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## Indirect Calorimetry in critically ill patients

### General Guidelines

#### Indirect calorimetry as point of care testing

*Sornwichate Rattanachaiwong, Pierre Singer. Clin Nutr. 2019 Jan*

The optimization of energy provision is a mainstay of nutrition therapy. IC has been shown to be successful in determining energy expenditure, superior to all predictive equations and has become the clear gold standard in various settings. The measurement of energy expenditure does not only provide a way to assess a patient's nutritional requirements, but also to provide clear solutions allowing the physician to adjust the caloric prescription to avoid under- and overfeeding in acute settings as well as to control the direction of long term nutritional management in chronic diseases. Therefore, bringing IC into clinical practice as point of care testing should be encouraged as a part of the individualized practice of modern medicine.

#### ESPEN guideline on clinical nutrition in the intensive care unit

*Pierre Singer, Annika Reintam Blaser, Mette M. Berger, Waleed Alhazzani, Philip C. Calder, Michael P. Casaer, Michael Hiesmayr, Konstantin Mayer, Juan Carlos Montejo, Claude Pichard, Jean-Charles Preiser, Arthur R.H. van Zanten, Simon Oczkowski, Wojciech Szczeklik, Stephan C. Bischoff. Clin Nutr. 2019 Feb;38(1):48-79*

Recommendation 15: In critically ill mechanically ventilated patients, EE should be determined by using indirect calorimetry. Grade of recommendation: B – strong consensus (95% agreement)

Statement 2: If calorimetry is not available, using VO<sub>2</sub> from pulmonary arterial catheter or VCO<sub>2</sub> derived from the ventilator will give a better evaluation on EE than predictive equations. Consensus (82% agreement)

#### Indirect calorimetry in nutritional therapy. A position paper by the ICALIC study group

*Taku Oshima, Mette M. Berger, Elisabeth De Waele, Anne Berit Guttormsen, Claudia-Paula Heidegger, Michael Hiesmayr, Pierre Singer, Jan Wernerman, Claude Pichard Clin Nutr. 2017 Jun;36(3):651-662*

Calorimetry is needed to optimize nutrition care for patients with various clinical conditions. The use of calorimetry is currently limited by various setbacks, mainly related to the lack of an adequate device. An ongoing initiative to develop a new calorimeter is expected to provide practical solutions for the current limitations, and make available a calorimeter corresponding to the requirements by clinicians for in- and outpatients, featuring accuracy, ease-of-use and affordable cost.

#### Guidelines for the Provision and Assessment of Nutrition Support Therapy in the Adult Critically Ill Patient: Society of Critical Care Medicine (SCCM) and American Society for Parenteral and Enteral Nutrition (A.S.P.E.N.)

*Stephen A. McClave, Beth E. Taylor, Robert G. Martindale, Malissa M. Warren, Debbie R. Johnson, Carol Braunschweig, Mary S. McCarthy, Evangelia Davanos, Todd W. Rice, Gail A. Cresci, Jane M. Gervasio, Gordon S. Sacks, Pamela R. Roberts, Charlene Compher, and the Society of Critical Care Medicine and the American Society for Parenteral and Enteral Nutrition. Journal of Parenteral and Enteral Nutrition Volume 40 Number 2 February 2016 159–211*

The report is an update and expansion of guidelines published by A.S.P.E.N. and SCCM in 2009. The intended use of these guidelines is for all healthcare providers involved in nutrition therapy of the critically ill—primarily, physicians, nurses, dietitians, and pharmacists. The study presents a list of recommendation for clinical practice, based on both the best available evidence and the risks and benefits to patients.

The recommendation regarding “What is the best method for determining energy needs in the critically ill adult patient?” The consensus answer is “We suggest that indirect calorimetry (IC) be used to determine energy requirements, when available and in the absence of variables that affect the accuracy of measurement.

### Useful Links

#### COSMED Indirect Calorimetry

<http://www.indirectcalorimetry.com>

#### COSMED Homepage

<http://www.cosmed.com>

### **Clinical Guide for the Use of Metabolic Carts. Indirect Calorimetry—No Longer the Orphan of Energy Estimation**

*Pierre Singer, Joelle Singer. Nutr Clin Pract December 24, 2015*

Critically ill patients often require nutrition support, but accurately determining energy needs in these patients is difficult. Energy expenditure is affected by patient characteristics such as weight, height, age, and sex but is also influenced by factors such as body temperature, nutrition support, sepsis, sedation, and therapies. Using predictive equations to estimate energy needs is known to be inaccurate. Therefore, indirect calorimetry measurement is considered the gold standard to evaluate energy needs in clinical practice. This review defines the indications, limitations, and pitfalls of this technique and gives practice suggestions in various clinical situations.

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

*Jean-Charles Preiser, Arthur RH van Zanten, Mette M Berger, Gianni Biolo, Michael P Casaer, Gordon S Doig, Richard D Griffiths, Daren K Heyland, Michael Hiesmayr, Gaetano Iapichino, Alessandro Laviano, Claude Pichard, Pierre Singer, Greet Van den Berghe, Jan Wernerman, Paul Wischmeyer, and Jean-Louis Vincent. Crit Care. 2015; 19(1): 35.*

This review presents an update in the management of nutrition in critically ill patients, identifying and discussing a number of areas for which consensus has been reached and others where controversy remains and presenting areas for future research. Among the areas of consensus (ICU patients with a more than 4-day length of stay) it is recognised that the estimation of energy expenditure requires indirect calorimetry and cannot be predicted by equations.

### **The use of indirect calorimetry in the intensive care unit**

*McClave SA, Martindale RG, Kiraly L. - Curr Opin Clin Nutr Metab Care. 2013 Mar;16(2):202-8.*

Appropriately performed indirect calorimetry is really the only true means to set accurate goals for nutrition therapy, avoiding the error in the design of feeding regimens and the demonstrated inaccuracies of calculating energy expenditure with increasing BMI. Emerging concepts pervading the ICU such as caloric deficit, permissive underfeeding, trophic feeding, and the dose of nutrition therapy required to change the outcome implicate the need for an accurate measurement of caloric requirements. Use of indirect calorimetry would be expected to increase in the future.

### **Indirect calorimetry: a guide for optimizing nutritional support in the critically ill child.**

*Sion-Sarid R1, Cohen J, Houriz, Singer P. Nutrition. 2013 Sep;29(9):1094-9.*

There is growing evidence from adult ICU studies for the need to measure energy expenditure accurately in order to track the dynamic energy needs of the critically ill, instead of prescribing for nutritional needs according to static predictive equations.

### **ESPEN Guidelines on Parenteral Nutrition: intensive care**

*Singer P, Berger MM, Van den Berghe G, Biolo G, Calder P, Forbes A, Griffiths R, Kreyman G, Leverve X, Pichard C, ESPEN - Clin Nutr. 2009 Aug;28(4):387-400.*

No precise amount of energy can be recommended to be provided by partial or total parenteral nutrition, since no large prospective study has demonstrated an advantage to any measurement technique or predictive formula. Studies are under way to determine the potential advantages of targeting energy delivery according to measured energy expenditure.

### **Guidelines for the Provision and Assessment of Nutrition Support Therapy in the Adult Critically Ill Patient: Society of Critical Care Medicine (SCCM) and American Society for Parenteral and Enteral Nutrition (A.S.P.E.N.)**

*McClave SA, Martindale RG, Vanek VW, McCarthy M, Roberts P, Taylor B, Ochoa JB, Napolitano L, Cresci G - JPEN J Parenter Enteral Nutr. 2009 May-Jun;33(3):277-316.*

Energy requirements may be calculated by predictive equations or measured by indirect calorimetry. Predictive equations should be used with caution, as they provide a less accurate measure of energy requirements than indirect calorimetry in the individual patient.

### **Indirect calorimetry: relevance to patient outcome.**

*McClave SA. Respir Care Clin N Am. 2006 Dec;12(4):635-50, vii.*

Indirect calorimetry provides an important adjunctive monitor for the provision of nutrition support in the critically ill patient. Accuracy in determining caloric requirements may serve to optimize benefit from nutrition therapy and improve patient outcome. A number of strategies in nutrition management in the intensive care setting (eg, dosing of enteral nutrition, monitoring cumulative caloric balance, and deliberate but “permissive” underfeeding) necessitate the determination of a fairly specific goal for caloric provision. Inaccuracy leading to inappropriate under- or overfeeding may generate additional morbidity and adverse clinical consequences for patients already at high risk from hypermetabolic stress response to injury.

### **AARC Clinical Practice Guideline: Metabolic Measurement Using Indirect Calorimetry During Mechanical Ventilation—2004 Revision & Update**

*AARC - Respiratory Care • September 2004 Vol 49 No 9*

This guideline from the American Association of Respiratory Care (AARC) defines the major aspects (indications, contraindications, assessment of test quality, frequency, and much more) metabolic measurement during mechanical ventilation.

### **Clinical use of the respiratory quotient obtained from indirect calorimetry.**

*McClave SA, Lowen CC, Kleber MJ, McConnell JW, Jung LY, Goldsmith LJ. - JPEN J Parenter Enteral Nutr. 2003 Jan-Feb;27(1):21-6.*

Although changes in the overall and nonprotein RQ correlate to percent calories provided/required, low sensitivity and specificity limit its efficacy as an indicator of over- or underfeeding. The RQ should not be used to finely adjust the nutrition support regimen. Elevation of overall measured RQ  $>$  or  $=$  1.0 may be associated with reduced tolerance and mild respiratory compromise. The clinical use of RQ is limited to a marker of test validity (to confirm measured RQ values are in physiologic range) and a marker for respiratory tolerance of the nutrition support regimen.

### **Achievement of steady state optimizes results when performing indirect calorimetry**

*McClave, S., & Spain, D. (2003). Journal of Parenteral . . . , 27(1), 16–26.*

We designed this prospective study to evaluate the necessity and significance of achieving steady state. These data support the use of steady state, best defined as an interval of 5 consecutive minutes whereby  $\dot{V}O_2$  and  $\dot{V}CO_2$  change by  $<10\%$ .

### **Should indirect calorimetry be used as part of nutritional assessment?**

*McClave SA, McClain CJ, Snider HL. J Clin Gastroenterol. 2001 Jul;33(1):14-9.*

The use of indirect calorimetry in the design of nutritional support regimens is poorly appreciated by clinicians, who fail to recognize the importance of providing a sufficient volume of enteral feeding to critically ill patients. In contrast to the overfeeding that routinely occurred in the past with the provision of total parenteral nutrition, patients placed on the enteral route of support tend to be underfed because of problems with intolerance and frequent cessation. Clearly identifying and coming as close as possible to the caloric goal may be required to achieve the therapeutic endpoints of enteral tube feeding (which include maintenance of gut integrity, attenuation of the stress response, prophylaxis against stress-induced gastropathy, and stimulation of immune function). Indirect calorimetry is a convenient, accessible, and highly accurate instrument for the measurement of caloric requirements and is a valuable tool for the optimization of nutritional support in the intensive care unit.

### **Indirect calorimetry in critically ill patients: clinical applications and practical advice**

*Brandi LS, Bertolini R, Calafà M - Nutrition. 1997 Apr;13(4):349-58.*

Currently, the potential useful clinical applications of indirect calorimetry in this category of patients can be summarized as follows: (1) assessment of energy expenditure in patients who fail to adequately respond to the estimated nutritional needs; (2) assessment of energy expenditure in patients with single- or multiple-organ dysfunction who need prolonged ICU care and artificial nutritional support; (3) assessment of the effects induced by artificial nutrition on the cardiocirculatory and respiratory systems in mechanically ventilated patients with acute respiratory failure; and (4) monitoring of  $\dot{V}O_2$  during weaning from mechanical ventilation

## **Use Of Indirect Calorimetry In Clinical Nutrition**

*McClave SA, Snider HL - 1992 Nutrition in Clinical Practice (NCP).7(5):207-21.*

This review study published in 1992 on the official journal of the American Society for Parenteral and Enteral Nutrition (ASPEN) was extremely influential in defining the clinical importance of indirect calorimetry in critical care. The study identifies the greatest theoretical advantage for the use of indirect calorimetry being the possibility to design nutritional TPN regimens that exactly meet patient energy requirements and avoid the complications of overfeeding. Indirect calorimetry can contribute to potential cost savings in nutrition support and may provide a useful tool for measuring the ability to wean patients from mechanical ventilation.

## **Optimal Energy Provision in critical care**

### **Does the use of indirect calorimetry change outcome in the ICU? Yes it does**

*De Waele E, Honoré P, Malbrain, Manu L.N.G. Current Opinion in Clinical Nutrition & Metabolic Care: January 15, 2018*

The use of indirect calorimetry, a validated, century-long studied method to gain information on one of the core functions of the human body, metabolism, should be implemented. Especially as the window of opportunity will arise by development of easy to use, cheap and accurate device. Agreement could exist on the fact that calorimetry is needed to optimize nutritional therapy, which can improve patients' outcome.

### **Supplemental parenteral nutrition in intensive care patients: A cost saving strategy.**

*Pradelli L, Graf S, Pichard C, Berger MM. Clin Nutr. 2018 Apr;37(2):573-579.*

Optimisation of energy provision using SPN is a cost-saving strategy in critically ill adults for whom EN is insufficient to meet energy requirements.

### **Supplemental Parenteral Nutrition Is the Key to Prevent Energy Deficits in Critically Ill Patients**

*Oshima T, Heidegger CP, Pichard C. Nutr Clin Pract. 2016 Aug;31(4):432-7.*

Our pragmatic approach is to start early EN to progressively test the gut tolerance and add supplemental PN on day 3 or 4 after ICU admission, only if EN does not meet the measured energy target. We believe that supplemental PN plays a pivotal role in the achievement of adequate feeding in critically ill patients with intolerance to EN and does not cause harm if overfeeding is avoided by careful prescription, ideally based on energy expenditure measured by indirect calorimetry.

### **Healthcare-Associated Infections Are Associated with Insufficient Dietary Intake: An Observational Cross-Sectional Study**

*Thibault R, Makhlof AM, Kossovsky MP, Iavindrasana J, Chikhi M, Meyer R, Pittet D, Zingg W, Pichard C - PLoS One. 2015 Apr 29;10(4):e0123695.*

Measured energy intake  $\leq$  70% of predicted energy needs is associated with HCAI in hospitalised patients. This suggests that insufficient dietary intake could be a risk factor of HCAI, without excluding reverse causality. Randomized trials are needed to assess whether improving energy intake in patients identified with decreased dietary intake could be a novel strategy for HCAI prevention.

### **Adequate enteral protein intake is inversely associated with 60-d mortality in critically ill children: a multicenter, prospective, cohort study.**

*Mehta NM, Bechard LJ, Zurakowski D, Duggan CP, Heyland DK. Am J Clin Nutr. 2015 Jul;102(1):199-206.*

Delivery of  $>$ 60% of the prescribed protein intake is associated with lower odds of mortality in mechanically ventilated children. Optimal prescription and modifiable practices at the bedside might enhance enteral protein delivery in the PICU with a potential for improved outcomes.

### **Optimisation of energy provision with supplemental parenteral nutrition in critically ill patients: a randomised controlled clinical trial**

*Heidegger CP, Berger MM, Graf S, Zingg W, Darmon P, Costanza MC, Thibault R, Pichard C. - Lancet. 2013 Feb 2;381(9864):385-93.*

Our findings provide evidence that individually optimised energy supplementation with SPN starting 4 days after admission should be considered as a strategy to improve clinical outcome in patients in the ICU with insufficient Enteral Nutrition.

### **Early ICU energy deficit is a risk factor for Staphylococcus aureus ventilator-associated pneumonia**

Faisy C, Candela Llerena M, Savalle M, Mainardi JL, Fagon JY. - *Chest*. 2011 Nov;140(5):1254-60.

This prospective, observational, cohort study by Prof. Faisy of the Medical Intensive Care Unit of the University Paris–Descartes (France) highlights the importance of indirect calorimetry in measuring energy deficit in ICU patients. This study was undertaken to determine the impact of patients'early in-ICU energy balance on the pathogens responsible for ventilator-associated pneumonia (VAP). Energy balance was compared according to the microbiologic results of the fiber-optic BAL cultures of 76 consecutive patients receiving acute prolonged mechanical ventilation who developed VAP during their ICU stay. The study conclusions found out that early ICU energy deficit is an independent determinant for acquiring S aureus Ventilator-associated Pneumonia in patients on acute prolonged mechanical ventilation. Therefore, limiting the energy deficit during the first week of ICU stay could be a way to optimize S aureus VAP prevention.

### **The tight calorie control study (TICACOS): a prospective, randomized, controlled pilot study of nutritional support in critically ill patients**

Singer P, Anbar R, Cohen J, Shapiro H, Shalita-Chesner M, Lev S, Grozovski E, Theilla M, Frishman S, Madar Z. - *Intensive Care Med*. 2011 Apr;37(4):601-9.

TICACOS is an influential prospective, randomized, single-center, pilot clinical trial led by Prof. Singer from the Department of General Intensive Care, Rabin Medical Center (Israel), who is also the ESPEN President and long-standing owner of several COSMED indirect calorimeters. The aim of the present pilot study was to determine whether nutritional support guided by repeated measurements of resting energy requirements improves the outcome of critically ill patients. The study population comprised mechanically ventilated patients (n = 130) expected to stay in ICU more than 3 days. The study conclusions point out that a bundle comprising actively supervised nutritional intervention and providing near target energy requirements based on repeated energy measurements was achievable in a general ICU and may be associated with lower hospital mortality.

A pilot prospective study compared calorie administration guided by indirect calorimetry to that following a 25 kcal/kg/day rule in 50 patients. Tight calorie control guided by indirect calorimetry apparently decreased hospital stay and hospital mortality by more than 50%.

### **Indirect calorimetry measurements in the ventilated critically ill patient: facts and controversies-- the heat is on.**

Lev S, Cohen J, Singer P. *Crit Care Clin*. 2010 Oct;26(4):e1-9. doi: 10.1016/j.ccc.2010.08.001.

The provision of nutrition to critically ill patients in the ICU often receives lower priority compared with hemodynamic and ventilation control. This frequently results in a significant calorie deficit. Overestimation of daily energy expenditure may also result in adverse outcomes. In many centers, nutritional decision making is based on predictive formulas, which have been shown to underestimate true energy requirements. Such estimations are ideally performed using indirect calorimetry. Nevertheless, the use of indirect calorimetry has been limited owing to costs and technical difficulties. Controversies about its actual clinical benefits are the focus of recent clinical studies and recommendations. The aim of this review was to describe the advantages of measuring indirect calorimetry within the concept of energy-protein goal-oriented therapy.

### **Guidelines for the provision and assessment of nutrition support therapy in the adult critically ill patient: Society of Critical Care Medicine and American Society for Parenteral and Enteral Nutrition: Executive Summary.**

Martindale RG, McClave SA, Vanek VW, McCarthy M, Roberts P, Taylor B, Ochoa JB, Napolitano L, Cresci G; American College of Critical Care Medicine; A.S.P.E.N. Board of Directors. *Crit Care Med*. 2009 May;37(5):1757-61.

The target goal of EN (defined by energy requirements) should be determined and clearly identified at the time of initiation of nutrition support therapy. Energy requirements may be calculated by predictive equations or measured by indirect calorimetry. Predictive equations should be used with caution, as they provide a less accurate measure of energy requirements than indirect calorimetry in the individual patient. In the obese patient, the predictive equations are even more problematic without availability of indirect calorimetry

### **The relationship between nutritional intake and clinical outcomes in critically ill patients: results of an international multicenter observational study.**

Alberda C, Gramlich L, Jones N, Jeejeebhoy K, Day AG, Dhaliwal R, Heyland DK. *Intensive Care Med*. 2009 Oct;35(10):1728-37.

Greater intakes of energy and protein were associated with better clinical outcomes of critically ill patients, particularly if their BMI is <25 or >35.

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

*Strack van Schijndel RJ, Weijs PJ, Koopmans RH, Sauerwein HP, Beishuizen A, Girbes AR. - Crit Care. 2009;13(4):R132.*

Main finding of our study is that reaching both an energy goal guided by indirect calorimetry and provision of protein in an amount of at least 1.2 g/kg pre-admission body weight during the period of artificial nutrition while mechanically ventilated, reduces ICU, 28-day and hospital mortality in the female part of the population.

**The relationship between nutritional intake and clinical outcomes in critically ill patients: results of an international multicenter observational study.**

*Alberda C, Gramlich L, Jones N, Jeejeebhoy K, Day AG, Dhaliwal R, Heyland DK. - Intensive Care Med. 2009 Oct;35(10):1728-37. doi: 10.1007/s00134-009-1567-4. Epub 2009 Jul 2.*

Increased intakes of energy and protein appear to be associated with improved clinical outcomes in critically ill patients, particularly when BMI is  $\geq 25$  or  $\geq 35$

**Feeding critically ill patients: what is the optimal amount of energy?**

*Stapleton RD, Jones N, Heyland DK. - Crit Care Med. 2007 Sep;35(9 Suppl):S535-40.*

Observational studies examining the association between amount of caloric intake and clinical outcomes suggest that providing somewhere in the range of 25% to 66% of calculated energy requirements is optimal.

**Computerized energy balance and complications in critically ill patients: an observational study.**

*Dvir D, Cohen J, Singer P. Clin Nutr. 2006 Feb;25(1):37-44.*

Negative energy balance may be correlated with the occurrence of complications in the ICU. The bedside CIS provides accurate information on energy balance in critically ill patients and may allow for early detection and prevention of severe negative energy balance and complications.

**Negative impact of hypocaloric feeding and energy balance on clinical outcome in ICU patients**

*Villet S, Chiolerio RL, Bollmann MD, Revelly JP, Cayeux RN MC, Delarue J, Berger MM. - Clin Nutr. 2005 Aug;24(4):502-9.*

This prospective observational study by Prof. Villet from the Anesthesiology department of the Centre Hospitalier Universitaire Vaudois (Switzerland) identifies that critically ill patients are also exposed to underfeeding, and to negative energy balances resulting from insufficient feed delivery intake, which favor the development of progressive malnutrition with complicated evolution. The study aimed at assessing the relationship between energy balance and outcome in critically ill patients. The study found out that negative energy balances were correlated with increasing number of complications, particularly infections. Energy debt appears as a promising tool for nutritional follow-up, which should be further tested. Delaying initiation of nutritional support exposes the patients to energy deficits that cannot be compensated later on.

**Dietary intake, resting energy expenditure, weight loss and survival in cancer patients.**

*Bosaeus I, Daneryd P, Lundholm K. - J Nutr. 2002 Nov;132(11 Suppl):3465S-3466S.*

These findings indicate that feedback regulation of dietary intake in relation to energy expenditure is frequently lost in patients with cancer. Hypermetabolism and weight loss were significant predictors of decreased survival. Mean survival time was about 8 mo; 189 patients survived 4 mo or more, and 153 could be reexamined. At the 4-mo follow-up during palliative care, group mean weight was nearly maintained, with large individual variations. Weight loss during follow-up predicted decreased survival. Energy intake increased slightly, also with great variation, and an increased energy intake predicted longer survival.

**Malnutrition in ICU**

**Malnutrition at Hospital Admission-Contributors and Effect on Length of Stay: A Prospective Cohort Study From the Canadian Malnutrition Task Force.**

*Allard JP, Keller H, Jeejeebhoy KN, Laporte M, Duerksen DR, Gramlich L, Payette H, Bernier P, Vesnaver E, Davidson B, Teterina A, Lou W. JPEN J Parenter Enteral Nutr. 2016 May;40(4):487-97.*

Malnutrition at admission and poor food intake early during hospitalization were associated with prolonged LOS, suggesting that prompt nutrition care or intervention and monitoring should be performed when patients are admitted to hospital.

### **Comparative analysis of undernutrition screening and diagnostic tools as predictors of hospitalisation costs.**

*Guerra RS, Sousa AS, Fonseca I, Pichel F, Restivo MT, Ferreira S, Amaral TF. J Hum Nutr Diet. 2016 Apr;29(2):165-73.*

Undernutrition is a predictor of hospitalisation costs, increasing costs by between 19% and 29%. Undernutrition screening tools have an ability for predicting hospitalisation costs similar to that of diagnostic tools.

### **The economic costs of disease related malnutrition.**

*Freijer K, Tan SS, Koopmanschap MA, Meijers JM, Halfens RJ, Nuijten MJ. Clin Nutr. 2013 Feb;32(1):136-41.*

Early recognition and treatment of Disease Related Malnutrition (DRM) can diminish the hospital length of stay and thus influence the total additional costs of DRM.

### **Malnutrition and its impact on cost of hospitalization, length of stay, readmission and 3-year mortality.**

*Lim SL, Ong KC, Chan YH, Loke WC, Ferguson M, Daniels L. Clin Nutr. 2012 Jun;31(3):345-50.*

Malnutrition was evident in up to one third of the inpatients and led to poor hospitalization outcomes and survival as well as increased costs of care, even after matching for DRG. Strategies to prevent and treat malnutrition in the hospital and post-discharge are needed.

### **Prevalence and costs of malnutrition in hospitalized patients; the PREDyCES Study.**

*Álvarez-Hernández J, Planas Vila M, León-Sanz M, García de Lorenzo A, Celaya-Pérez S, García-Lorda P, Araujo K, Sarto Guerri B; PREDyCES researchers. Nutr Hosp. 2012 Jul-Aug;27(4):1049-59.*

Disease-related malnutrition is a common medical condition not only serious, but affecting significantly patient's recovery; and still it is not adequately dealt with in routine clinical practice in Spain. Malnutrition is most often associated with pathologies such as cancer and diabetes, with the presence of dysphagia, being elderly and female as well as with emergency admission to hospital. Measures required for prevention and integrated care of the patient at risk of malnutrition or undernourished are simple, while the cost of malnutrition is much higher, both in economic terms and respect to the course and outcome of the disease.

### **Hospital malnutrition: prevalence, identification and impact on patients and the healthcare system.**

*Barker LA, Gout BS, Crowe TC. Int J Environ Res Public Health. 2011 Feb;8(2):514-27.*

Unidentified malnutrition not only heightens the risk of adverse complications for patients, but can potentially result in foregone reimbursements to the hospital through casemix-based funding schemes. It is strongly recommended that mandatory nutrition screening be widely adopted in line with published best-practice guidelines to effectively target and reduce the incidence of hospital malnutrition

### **The relationship between nutritional intake and clinical outcomes in critically ill patients: results of an international multicenter observational study.**

*Alberda C, Gramlich L, Jones N, Jeejeebhoy K, Day AG, Dhaliwal R, Heyland DK. Intensive Care Med. 2009 Oct;35(10):1728-37.*

Increased intakes of energy and protein appear to be associated with improved clinical outcomes in critically ill patients, particularly when BMI is <25 or >35.

### **Prognostic impact of disease-related malnutrition.**

*Norman K, Pichard C, Lochs H, Pirlich M. Clin Nutr. 2008 Feb;27(1):5-15. Epub 2007 Dec 3.*

Studies have repeatedly shown that clinical malnutrition however has serious implications for recovery from disease, trauma and surgery and is generally associated with increased morbidity and mortality both in acute and chronic diseases. Length of hospital stay is significantly longer in malnourished patients and higher treatment costs are reported in malnutrition. Since it has been demonstrated that proper nutritional care can reduce the prevalence of hospital malnutrition and costs, nutritional assessment is mandatory in order to recognise malnutrition early and initiate timely nutritional therapy.

### **The impact of malnutrition on morbidity, mortality, length of hospital stay and costs evaluated through a multivariate model analysis.**

*Correia MI, Waitzberg DL. Clin Nutr. 2003 Jun;22(3):235-9.*

Nutritional assessment should be routinely performed at admission in an attempt to reduce nutrition-related complications.

### **Cost containment through nutrition intervention.**

*Tucker HN, Miguel SG. Nutr Rev. 1996 Apr;54(4 Pt 1):111-21.*

Cost containment through nutrition intervention is a managed process. Its success depends on how much improvement in nutrition services occurs and how that improvement is documented through cost sensitive evaluation and monitoring tools.

### **Indirect Calorimetry vs Predicted Equations**

#### **Predictive energy equations are inaccurate for determining energy expenditure in adult burn injury: a retrospective observational study**

*James Leung, Emma J. Ridley, Heather Cleland, Joshua F. Ihle, Eldho Paulk and Susannah J. King. ANZJSurg. 2019 Apr.*

Patients with severe burn injury requiring MV are hypermetabolic compared to commonly used predictive estimates. Poor agreement was observed on an individual level between EE measured by IC and energy requirements calculated using equations. Accurate determination of EE in burn patients mandates the use of IC.

#### **Are Predictive Energy Expenditure Equations in Ventilated Surgery Patients Accurate?**

*Tignanelli CJ, Andrews AG, Sieloff KM, Pleva MR, Reichert HA, Wooley JA, Napolitano LM, Cherry-Bukowiec JR. J Intensive Care Med. 2017 Jan 1:885066617702077*

Using HBE, 20, 25, or 30 kcal/kg/d to estimate daily caloric requirements in critically ill surgical patients is inaccurate compared to REE measured by IC. In SICU patients with nutrition requirements essential to recovery, IC measurement should be performed to guide clinicians in determining goal caloric requirements.

#### **Harris-Benedict Equation and Resting Energy Expenditure Estimates in Critically Ill Ventilator Patients.**

*Piccolo MF, Lago AF, Meneguetti MG, Nicolini EA, Basile-Filho A, Nunes AA, Martins-Filho OA, Auxiliadora-Martins M. Am J Crit Care. 2016 Jan;25(1)*

For measuring REE in critically ill patients undergoing mechanical ventilation, calculation via the Harris-Benedict equation, regardless of the source of body weight, cannot be substituted for indirect calorimetry.

#### **Energy expenditure in different patient populations on intensive care: One size does not fit all**

*C. M. Mooij, C.J. Beurskens, N.P. Juffermans - Netherlands Journal of Critical Care – volume 17 – no 3 – july 2013*

EE differs among critically ill patient populations. The use of a 'one size fits all' formula to estimate caloric need in the critically ill may not be appropriate in the design of studies on caloric need nor in patient care.

#### **A Comparison of Predictive Equations of Energy Expenditure and Measured Energy Expenditure in Critically Ill Patients**

*Erin K. Kross, Matthew Sena, Karyn Schmidt, and Renee D. Stapleton - J Crit Care. 2012 June; 27(3): 321. e5–321.e12.*

There was bias and poor agreement between measured REE and REE predicted by the Harris-Benedict, Owen, ACCP, and Mifflin equations ( $p > 0.05$ ).

#### **Determining energy needs in critically ill patients: equations or indirect calorimeters.**

*Cooney RN1, Frankenfield DC. Curr Opin Crit Care. 2012 Apr;18(2):174-7.*

Indirect calorimetry is the most accurate way to determine calorie needs in critically ill patients.

#### **Resting energy expenditure in malnourished older patients at hospital admission and three months after discharge: predictive equations versus measurements.**

*Neelemaat F, van Bokhorst-de van der Schueren MA, Thijs A, Seidell JC, Weijs PJ. Clin Nutr. 2012 Dec;31(6):958-66. doi: 10.1016/j.clnu.2012.04.010. Epub 2012 Jun 1.*

Study comparing 23 predictive equation and 11 fixed weight-based factors, The REE predictive equations are not adequate to predict REE in malnourished hospitalized older patients. There is an urgent need for either a new accurate REE predictive equation, or accurate easy-to-use equipment to measure REE in clinical practice.



### **Harris-Benedict equation for critically ill patients: are there differences with indirect calorimetry?**

*Japur CC, Penaforte FR, Chiarello PG, Monteiro JP, Vieira MN, Basile-Filho A. - J Crit Care. 2009 Dec;24(4):628.e1-5.*

The EE measured by indirect calorimetry showed good agreement when compared to calculated by the equation of Harris-Benedict; however, when we evaluate by the clinical point of view, this change could represent an important deficit or excess of energy.

### **Analysis of estimation methods for resting metabolic rate in critically ill adults**

*Frankenfield DC, Coleman A, Alam S, Cooney RN - JPEN J Parenter Enteral Nutr. 2009 Jan-Feb;33(1):27-36.*

Accuracy rates in the study population ranged from 67% for the Penn State equation to 18% for the weight-adjusted Harris Benedict equation (without multiplication). Within subgroups, the highest accuracy rate was 77% in the elderly nonobese using the Penn State equation and the lowest was 0% for the weight-adjusted Harris Benedict equation.

### **Comparison of resting energy expenditure prediction methods with measured resting energy expenditure in obese, hospitalized adults**

*Anderegg BA, Worrall C, Barbour E, Simpson KN, Delegge M. - JPEN J Parenter Enteral Nutr. 2009 Mar-Apr;33(2):168-75.*

Measured energy expenditure with indirect calorimetry should be employed when developing nutrition support regimens in obese, hospitalized patients, as estimation strategies are inconsistent and lead to inaccurate predictions of energy expenditure in this patient population.

### **Predictive equations for energy needs for the critically ill**

*Walker RN, Heuberger RA. - Respir Care. 2009 Apr;54(4):509-21.*

Prediction accuracy among equations is rarely within 10% of the measured energy expenditure; however, in the absence of indirect calorimetry, a prediction equation is the best alternative.

### **Accurate determination of energy needs in hospitalized patients.**

*Boullata J, Williams J, Cottrell F, Hudson L, Compher C. J Am Diet Assoc. 2007 Mar;107(3):393-401.*

No equation accurately predicted REE in most hospitalized patients. Without a reliable predictive equation, only indirect calorimetry will provide accurate assessment of energy needs. Without knowing which patient's REE is being accurately predicted, indirect calorimetry may still be necessary in difficult to manage hospitalized patients.

### **Poor agreement between continuous measurements of energy expenditure and routinely used prediction equations in intensive care unit patients**

*Reid CL. - Clin Nutr. 2007 Oct;26(5):649-57. Epub 2007 Apr 6.*

Limits of agreement between the different equations and TEE values were unacceptably wide. Prediction equations may result in significant under or overfeeding in the clinical setting.

### **Assessment of resting energy expenditure in mechanically ventilated patients**

*Faisy C, Guerot E, Diehl JL, Labrousse J, Fagon JY - Am J Clin Nutr. 2003 Aug;78(2):241-9.*

Measured REE was 25% higher than the calculated REE obtained with the Harris-Benedict equations.

### **Comparison of indirect calorimetry, the Fick method, and prediction equations in estimating the energy requirements of critically ill patients**

*Flanckbaum L, Choban PS, Sambucco S, Verducci J, Burge JC - Am J Clin Nutr. 1999 Mar;69(3):461-6.*

These data do not support previous findings showing a strong correlation between REE determined by the Fick method and other prediction equations and indirect calorimetry. In critically ill patients receiving TPN, indirect calorimetry, if available, remains the most appropriate clinical tool for accurate measurement of REE.

### **Are patients fed appropriately according to their caloric requirements?**

*McClave SA, Lowen CC, Kleber MJ, Nicholson JF, Jimmerson SC, McConnell JW, Jung LY. - JPEN J Parenter Enteral Nutr. 1998 Nov-Dec;22(6):375-81.*

Because energy expenditure is difficult to predict on the basis of conventional equations, patients in long-term acute care facilities routinely are overfed and underfed, with only 25% receiving calories within 10% of required needs. Measuring a patient's energy requirement at least once by IC is important, because the degree of metabolism predicts how easily a patient will be underfed or overfed.

### **Resting energy expenditure in children in a pediatric intensive care unit: comparison of Harris-Benedict and Talbot predictions with indirect calorimetry values**

*Coss-Bu JA, Jefferson LS, Walding D, David Y, Smith EO, Klish WJ - Am J Clin Nutr. 1998 Jan;67(1):74-80.*

Neither the Harris-Benedict nor the Talbot method will predict resting energy expenditure with acceptable precision for clinical use. Indirect calorimetry appears to be the only useful way of determining resting energy expenditure in these patients.

### **Resting metabolic rate of the critically ill patient: measured versus predicted**

*Weissman C, Kemper M, Askanazi J, Hyman AI, Kinney JM - Anesthesiology. 1986 Jun;64(6):673-9.*

There was only a moderate correlation between measured resting energy expenditure and that predicted using the Harris-Benedict ( $r = 0.57$ ) and Aub-Dubois ( $r = 0.59$ ) formulae. There was little correlation between the ratio of the measured to the predicted (Harris-Benedict) resting energy expenditure and age, or the ratio of actual to ideal body weight and body weight. The measured resting energy expenditure differed widely (70-140%) from predicted, reflecting the many complex factors that influence these patients' metabolic rate. The role of standard predictive formulae in such patients is as an arbitrary reference point to be used to define hypermetabolism (measured greater than predicted) and hypometabolism (predicted greater than measured).

### **Energy expenditure in malnourished cancer patients.**

*L S Knox, L O Crosby, I D Feurer, G P Buzby, C L Miller, and J L Mullen . Ann Surg. 1983 Feb; 197(2): 152–162.*

Cancer patients exhibit major aberrations in energy metabolism, but are not uniformly hypermetabolic. Energy expenditure cannot be accurately predicted in cancer patients using standard predictive formulae.

## **Product Validations**

### **Evaluation of the accuracy and precision of a new generation indirect calorimeter in canopy dilution mode.**

*Delsoglio M, Dupertuis YM, Oshima T, van der Plas M, Pichard C. Clin Nutr. 2019 Sep 10. pii: S0261-5614(19)33029-8. [Epub ahead of print]*

Both in vitro and in vivo measurements of  $\text{VO}_2$ ,  $\text{VCO}_2$ , RQ and EE on three Q-NRG<sup>®</sup> units showed minimal differences compared to expected values and MS and very low intra- and inter-unit variability. These results confirm the very good accuracy and precision of the Q-NRG<sup>®</sup> indirect calorimeter in canopy dilution mode in spontaneously breathing adults.

### **In vitro validation of indirect calorimetry device developed for the ICALIC project against mass spectrometry.**

*Oshima T, Dupertuis YM, Delsoglio M, Graf S, Heidegger CP, Pichard C. Clin Nutr ESPEN. 2019 Aug;32:50-55.*

In vitro evaluation confirms that the accuracy of the Q-NRG<sup>®</sup> indirect calorimeter is within 5% at oxygen enrichment to 70%; i.e. maximum expected for clinical use. Further recommendations for the clinical use of the Q-NRG<sup>®</sup> by will be released once the ongoing multi-center study is completed.

### **Indirect calorimetry in critically ill mechanically ventilated patients: Comparison of E-sCOVX with the deltatrac.**

*Stapel SN, Weijts PJM, Girbes ARJ, Oudemans-van Straaten HM. Clin Nutr. 2019 Oct;38(5):2155-2160.*

The E-sCOVX metabolic monitor is not accurate in estimating EE in critically ill mechanically ventilated patients when compared to the Deltatrac, the present reference method. The E-sCOVX overestimates EE with a bias and precision that are clinically unacceptable.

### **Indirect Calorimetry in Mechanically Ventilated Patients: A Prospective, Randomized, Clinical Validation of 2 Devices Against a Gold Standard**

*Allingstrup MJ, Kondrup J, Perner A, Christensen PL, Jensen TH, Henneberg SW. JPEN J Parenter Enteral Nutr 2017 Nov;41(8):1272-1277.*

The QUARK RMR ICU Indirect Calorimeter compared better with the gold standard for values of Formula O2 and REE than did the CCM Express Indirect Calorimeter in mechanically ventilated patients who were circulatory and respiratory stable. Both indirect calorimeters had low precision. Although precision and accuracy could be further improved, measurements of REE using the QUARK RMR ICU Indirect Calorimeter may be of value, because the alternative (eg, equations) is likely to be less precise.

**Evaluation of three indirect calorimetry devices in mechanically ventilated patients: which device compares best with the Deltatrac II(®)? A prospective observational study**

*Graf S, Karsegard VL, Viatte V, Heidegger CP, Fleury Y, Pichard C, Genton L. Clin Nutr. 2015 Feb;34(1):60-5.*

There was no difference in mean REE measurements between Deltatrac,  $1749 \pm 389$  kcal/24 h and Quark RMR,  $1788 \pm 494$  kcal/24 h ( $P = 0.166$ ). CCM Express produced 64% higher mean REE values ( $2876 \pm 656$  kcal/24 h) than Deltatrac ( $P < 0.0001$ ). All instruments registered different values for RQ and expiratory minute volume. Quark RMR(®) compares better with Deltatrac II(®) than CCM express(®), but it suffers an EE variance of 441 kcal, which is not acceptable for clinical practice. New indirect IC should be further improved before recommending their clinical use in ICU.

**Indirect calorimetry in mechanically ventilated patients. A systematic comparison of three instruments.**

*Sundström M, Tjäder I, Rooyackers O, Wernerman J. Clin Nutr. 2013 Feb;32(1):118-21.*

Available instruments for indirect calorimetry give conflicting estimates of energy expenditure in mechanically ventilated patients. Whilst the Quark RMR compares better with the Deltatrac than CCM Express, the mechanisms behind this difference needs to be further explored.