 \text{ L/min} - 0.00186 \text{ L/min} = 0.187 \text{ L/min} = 187 \text{ ml/min}$$

- $\text{VCO}_2 \text{ native lung} = (\text{FECO}_2 \times \text{VE}_{\text{native lung}}) - (\text{FiCO}_2 \times \text{VI}_{\text{native lung}})$

$$\text{VCO}_2 \text{ native lung} = (0.00429 \times 4.22 \text{ L/min}) - (0.00051 \times 4.22 \text{ L/min})$$

$$= 0.0181 \text{ L/min} - 0.00215 \text{ L/min} = 0.0160 \text{ L/min} = 16 \text{ ml/min}$$



Conclusions

Conclusions (1)

- Nutritional therapy quality was low in our ICU
- Indirect calorimetry is feasible in daily clinical practice and indicated in half of ICU patients
- Equations used to estimate Energy Expenditure correlate very weakly with IC-EE

Conclusions (2)

- Nutritional treatment recommendations for patients undergoing Renal Replacement Therapy
- Indirect Calorimetry is made feasible in patients on Extra Corporeal Membrane Oxygenation



Energy Expenditure and Nutritional Therapy in Critically ill Patients

Thank you

