



Indirect Calorimetry Literature Summary

2022

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Articles on research conducted with GE Healthcare respiratory modules

Ang, D., R. Chari, A. Garcia, J. Clark, J. Farrah, J. Hagan, C. Watson, W. Richards, H. Liu, D. Donaldson, J. Barde and T. Alderman (2019). "Optimizing energy expenditure and oxygenation toward ventilator tolerance is associated with lower ventilator and intensive care unit days." *J Trauma Acute Care Surg* **87**(3): 559-565.

Summary: IC: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): The hypothesis of this study was that if both EE and oxygenation are optimized toward ventilator tolerance ($RQ = 0.7$ to 1.0); this would provide patients with the best condition to be liberated from the ventilator. In this single-center prospective study of trauma patients requiring mechanical ventilation, 1,090 patients were included in a primary analysis of ventilator days between the intervention arm and historical controls. The primary outcome favored the intervention arm by approximately three days. In this study, all patients achieved the RQ goal (between 0.7 - 1.0) and over 95% met their REE nutritional goal.

Bae, E., et al. (2018). "Increased energy expenditure using indirect calorimetry among acute phase patients in neurosurgical intensive care unit." **37**: S52.

Summary: This study evaluated IC measured using the CARESCAPE B650 compared to predictive equations in neurosurgical critically ill patients. Predictive equations were found to underestimate EE in both acute (<14 day LOS) neurosurgical patients, and to a lesser extent, in chronically ill (>14 day LOS) patients. IC should be used to assess EE in neurosurgical patients, notably during the acute phase of disease.

Chen, Y. H., et al. Comparison of the Metabolic Load in Patient Ventilated with Pressure Support Ventilation and Adaptive Support Ventilation Mode with the Same Minute Ventilation. A104. CRITICAL CARE: INVASIVE, NON-INVASIVE, CONVENTIONAL, AND NON-CONVENTIONAL VENTILATION IN ACUTE RESPIRATORY FAILURE: A2550-A2550.

Summary: The Engström CareStation was used to evaluate VO_2 and VCO_2 during pressure-support ventilation (PSV) and adaptive support ventilation (ASV). Metabolic load was significantly lower during ASV versus PSV, as were VO_2 and VCO_2 . It is suggested that this lower metabolic load is the result of reduced work of breathing.

Ferreruela, M., et al. (2017). "Effect of FiO_2 in the measurement of VO_2 and VCO_2 using the E-COVX metabolic monitor." *Med Intensiva* **41**(8): 461-467.

Summary: This study demonstrated good precision for VO_2 and VCO_2 with the GE Healthcare E-COVX module with FiO_2 up to 0.40 . There was no clinically significant bias observed with FiO_2 0.40 - 0.80 . Precision was vulnerable to increased FiO_2 , with clinically inadequate VO_2 observed when FiO_2 exceeded 0.6 . Measurement of VCO_2 was not affected by changes in FiO_2 .

Lee, I. H., Y.-W. Kuo, F.-C. Lin, C.-W. Wu, J.-S. Jerng, P.-H. Kuo, J.-C. Cheng, Y.-C. Chien, C.-K. Huang and H.-D. Wu (2020). "Kinetics of oxygen uptake during unassisted breathing trials in prolonged mechanical ventilation: a prospective pilot study." *Scientific Reports* **10**(1): 14301.

Summary: GE Healthcare CARESCAPE Monitor B650 and Engström Carestation: This pilot study investigated the kinetics of VO_2 during unassisted breathing trials (UBT) in patients with prolonged mechanical ventilation. 49 patients were evaluated in a prospective observational trial. The median VO_2 increased significantly (from 235.8 to 298.2 ml/min; $P = 0.025$) in the failure group, but there was no significant change in the success group (from 223.1 to 221.6 ml/min; $P = 0.505$). In multivariate logistic regression analysis, an increase in $VO_2 > 17\%$ from the beginning period and a peak inspiratory pressure greater than -30 cm H₂O were significantly associated with the success of 120-minute UBT. The authors concluded, "Our findings show the potential of monitoring VO_2 in the final phase of weaning in tracheostomized patients with prolonged mechanical ventilation."

Panitchote, A., et al. (2017). "Energy expenditure in severe sepsis or septic shock in a Thai Medical Intensive Care Unit." *Asia Pac J Clin Nutr* **26**(5): 794-797.

Summary: This study aimed to measure energy expenditure in severe sepsis/septic shock patients by indirect calorimetry and to assess the correlation of energy expenditures between indirect calorimetry and predictive equations. IC was measured using an Engström Carestation mechanical ventilator. There was poor agreement and correlation between EE using predictive equations versus EE using IC. The Bland-Altman analysis showed a mean difference (limits of agreement) of -757 kcal/day between EE using IC and EE using predictive equations.

Satoh, D., *et al.* (2018). "Effects of intraoperative nutrients administration on energy expenditure during general anesthesia." *Nutrition* **45**: 37-40.

Summary: This study explored the physiological benefits of the administration of exogenous nutrients during general anesthesia. Recent reports have indicated that intraoperative infusions of glucose and amino acids exert anticatabolic effects. IC was measured with the GE Healthcare E-COVX module. The number of days of intubation and the length of the ICU stay did not differ among the three patient groups studied. The lengths of hospital stay were shorter in the groups receiving intraoperative glucose and amino acids, compared to the control group. Additionally, these results indicate that the infusion of glucose and amino acids during general anesthesia increases REE and exerts a thermogenic effect.

Smallwood, C. D. and N. M. Mehta (2013). "Gas exchange measurement during pediatric mechanical ventilation--agreement between gas sampling at the airway and the ventilator exhaust." *Clin Nutr* **32**(6): 988-992.

Summary: This investigation compared oxygen consumption (VO_2), carbon dioxide elimination (VCO_2), Resting Energy Expenditure (REE) and respiratory quotient (RQ) in mechanically ventilated children, obtained by two devices using distinct gas sampling methods. Despite strong correlations and small mean biases for VO_2 , VCO_2 and REE obtained by the Viasys Healthcare Vmax® and GE Healthcare E-COVX®, the limits of agreement were beyond the clinically acceptable range. These devices should not be used interchangeably for gas exchange measurements in mechanically ventilated children.

Smallwood, C. D., *et al.* (2017). "Accuracy of Oxygen Consumption and Carbon Dioxide Elimination Measurements in 2 Breath-by-Breath Devices." *Respir Care* **62**(4): 475-480.

Summary: This study assessed the accuracy and agreement of two devices used to quantify oxygen consumption (VO_2) and carbon dioxide elimination (VCO_2) in children, using a pediatric in vitro model of gas exchange. Of the two devices tested, only the newest module demonstrated a bias and limits of agreement that were within an a priori determined clinically acceptable range of $\pm 20\%$ for VO_2 and VCO_2 (E-sCAiOVX). The limits of agreement were clinically acceptable from 40 to 100 mL/min. This range corresponds to approximate patient weights of 5-16 kg. The older device (E-COVX) did not demonstrate agreement with the simulated values and therefore is not clinically acceptable for use in pediatric patients.

Stapel, S. N., *et al.* (2018). "Indirect calorimetry in critically ill mechanically ventilated patients: Comparison of E-sCOVX with the deltatrac." *Clin Nutr*.

Summary: In this prospective study with Deltatrac and E-sCOVX, measurements of energy expenditure (EE) in critically ill, mechanically ventilated patients were performed simultaneously. Mean EE-E-sCOVX was higher than EE-Deltatrac, with a bias of 235 ± 149 kcal/day, corresponding to a percentage error of 12.1% of the reference method. EE, VCO_2 and VO_2 measured by E-sCOVX and Deltatrac were significantly correlated. RQ was not. The authors concluded –that the E-sCOVX is not accurate and its use is therefore not recommended in critically ill patients. Because maintenance of the Deltatrac is no longer supported, there is a need for a new and reliable device.

Sundström Rehal, M., *et al.* (2016). "Measuring energy expenditure in the intensive care unit: a comparison of indirect calorimetry by E-sCOVX and Quark RMR with Deltatrac II in mechanically ventilated critically ill patients." **20**(1): 54.

Summary: The aim of this study was to determine the level of agreement in gas exchange measurements between the E-sCOVX, Quark RMR and the Deltatrac II in mechanically ventilated ICU patients. There was a significant bias toward higher VO_2 and VCO_2 values with both E-sCOVX and Quark RMR as compared to Deltatrac; that corresponded to 10% overestimation of REE.

Tan, J., *et al.* (2018). "Pilot experience with use of continuous indirect calorimetry in ICU." **37**: S53.

Summary: This pilot study evaluated the GE Healthcare R860 ventilator for determining REE. The technology was easy to use by staff. REE was not affected by time of day and therefore measurement can be obtained daily.

Uber, A., *et al.* (2018). "Preliminary observations in systemic oxygen consumption during targeted temperature management after cardiac arrest." **127**: 89-94.

Summary: Cardiac arrest patients receiving targeted temperature management were evaluated. Continuous VO_2 and VCO_2 measurements were obtained with the GE Healthcare CARESCAPE™ B650 monitor and the CARESCAPE E-sCOVX respiratory module. In a post-hoc analysis of the first 12 hours after return of spontaneous circulation, VO_2 was associated with survival (median VO_2 in survivors 3.35 mL/kg/min [2.98, 3.88] vs. non-survivors 2.61 mL/kg/min $p=0.039$). There was no cut-off value for VO_2 that differentiated survivors and non-survivors. There was no association between VCO_2 and survival. The RQ was higher in survivors -- patients whose first measured RQ was <0.7 had a survival rate of 17%, compared to 64% in patients whose initial RQ was ≥ 0.7 . Venous hyperoxia may offer future prognostic benefit in this population - venous hyperoxia as a state in which central venous oxygen saturation remains elevated despite low-to-normal cardiac output suggests a cellular inability to utilize oxygen and portends a poor prognosis.

Vasileiou, G., M. B. Mulder, S. Qian, R. Iyengar, L. M. Gass, J. Parks, E. Lineen, P. Byers and D. D. Yeh (2020). "Continuous Indirect Calorimetry in Critically Injured Patients Reveals Significant Daily Variability and Delayed, Sustained Hypermetabolism." *JPEN J Parenter Enteral Nutr* **44**(5): 889-894.

Summary: IC: E-sCOVX or E-COVX (GE Healthcare): This study evaluated the use of continuous indirect calorimetry over a two-week period among trauma patients in the ICU. Data from multiple 10-minute periods was collected daily during steady state and was used to calculate REE daily maximum, REE daily minimum, REE daily average and REE variability. 55 patients comprised the final analysis, the majority with blunt injuries (69%). A 25% increase in average REE was noted on Day 7 that was sustained through Day 14. The authors concluded: "Isolated REE measurements may not accurately reflect the true metabolic requirements (especially during early hospitalization), and continuous REE measurements, if available, are recommended for capturing the variations of metabolism as they occur on a day-to-day basis."

Articles involving use of GE Healthcare Technology

Diehl, J. L., N. Peron, R. Chocron, B. Debuc, E. Guerot, C. Hauw-Berlemont, B. Hermann, J. L. Augy, R. Younan, A. Novara, J. Langlais, L. Khider, N. Gendron, G. Goudot, J. F. Fagon, T. Mirault and D. M. Smadja (2020). "Respiratory mechanics and gas exchanges in the early course of COVID-19 ARDS: a hypothesis-generating study." *Ann Intensive Care* **10**(1): 95.

Summary: IC: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): This study evaluated the respiratory mechanics and gas exchange associated with COVID-19 infected patients with ARDS. A total of 22 patients were evaluated, and gas exchange was characterized by hypercapnia and high physiological dead space. The ventilatory ratio was 2.9.

Fabiano Alves, V. G., E. E. M. da Rocha, M. C. Gonzalez, R. B. Vieira da Fonseca and M. H. do Nascimento Silva (2019). "Resting Energy Expenditure Measured by Indirect Calorimetry in Obese Patients: Variation Within Different BMI Ranges." *Journal of Parenteral and Enteral Nutrition* **44**(1): 129-137.

Summary (IC: Deltatrac II): This study aimed to determine if there was an appreciable difference in REE in obese patients between the fasted and fed state. In total, 97 IC measurements were obtained from 63 patients during 2009 - 2012 with a BMI range of 27.3 to 53.4 kg/m². There was no difference in measured REE between fasted and fed states across three BMI groups (overweight, obese, morbidly obese). Additionally, there was a negative correlation between REE and progression of BMI from overweight through morbidly obese ($r=-0.35$, $p=0.04$). The authors concluded that no method can be recommended to estimate REE in extremely obese patients given the risk of underestimating energy requirements.

Lee, S. J., H.-J. Lee, Y.-J. Jung, M. Han, S.-G. Lee and S.-K. Hong (2020). "Comparison of Measured Energy Expenditure Using Indirect Calorimetry vs Predictive Equations for Liver Transplant Recipients." *Journal of Parenteral and Enteral Nutrition* n/a(n/a).

Summary (IC: GE Healthcare, specific device not specified): In this study, commonly used predictive equations were compared to EE measured via IC in patients undergoing liver transplantation. The four predictive methods evaluated were the simple weight-based equation (25 kcal/kg/day, rule of thumb) and Harris-Benedict, Ireton-Jones (for ventilated patients), and Penn State 1988 equations. In total, 46 patients were evaluated. The predicted REE calculated using the Penn State 1988 method agreed with the measured REE. All four predictive equations showed a fixed bias and appeared to be inaccurate for predicting REE in this cohort of liver transplant recipients. The authors concluded that precise measurements using IC may be helpful when treating critically ill patients to avoid underestimating or overestimating their metabolic needs.

Pereira-da-Silva, L., S. Barradas, A. C. Moreira, M. Alves, A. L. Papoila, D. Virella and G. Cordeiro-Ferreira (2020). "Evolution of Resting Energy Expenditure, Respiratory Quotient, and Adiposity in Infants Recovering from Corrective Surgery of Major Congenital Gastrointestinal Tract Anomalies: A Cohort Study." *Nutrients* **12**(10): 1-17.

Summary (IC: Deltatrac II): This study aimed at quantifying the evolution of REE, RQ, and adiposity of infants during the late anabolic phase after corrective surgery of major congenital gastrointestinal tract anomalies and to explore the determinants associated with these components of energy balance. 29 neonates were included for analysis, which included 15 pre-term infants. In total, 317 longitudinal calorimetry measurements were performed. In infants born pre-term, the median REE varied between 55.7 and 67.4 kcal/kg/day, and median RQ changed from 0.70 to 0.86-0.92 between 34 and 42 weeks. In infants born at term, the median REE varied between 57.3 and 67.9 kcal/kg/day while the median RQ increased from 0.63 to 0.84-0.88 from 38 to 44 weeks PMA (post-menopausal age).

Poulsen, M. K., L. P. Thomsen, S. Kjærgaard, S. E. Rees and D. S. Karbing (2019). "Reliability of, and Agreement Between, two Breath-by-Breath Indirect Calorimeters at Varying Levels of Inspiratory Oxygen." *Nutrition in Clinical Practice* 34(5): 767-774.

Summary: IC: Beacon 3 (Mermaid Care, device 2) and ECOVX (GE Healthcare, device 1), reference method): This study investigated whether measurements of EE, VO_2 , and VCO_2 by breath-by-breath IC devices 1 and 2 were within-day reliable under conditions of varying FiO_2 , and whether the two systems measured in agreement. (Device 2 does not use the Haldane transformation). The study was conducted in 20 healthy male subjects and IC was measured while breathing through a ventilator facemask, conscious and sitting. Both systems measured EE, VO_2 , and VCO_2 at 21%–85% FiO_2 reliably, but with bias at 85% FiO_2 . The devices were in agreement at 21% and 50% FiO_2 , but further studies need to confirm accuracy at high FiO_2 .

Singer, P., E. De Waele, C. Sanchez, S. Ruiz Santana, J. C. Montejó, P. F. Laterre, A. Soroksky, E. Moscovici and I. Kagan (2021). "TICACOS international: A multi-center, randomized, prospective controlled study comparing tight calorie control versus Liberal calorie administration study." *Clinical nutrition (Edinburgh, Scotland)* 40(2): 380-387.

Summary: IC: Deltatrac II, COVX (both GE Healthcare) and Quark (Cosmed): This follow-on to the compendium of TICACOS studies completed to date evaluated the impact of measuring daily REE and the impact on infection rates in critically ill patients. In total 332 patients were allocated into a control or study intervention arm; but the study failed to achieve the targeted enrollment numbers. The primary outcome of infection was not significantly decreased between the study and control groups. There was a trend for decreased hospital mortality in the study arm that did not reach statistical significance. The authors concluded, "these results together with other prospective randomized studies using indirect calorimetry might give a signal toward improved survival when patients' medical nutritional therapy is guided by indirect calorimetry."

Smetana, K. S., Y. Hannawi and C. C. May (2020). "Indirect Calorimetry Measurements Compared With Guideline Weight-Based Energy Calculations in Critically Ill Stroke Patients." *JPEN. Journal of parenteral and enteral nutrition*.

Summary: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): The energy requirements of neuro-critical care patients are largely unknown. This study in critically ill stroke patients evaluated the energy requirements during the acute disease process. In this single-center, retrospective, observational study, IC was obtained at the baseline of the critical-care journey and low-weight and high-weight-based energy estimates were compared. The low-weight-based group was significantly lower than the REE target measured by IC, while high-weight-based group was similar to IC REE targets. Linear regression analysis showed that weight, height, and hemorrhagic stroke subtype were associated with IC.

Sungurtekin, H., S. Karakuzu and S. Serin (2019). "Energy Expenditure in Mechanically Ventilated Patients: Indirect Calorimetry vs Predictive Equations." *Dahili ve Cerrahi Bilimler Yoğun Bakım Dergisi* 10(1): 7-12.

Summary: IC: M-CAiOVX (GE Healthcare): This prospective study evaluated multiple predictive equations compared to indirect calorimetry measurements in mechanically ventilated critically ill patients. In total, 114 patients were evaluated. All of the predictive equations showed moderate correlation among themselves ($P < 0.05$). The Harris-Benedict and Penn State equations showed the better agreement with IC, compared to other equations. The authors concluded: "Predictive equations are not reliable in determining EE; the confidence intervals are very high and can lead to inadequate feeding or overfeeding."

Tamura, T., T. Yatabe and M. Yokoyama (2019). "Energy expenditure measured using indirect calorimetry after elective cardiac surgery in ventilated postoperative patients: A prospective observational study." *Clinical Nutrition Experimental* 24: 15-23.

Summary: IC: CARESTATION Engstrom ventilator (GE Healthcare): This study evaluated REE in patients undergoing cardiac surgery during the post-operative period. This prospective observational study enrolled 47 patients. Bland-Altman analysis was conducted. The mean difference was 116.6 kcal/day between REE measured and REE estimated by Harris-Benedict. Secondary analysis determined no significant difference in REE between on-pump and off-pump groups.

Vasileiou, G., S. Qian, R. Iyengar, M. B. Mulder, L. M. Gass, J. Parks, G. D. Pust, R. Rattan, E. Lineen, P. Byers and D. D. Yeh (2019). "Use of Predictive Equations for Energy Prescription Results in Inaccurate Estimation in Trauma Patients." *Nutrition in Clinical Practice* 35(5): 927-932.

Summary: CARESCAPE R860 with integrated IC: This study of 55 mechanically ventilated trauma ICU patients showed that predictive equations (e.g. Harris-Benedict) overestimated REE compared to IC. On the first day of REE measurement, overestimation was 26%; over seven days, the overestimation was 13%, and at 14 days, the overestimation remained greater than IC at 7%. The study concluded that "The use of weight-based equations and formulas fails to account for the continuous metabolic changes that occur in this population during the first days after injury."

Articles on research conducted with Deltatrac monitor

Kagan, I., et al. (2018). "Validation of carbon dioxide production (VCO_2) as a tool to calculate resting energy expenditure (REE) in mechanically ventilated critically ill patients: a retrospective observational study." *Crit Care* **22**(1): 186.

Summary: A retrospective observational study involving ventilated patients compared the REE derived from VCO_2 (REE- VCO_2) with the REE derived from IC (REE-IC). REE and RQ were calculated using the Weir equation. 497 measurements were conducted with a median of three measurements per patient. Results showed that there was wide variability without a consistent bias, suggesting that the VCO_2 measurement could widely under- and over-estimate REE. Therefore, REE via IC remains the best tool to estimate caloric needs.

Weintraub, V., F. B. Mimouni and S. Dollberg (2007). "Changes in energy expenditure in preterm infants during weaning: a randomized comparison of two weaning methods from an incubator." *Pediatr Res* **61**(3): 341-344.

Summary: IC: Deltatrac II (GE Healthcare): In this study, 42 preterm infants were assessed in an RCT with one of two weaning methods to assess the impact on REE. REE increased significantly at the time an infant was weaned from the incubator, regardless of weaning method. A comparison of the six infants who failed weaning with the 36 that had a successful weaning from the incubator revealed that mode of weaning was not significantly influential (two failures/19 infants (10.5%) in the warming bassinet group versus 4/23 (17.4%) in the incubator group, $p = 0.67$). Baseline REE was almost significantly lower ($p = 0.06$) in the failed group (219 ± 11 kJ/kg/d) than in the successful group (236 ± 7 kJ/kg/d).

Zusman, O., et al. (2016). "Resting energy expenditure, calorie and protein consumption in critically ill patients: a retrospective cohort study." *Crit Care* **20**(1): 367.

Summary: This study, the largest retrospective study ($n=6994$) completed using indirect calorimetry as opposed to predictive equations to determine energy requirements in mechanically ventilated, critically ill patients, demonstrated a non-linear, significant association between the percent Administered Calories/REE and mortality by 60 days. The findings suggest that both underfeeding and overfeeding appear to be harmful to mechanically ventilated, critically ill patients. Intuitively, achieving a goal of 100 % calories administered would be optimal; in fact, the ideal goal for calories administered with the most favorable survival was achieved at 70%.

Zusman, O., et al. (2018). "Predictive equations versus measured energy expenditure by indirect calorimetry: A retrospective validation." *Clin Nutr*.

Summary: A retrospective study in ICU patients evaluating REE estimates compared to IC (Deltatrac) was conducted on 1,565 patients, for a total of 5,847 measurements. This is the largest study evaluating REE versus predictive equations. The results confirm what has been observed in many smaller studies as well as a systematic review, showing a large variability and poor accuracy of predictive equations. The level of accuracy never exceeded 50%.

Articles on research conducted with non-GE technology

Allingstrup, M. J., et al. (2017). "Indirect Calorimetry in Mechanically Ventilated Patients: A Prospective, Randomized, Clinical Validation of 2 Devices Against a Gold Standard." *JPEN J Parenter Enteral Nutr* **41**(8): 1272-1277.

Summary: In this study, the QUARK RMR ICU indirect calorimeter compared better with the gold standard (modified Tissot bell-spirometer method) for values of VO_2 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.

Baek, J. K., S. J. Lee, H. J. Lee, Y. J. Jung and S. K. Hong (2019). "OR04: Assessing the Appropriate Energy Expenditure Requirement Using Indirect Calorimetry for Liver Transplant Recipients." *Clinical Nutrition* **38**: S5-S6.

Summary: This study compared predictive equations with indirect calorimetry to identify the appropriate energy expenditure requirement of liver transplant recipients. 46 patients were enrolled, and the REE with the strongest agreement was the Penn State 1988 equation (65%) followed by the Harris-Benedict method (56%, $P < 0.001$). All three predictive equations evaluated showed unsatisfactory agreement with measured REE.

Berger, M. M., et al. (2017). "Impact of the reduction of the recommended energy target in the ICU on protein delivery and clinical outcomes." *Clin Nutr* **36**(1): 281-287.

Summary: Energy targets are a matter of debate for ICU patients. As the guidelines have evolved, energy targets have been reduced, while protein intake objectives have increased. The impact of these changes remains largely unknown. This quality study investigated the clinical impact of these changes in patients with an ICU stay > 3 days. A linear reduction in energy target recommendation without changing the feed composition led to an unplanned and significant reduction in protein delivery, which was associated with a prolonged duration of ventilation and an extended hospital stay.

CARDIA, L., et al. (2017). "Resting Metabolic Rate In Patients Submitted To Bariatric Surgery: Comparison of Indirect Calorimetry With Predictive Equations." *Surgery for Obesity and Related Diseases* **13**(10): S141.

Summary: In this study, IC was measured with Ultima CPX (MedGraphics). Gastric bypass patients were evaluated before surgery, peri-operative, and 6 months and 36 months after. The study displayed descriptive statistics only and no conclusions on the application of IC before during or after bariatric surgery were offered.

Clark, A., et al. (2017). "Nutrition and metabolism in burn patients." *Burns Trauma* **5**: 11.

Summary: This review article involving nutritional support for burn patients listed a few highlights. 1) Nutritional support is critical in the treatment of burn patients, in whom the metabolic rate can be greater than twice the normal rate. 2) The primary goal of nutritional support in burn patients is to fulfill the increased caloric requirements caused by the hypermetabolic state while avoiding overfeeding. 3) IC is considered the gold standard with a great concern about overfeeding, which is commonly associated with difficulty in weaning from the mechanical ventilator.

De Waele, E., et al. (2015). "Measuring resting energy expenditure during extracorporeal membrane oxygenation: preliminary clinical experience with a proposed theoretical model." *Acta Anaesthesiol Scand* **59**(10): 1296-1302.

Summary: This pilot study evaluated the use of IC in patients with severe respiratory failure undergoing ECMO. [Unknown IC device]

De Waele, E., et al. (2016). "VCO₂ calorimetry: stop tossing stones, it's time for building!" *Acta Anaesthesiol Scand*. **20**(1): 399.

Summary: The commenters concurred that VO₂ is the most relevant variable for EE measurement. However, the most accurate and precise estimation of EE in a critically ill population can only be obtained by sampling of inspired and expired oxygen/carbon dioxide concentrations and by measuring expired gas flow. This is the core task of indirect calorimetry.

De Waele, E., et al. (2018). "The CoCoS trial: Caloric Control in Cardiac Surgery patients promotes survival, an interventional trial with retrospective control." *Clinical Nutrition* **37**(3): 864-869.

Summary: Malnutrition is an often overlooked comorbid condition in patients scheduled for cardiac surgery and affects 10-25% of patients. The patients are often considered to have higher in-hospital mortality, have increased length of intensive care and hospital stay, need longer antibiotic and vasopressor treatment and more frequently have positive blood cultures. IC was measured using Vmax™ Encore 29n. Targeted nutrition therapy conferred a survival benefit in female patients, but not in male patients. In addition, there were significantly fewer cardiac arrhythmias in males following surgery that were in the nutrition therapy group. The authors conclude that nutrition therapy can largely benefit elective cardiac surgery patients and deserves to be implemented as a standard-of-care supportive therapy in this setting.

Ebihara, T., et al. (2018). "Low energy expenditure among elderly patients in acute, sepsis." *Clinical Nutrition* **37**: S174.

Summary: REE is typically increased in septic patients, but it is unknown if that applies to the elderly (>65 yoa). Comparisons were made in REE (measured) and BEE (estimated) in the elderly and in control (<65 yoa) population. A BEE/REE < 80% was only observed in the elderly population. A BEE/REE > 120% was associated with a high likelihood of death (66.7% in elderly, 0% in controls). In summary, low energy expenditure was only observed in the elderly population and conferred a survival benefit.

Fetterplace, K., et al. (2018). "Targeted Full Energy and Protein Delivery in Critically Ill Patients: A Pilot Randomized Controlled Trial (FEED Trial)." *JPEN J Parenter Enteral Nutr*.

Summary: This pilot study looked at protocol-based care (volume target enteral feeding) versus the standard of care. No IC measurement was mentioned to support the protocol treatment arm. The results show that protocol-based feeding resulted in significant improvements in skeletal muscle mass. However, there were no differences in outcomes (mortality and LOS) between the two groups.

Graf, S., et al. (2017). "Energy expenditure in mechanically ventilated patients: The weight of body weight!" *Clin Nutr* **36**(1): 224-228.

Summary: This study aimed to determine the best prediction strategy when IC is not available. Correlations between estimated EE and IC were poor regardless of body weight, and agreement was also poor.

Graham, J. (2018). "Oxygen Consumption in Sepsis.", *University of San Diego*

Summary: This study (a dissertation) evaluated metabolics between septic and non-septic patients. There was a difference in oxygen consumption between the two groups of cases [VO₂ (t 3.919, p 0.001), VCO₂ (η = 608, p = 0.003), and lactate (η = 621, p = 0.003)]. The authors stated that future research is needed using larger samples to test predictive models for sepsis so that nurses can intervene to prevent the deterioration of these patients

Graham, J. and E. Goulette (2019). "Accurate determination of resting energy expenditure in the critically ill adult." *Critical Care Medicine* **47**(1).

Summary: This prospective evaluation of mechanically ventilated critically ill patients compared the PENN predictive equation to indirect calorimetry assessment of REE. A total of 21 patients were enrolled, and a statistically significant difference was noted between the predictive and measured REE, where PENN underestimated IC ($P < 0.001$). This study supports the growing evidence that use of predictive equations increases the risk of overfeeding.

Hung, R., et al. (2017). "Comparison of estimates of resting energy expenditure equations in haemodialysis patients." *Int J Artif Organs* **40**(3): 96-101.

Summary: In hemodialysis patients, standard equations underestimated REE.

Inadomi, C., et al. (2008). "Comparison of oxygen consumption calculated by Fick's principle (using a central venous catheter) and measured by indirect calorimetry." *J Anesth* **22**(2): 163-166.

Summary: This study investigated the clinical usefulness of the Fick method using central venous oxygen saturation ($ScvO_2$) and cardiac output (CO) measured by Pulse Dye -Densitometry (PDD) for monitoring oxygen consumption (VO_2). This prospective clinical study was performed in 28 mechanically ventilated postoperative patients after major abdominal surgery. VO_2 values determined by the Fick method were significantly lower than those measured by indirect calorimetry.

Kamel, A., L. Robayo, D. Liang, M. Rosenthal, S. Voils and P. Efron (2019). "Estimated versus measured energy expenditure in ventilated surgical trauma critically ill patients." *Critical Care Medicine* **47**(1).

Summary: This study evaluated the REE via predictive equations compared to indirect calorimetry in surgical trauma patients. A total of 10 predictive equations were used. 104 patients were analyzed. and the closest estimate to IC-REE was the modified Harris-Benedict equation ($r = 0.6515$). The authors concluded that predictive equations offer limited effectiveness for estimating REE in this patient population.

Karlsson, M., et al. (2017). "Ability to predict resting energy expenditure with six equations compared to indirect calorimetry in octogenarian men." **92**: 52-55.

Summary: The accuracy of predictive equations for calculating resting energy expenditure (REE) in elderly people has been questioned. Aging is associated with progressive declines in REE, which is partly explained by loss of fat-free mass (FFM). The Mifflin-St Jeor equation (using FFM) is the most accurate equation for estimating REE in these octogenarian men. The Harris-Benedict or WHO equations are potential alternatives if information on FFM is unavailable, although their accuracy on an individual level is limited. (An unknown IC device used in this study.)

Koekkoek, W. A. C., G. Xiaochen, D. van Dijk and A. R. H. van Zanten (2020). "Resting energy expenditure by indirect calorimetry versus the ventilator- VCO_2 derived method in critically ill patients: The DREAM- VCO_2 prospective comparative study." *Clinical Nutrition ESPEN* **39**: 137-143.

Summary: IC: Quark RMR (Cosmed); VCO_2 : Hamilton-S1 mechanical ventilator, Hamilton Medical AG): This study compared energy expenditure via measurement of expired gases ($EEVCO_2$) against the reference standard of indirect calorimetry in a prospective observational study involving critically ill patients. $EEVCO_2$ was derived from CO_2 using an adjusted version of Weir's equation, and RQ estimated at 0.86. In total, 31 patients were included for analysis. The mean $EEVCO_2$ was 2,134 kcal/d compared to a mean EE from IC of 1,623 kcal/d. $EEVCO_2$ overestimated EE in 92.8% of cases and underestimated in 0.2% of cases. The authors concluded that predictive equations, albeit inaccurate, may even predict EE better compared with the $EEVCO_2$ method.

Kovachev, I., et al. (2002). "[Assessment of oxygen delivery (DO_2) and oxygen consumption (VO_2) in severe pre-eclamptic patients]." *Akush Ginekol (Sofia)* **41**(3): 18-23.

Summary: No results can be determined except for demonstration of use of VO_2 in management of preeclampsia.

Ławiński, M., M. K. Skroński, A. Ukleja, M. Andrzejewska, P. Nyckowski, M. Słodkowski, M. Theilla and P. Singer (2019). "MON-PO600: Indirect Calorimetry in Oncological Surgery Liver Patients – Comparison of Resting Energy Expenditure with Prediction Equations." *Clinical Nutrition* **38**: S281-S282.

Summary: This study evaluated the utility of predictive equations compared to calorimetry in patients undergoing liver resection surgery. In total, 100 patients were enrolled. There was no appreciable difference in the resting metabolic rate between Day 0 and Day 7 following surgery. If IC not available, the Mifflin formula offered the best correlation with IC during pre-surgery evaluation ($R = 0.85$). However, there is no optimal predictive formula for REE evaluation for this surgical patient group.

Lee, P. S.-P., et al. (2017). "Metabolic Requirement of Septic Shock Patients Before and After Liberation From Mechanical Ventilation." **41**(6): 993-999.

Summary: This study identified the difference in energy expenditure and substrate utilization of patients during and upon liberation from mechanical ventilation. The authors concluded that measured energy expenditure was higher during than upon liberation from mechanical ventilation. This could be the increase in work of breathing from the continuous positive pressure support, repeated weaning cycles from mechanical ventilation, and/or the asynchronization between patients' respiration and ventilator support. Future studies should examine whether more appropriately matching energy expenditure with energy intake would promote positive health outcomes. (An unknown IC device used in this study.)

Liu, W., et al. (2017). "Measurements of resting energy expenditure in surgical critically ill patients with mechanical ventilator." **44**(7): 452-455.

Summary: This study compared the differences between measured resting energy expenditure calculated by the indirect calorimetry and the resting energy expenditure calculated by the Harris-Benedict formula. Resting energy expenditure by the Harris-Benedict formula was significantly higher than calculated from indirect calorimetry ($P < 0.05$). Resting energy expenditure by the weight formula was significantly lower than calculated from indirect calorimetry ($p < 0.05$). Although the Harris-Benedict formula and weight formula are convenient in clinical use, the results calculated by them is significantly different from the results calculated by indirect calorimetry. So clinical nutrition support should rely on indirect calorimetry as far as possible. (An unknown IC device used in this study.)

Oliveira, A., C. C. de Oliveira, M. T. de Jesus, N. N. B. Menezes, F. N. de Gois, J. T. da Silva and L. M. Santos (2020). "Comparison of Equations to Predict Energy Requirements with Indirect Calorimetry in Hospitalized Patients." *Journal of Parenteral and Enteral Nutrition*.

Summary: IC: CCM Express (MedGraphics): This study evaluated the degree of agreement between the REE measurement via IC (REE-IC) and REE estimated by predictive equations in ICU patients. There was a significant difference in REE measured by IC as compared to predictive equations (Harris-Benedict and Ireton Jones).

Patkova, A., et al. (2018). "Prognostic value of respiratory quotients in severe polytrauma patients with nutritional support." **49**: 90-95.

Summary: This study aimed to evaluate the association between energy metabolism and prognosis in polytrauma patients. IC was performed on the fourth ICU day in order to evaluate the impact of EE on outcomes. RQ was significantly lower in fasted polytrauma patients than in those receiving nutritional support (parenteral nutrition). Significant association was demonstrated between ICU LOS and duration of mechanical ventilation for those receiving nutritional support.

Peerless, J. R., et al. (2000). "Oxygen consumption in the early postinjury period: use of continuous, on-line indirect calorimetry." *Crit Care Med* **28**(2): 395-401.

Summary: This study aimed to determine patterns of oxygen consumption (VO_2) using indirect calorimetry (IC) for the first 24 hours after serious blunt traumatic injury. The authors found that seriously injured patients are hypermetabolic in the early post-injury period. The level of VO_2 was unrelated to injury severity and did not predict the onset of multiorgan dysfunction.

Pelekhaty, S. L., C. L. Ramirez, J. M. Massetti, D. Gaetani, K. Riggin, G. Schwartzbauer and D. M. Stein (2020). "Measured vs Predicted Energy Expenditure in Mechanically Ventilated Adults With Acute, Traumatic Spinal Cord Injuries." *Nutrition in Clinical Practice*.

Summary: IC: Vmax 229 (SensorMedics): This study evaluated measured energy expenditure from indirect calorimetry versus predicted energy expenditure in critically ill patients with acute spinal cord injuries. A total of 115 IC studies were conducted in 51 patients. Penn State 2003b predicted within 10% of measured energy expenditure most frequently. All equations were biased toward overfeeding, except for PS 2003b in the obese subset. Therefore, in the absence of IC, the Penn State or the derived Weir equation may be acceptable predictive equations in this patient population.

Peyton, P. J. and G. J. Robinson (2005). "Measured pulmonary oxygen consumption: difference between systemic oxygen uptake measured by the reverse Fick method and indirect calorimetry in cardiac surgery." *Anaesthesia* **60**(2): 146-150.

Summary: Measurement of oxygen uptake by indirect calorimetry was compared with the reverse Fick method in a series of patients undergoing cardiac surgery. IC was performed with non-GE technology. Indirect calorimetry overestimated the reverse Fick value by 11.3% ($p < 0.001$), a finding consistent with the results of previous studies with similar patient groups.

Piccolo, M. F., et al. (2016). "Harris-Benedict Equation and Resting Energy Expenditure Estimates in Critically Ill Ventilator Patients." *Am J Crit Care* **25**(1): e21-29.

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

Piot, J., et al. (2018). "An elevated respiratory quotient predicts complications after cardiac surgery under extracorporeal circulation: an observational pilot study." *J Clin Monit Comput*.

Summary: Following cardiac surgery, hyperlactatemia due to anaerobic metabolism is associated with an increase in both morbidity and mortality. Researchers previously found that an elevated respiratory quotient (RQ) predicted anaerobic metabolism. In the present study, the authors aimed to demonstrate that increased RQ is associated with poor outcomes following cardiac surgery. This was confirmed.

Ramos, F., et al. (2017). "Comparison of predictive equations of resting energy expenditure in older adults with chronic obstructive pulmonary disease." **23**(1): 40-42.

Summary: The authors concluded that the majority of equations underestimated the REE and all equations showed low association with IC. Therefore, they suggested that the REE equations used at present study should not be used in older adults with COPD. The main limitation of this study was that the small sample size constituted mainly by male patients does not permit speculation about these results in general COPD population and more studies evaluating higher number of older adults with COPD are needed.

Reneau, J., B. Obi, A. Moosreiner and S. Kidambi (2019). "Do we need race-specific resting metabolic rate prediction equations?" *Nutrition & Diabetes* **9**(1).

Summary: IC: Parvo TrueOne2400: This study aimed to evaluate racial impacts on REE between predictive and calorimetry-based measurements. A total of 114 healthy subjects were enrolled. The authors determined that the formula using height, weight, gender and age systematically overestimated REE and hence predicted higher caloric needs among African-American patients.

Segadilha, N., et al. (2017). "Energy Expenditure in Critically Ill Elderly Patients: Indirect Calorimetry vs Predictive Equations." *JPEN J Parenter Enteral Nutr* **41**(5): 776-784.

Summary: This study evaluated the degree of agreement between and the accuracy of the REE measured by IC (REE-IC) and REE estimated by predictive equations (REE-PE) in mechanically ventilated elderly patients. The authors concluded that estimated REE showed limited effectiveness in this patient population.

Silva, T. A., F. d. C. P. Maia, M. C. A. Zocrato, S. F. Mauricio, M. I. T. D. Correia and S. d. V. Generoso (2021). "Preoperative and Postoperative Resting Energy Expenditure of Patients Undergoing Major Abdominal Operations." *Journal of Parenteral and Enteral Nutrition* **45**(1): 152-157.

Summary: IC: Quark RMR (Cosmed): This study assessed REE after major abdominal procedures and its associated factors. In total, 54 patients were included in the analysis. There were no significant changes in REE at any of the assessed periods in the pre-operative or post-operative periods. There was a decrease in the RQ during the post-operative period when compared with the pre-operative assessment, accompanied by a decrease in carbohydrate oxidation and an increase in lipid oxidation.

Soussi, S., et al. (2017). "Measurement of Oxygen Consumption Variations in Critically Ill Burns Patients: Are the Fick Method and Indirect Calorimetry Interchangeable?" *Shock* **48**(5): 532-538.

Summary: This study conducted in 23 critically ill burn patients evaluated the interchangeability of oxygen consumption variations measured with the Fick equation versus indirect calorimetry. The results demonstrated poor agreement, and therefore VO_2 measurements by means of IC are not interchangeable with VO_2 obtained by Fick.

Tah, P. C., Z.-Y. Lee, B. K. Poh, H. Abdul Majid, V.-R. Hakumat-Rai, M. B. Mat Nor, C. C. Kee, M. Kamarul Zaman and M. S. Hasan (2020). "A Single-Center Prospective Observational Study Comparing Resting Energy Expenditure in Different Phases of Critical Illness: Indirect Calorimetry Versus Predictive Equations." *Critical Care Medicine* **48**(5): e380-e390.

Summary: This single center prospective observational study evaluated REE during different phases of critical illness. The main evaluation was accuracy of predictive equations compared to indirect calorimetry. In brief, none of the resting energy expenditure calculations from predictive equations showed very good agreement or accuracy.

Tah, P. C., V. R. Hakumat-Rai, B. K. Poh, M. B. Mat Nor, H. Abdul Majid, C. C. Kee, M. K. Zaman, Z. Y. Lee and M. S. Hasan (2019). "MON-PO621: Validity of Predictive Equations for Estimation of Resting Energy Expenditure Among Mechanically Ventilated Critically Ill Patients at Different Phases of Critical Illness." *Clinical Nutrition* **38**: S289-S290.

Summary: This study evaluated predictive equations compared to indirect calorimetry in critically ill patients amongst Southeast Asian populations. Comparison methodology was applied during the acute, late and chronic phases of the ICU stay. In the acute phase, the Penn State equation showed the highest level of agreement. During the late phase, the Brandi equation was the best, and during the chronic phase, the Faisy equation had the highest agreement. Based on the Bland-Altman test, good agreement was also observed between REE-PE and REE-IC, which was characterized by a narrow interval.

Tignanelli, C. J., A. G. Andrews, K. M. Sieloff, M. R. Pleva, H. A. Reichert, J. A. Wooley, L. M. Napolitano and J. R. Cherry-Bukowiec (2017). "Are Predictive Energy Expenditure Equations in Ventilated Surgery Patients Accurate?" *J Intensive Care Med*: 885066617702077.

Summary: This study compared the REE measured by IC with REE calculated using specific calorie goals or predictive equations for nutritional support in ventilated adult SICU patients. 419 patients were evaluated in this retrospective study. The HBE, 20, 25, and 30 kcal/kg/d estimates of REE were found to be inaccurate regardless of age, gender, or weight. The HBE and 20 kcal/kg/d underestimated REE, while 25 and 30 kcal/kg/d overestimated REE.

Tignanelli, C. J., *et al.* (2017). "Are Predictive Energy Expenditure Equations in Ventilated Surgery Patients Accurate?": 0885066617702077.

Summary: Prior studies suggest these equations frequently misjudge actual resting energy expenditure (REE) in medical and mixed intensive care unit (ICU) patients; however, their utility for surgical ICU (SICU) patients has not been fully evaluated. In SICU patients with nutrition requirements essential to recovery, REE was found to be inaccurate and IC measurement should be performed to guide clinicians in determining goal caloric requirements.

Wen-Yi, C., *et al.* (2017). "PT07. 3: The Clinical Outcomes and Medical Costs in Chronic Obstructive Pulmonary Disease Patients on Prolonged Mechanical Ventilation with and without Malnutrition." **36**: S44.

Summary: In patients with chronic obstructive pulmonary disease on prolonged mechanical ventilation, malnutrition was associated with worse clinical outcomes: increased mortality rate and 30-day readmission rates. In addition, hospital charges were 1.7 greater in the malnutrition cohort.

Wen-Yi, C., *et al.* (2017). "PT07.4: The Clinical Outcomes and Medical Costs in Non-Dialysis Chronic Kidney Disease Patients with and without Malnutrition." *Clinical Nutrition* **36**: S44-S45.

Summary: In patients with non-dialysis chronic kidney disease, malnutrition was associated with worse clinical outcomes: increased mortality rate and 30-day readmission rates.

Yoshimura, S., *et al.* (2015). "A short period of fasting before surgery conserves basal metabolism and suppresses catabolism according to indirect calorimetry performed under general anesthesia." *J Anesth* **29**(3): 453-456.

Summary: The authors' findings suggest that a short period of fasting (<8 h) before surgery is more strongly associated with the conservation of basal metabolism.

Special Patient Populations

Pediatrics

Acar-Tek, N., *et al.* (2017). "Estimation of Resting Energy Expenditure: Validation of Previous and New Predictive Equations in Obese Children and Adolescents." *J Am Coll Nutr* **36**(6): 470-480.

Summary: Previously developed predictive equations mostly provided inaccurate and biased estimates of REE. However, the new predictive equations allow clinicians to estimate REE in obese children and adolescents with sufficient and acceptable accuracy.

Beggs, M. R., *et al.* (2016). "Do PICU patients meet technical criteria for performing indirect calorimetry?" *Clin Nutr ESPEN* **15**: 80-84.

Summary: Indirect calorimetry is the gold standard for measuring energy expenditure. However, in this current study, technical criteria for IC were met on only one third of total patient days. Moreover, criteria were met on only 29% of days for infants 6 months and younger. Children 24 months of age and older still only met criteria on 40% of patient days. This study highlights a major gap in the feasibility of current recommendations for the care of this population, particularly vulnerable infants. Future studies are needed to develop improved methods to accurately predict and measure energy requirements in critically ill children who do not meet current criteria for indirect calorimetry.

Briassoulis, G., *et al.* (2009). "The effects of endotracheal suctioning on the accuracy of oxygen consumption and carbon dioxide production measurements and pulmonary mechanics calculated by a compact metabolic monitor." *Anesth Analg* **109**(3): 873-879.

Summary: E-COVX indirect calorimetry measurements in pediatric sepsis or head injury were not affected by endotracheal suctioning (ETS). Metabolics were reliably measured within 5 minutes following ETS.

Briassoulis, G., *et al.* (2009). "Influence of different ventilator modes on VO₂ and VCO₂ measurements using a compact metabolic monitor." *Nutrition* **25**(11-12): 1106-1114.

Summary: The influence of different ventilator modes on VO₂ and VCO₂ measurements in adequately sedated critically ill children is not significant. The E-COVX metabolic module is suitable for repeated measurements in well-sedated mechanically ventilated children with stable respiratory patterns.

Carpenter, A., *et al.* (2017). "Predictive Equations Are Inaccurate in the Estimation of the Resting Energy Expenditure of Children With End-Stage Liver Disease." *JPEN J Parenter Enteral Nutr* **41**(3): 507-511.

Summary: This study found that commonly used predictive equations perform poorly in infants and young children with ESLD. Indirect calorimetry should be used when available to guide energy provision, particularly in children who are already malnourished.

Ismail, J., A. Bansal, M. Jayashree, K. Nallasamy and S. V. Attri (2019). "Energy Balance in Critically Ill Children With Severe Sepsis Using Indirect Calorimetry: A Prospective Cohort Study." *Journal of pediatric gastroenterology and nutrition* **68**(6): 868-873.

Summary: This study evaluated the daily energy balance in children with severe sepsis. IC was measured with the Quark RMR (Cosmed) metabolic cart. 40 patients were evaluated and the study demonstrated a persistent negative energy balance from days 1 to 7. Furthermore, a persistent negative nitrogen balance was observed from day 1 to 5. There also was poor agreement between predicted and measured REE. The authors concluded: "Predictive equations are inaccurate in estimating the REE in critically ill children with severe sepsis. IC remains the criterion standard for accurate assessment of energy intake, and it should be considered in all patients with metabolic disturbances."

Jhang, W. K. and S. J. Park (2020). "Energy Expenditure in Mechanically Ventilated Korean Children: Single-Center Evaluation of a New Estimation Equation." *Pediatric Critical Care Medicine Publish Ahead of Print* **(8)**: e522-e529.

Summary: This study aimed at developing a novel energy expenditure equation compared to EE measured via IC. This predictive equation performs better than other equations used. There is a need to further validate the use of this equation in pediatric ICU patients.

Jimenez, L., *et al.* (2017). "Timing of the initiation of parenteral nutrition in critically ill children." *Curr Opin Clin Nutr Metab Care* **20**(3): 227-231.

Summary: This review article is very good for background understanding of parenteral nutrition in critically ill children. The authors summarize guidelines for parenteral nutrition initiation, relying on risk stratification of malnutrition and the ability to accurately assess energy expenditure via indirect calorimetry

Jotterand Chaparro, C., et al. (2017). "Performance of Predictive Equations Specifically Developed to Estimate Resting Energy Expenditure in Ventilated Critically Ill Children." *J Pediatr* **184**: 220-226.e225.

Summary: 15 predictive equations were used to estimate REE. None of the predictive equations tested met the performance criteria for the entire range of REE between 200 and 1,000 kcal/day. Even the equations with the smallest bias may entail a risk of underfeeding or overfeeding, especially in the youngest children. The authors concluded that indirect calorimetry measurement must be preferred in this patient population.

Jotterand Chaparro, C., et al. (2018). "Estimation of Resting Energy Expenditure Using Predictive Equations in Critically Ill Children: Results of a Systematic Review." *JPEN J Parenter Enteral Nutr* **42**(6): 976-986.

Summary: This meta analysis included 22 studies with 21 equations that estimate REE in children. Only six equations were evaluated by at least three studies in critically ill children; no equation predicted REE within $\pm 10\%$ of MEE in $>50\%$ of observations. The Schofield equations and Talbot tables were the least inaccurate of the predictive equations. The author concluded that there is an urgent need for a new validated IC measurement for pediatric ICU patients.

Ladd, A. K., et al. (2018). "Preventing Underfeeding and Overfeeding: A Clinician's Guide to the Acquisition and Implementation of Indirect Calorimetry." *Nutr Clin Pract* **33**(2): 198-205.

Summary: In this quality improvement (QI) initiative around IC implementation in a PICU, 69% of measurements resulted in adjustments to energy delivery. 47% of energy prescriptions decreased by a mean of 27%, and 22% increased by a mean of 17%. The authors concluded that their QI initiative demonstrated the implementation and application of IC in the critically ill population and the ability to target energy provision to prevent energy imbalances.

Larsen, B. M. K., et al. (2018). "Can energy intake alter clinical and hospital outcomes in PICU?" *Clin Nutr ESPEN* **24**: 41-46.

Summary: This study aimed to determine the incidence of over- and under-feeding and to compare hospital outcomes between these feeding categories in children admitted to the PICU. It found that only 12% of critically ill children were appropriately fed, while 53% were overfed and 35% underfed. Those that were overfed had longer hospital and PICU LOS than those appropriately fed, while those that were underfed had shorter hospital and PICU LOS than those appropriately fed.

Martinez, E. E., et al. (2017). "Energy and Protein Delivery in Overweight and Obese Children in the Pediatric Intensive Care Unit." *Nutr Clin Pract* **32**(3): 414-419.

Summary: In this investigation involving overweight and obese children, the study cohort had suboptimal nutrition assessments (34%) and macronutrient delivery during their PICU course. Mortality and duration of PICU stay were greater when compared with the general PICU population. PICU duration was 8 days vs 5 days for obese patients compared to the general PICU population. The mortality rate was 7.2% vs 3.3% ($P = .045$) between obese and general PICU populations. Nutritional assessments were conducted in only 60% of obese patients. There is a need to improve nutritional assessments, utilization of indirect calorimetry-guided energy prescriptions, and optimization of energy and protein delivery in this pediatric population.

Moreno, Y. M., et al. (2016). "Problems With Optimal Energy and Protein Delivery in the Pediatric Intensive Care Unit." *Nutr Clin Pract* **31**(5): 673-680.

Summary: On average, actual energy intake in critically ill children was 47% of the predicted energy expenditure, and 68% of patients were underfed. Significant gaps in predicted energy requirements combined with prescription and delivery of energy and protein resulted in underfeeding in this PICU population.

Mouzaki, M., et al. (2017). "Can VCO₂-Based Estimates of Resting Energy Expenditure Replace the Need for Indirect Calorimetry in Critically Ill Children?" *JPEN J Parenter Enteral Nutr* **41**(4): 619-624.

Summary: This study found that in pediatric patients undergoing cardiopulmonary bypass, indirect calorimetry was the most accurate method (compared to VCO₂-derived estimates) to determine REE. The authors noted that further evaluation is needed to assess the utility of VCO₂-derived REE estimation.

Mtaweh, H., C. Garros, A. Ashkin, L. Tuira, J. P. Allard, P. Pencharz, E. Pullenayegum, A. Joffe and C. S. Parshuram (2020). "An Exploratory Retrospective Study of Factors Affecting Energy Expenditure in Critically Ill Children." *Journal of Parenteral and Enteral Nutrition* **44**(3): 507-515.

Summary: This study in pediatric patients aimed to evaluate the factors available at the bedside and to determine any association with EE. IC was measured at this multicenter study with the Vmax Encore 29n metabolic cart (Vyaire medical). The authors identified significant associations between EE and factors representative of body size, cardiac output, minute ventilation, and administered sedatives. Future prospective evaluations are warranted to determine the true predictive nature of these variables.

Patt, P. L., *et al.* (2007). "Estimation of resting energy expenditure in children with spinal cord injuries." *J Spinal Cord Med* **30 Suppl 1**: S83-87.

Summary: This study found that measured REE was lower than the results of prediction equations in pediatric patients with spinal cord injuries. Further validation studies are needed.

Pereira-da-Silva, L., S. Barradas, A. C. Moreira, M. Alves, A. L. Papoila, D. Virella and G. Cordeiro-Ferreira (2020). "Evolution of Resting Energy Expenditure, Respiratory Quotient, and Adiposity in Infants Recovering from Corrective Surgery of Major Congenital Gastrointestinal Tract Anomalies: A Cohort Study." *Nutrients* **12**(10): 1-17.

Summary: (IC: Deltatrac II): This study aimed to quantify the evolution of REE, RQ, and adiposity of infants during the late anabolic phase after corrective surgery of major congenital gastrointestinal tract anomalies and to explore the determinants associated with these components of energy balance. 29 neonates were included for analysis, which included 15 pre-term infants. In total 317 longitudinal calorimetry measurements were performed. In infants born pre-term, the median REE varied between 55.7 and 67.4 kcal/kg/day, and median RQ changed from 0.70 to 0.86-0.92 between 34 and 42 weeks. In infants born at term, the median REE varied between 57.3 and 67.9 kcal/kg/day, while the median RQ increased from 0.63 to 0.84-0.88 from 38 to 44 weeks PMA (post-menopausal age).

Roebuck, N., C. P. S. Fan, A. Floh, Z. L. Harris and M. L. Mazwi (2020). "A Comparative Analysis of Equations to Estimate Patient Energy Requirements Following Cardiopulmonary Bypass for Correction of Congenital Heart Disease." *JPEN. Journal of parenteral and enteral nutrition* **44**(3): 444-453.

Summary: This study used a novel method to determine REE in pediatric patients following cardiopulmonary bypass for repair of congenital heart disease. IC was measured leveraging respiratory mass spectrometry (AMIS 2000, Innovision A/S). In total, 107 patients were evaluated with no predictive equation showing suitable accuracy compared to IC measurement of REE.

Smallwood, C. D. and N. M. Mehta (2013). "Gas exchange measurement during pediatric mechanical ventilation--agreement between gas sampling at the airway and the ventilator exhaust." *Clin Nutr* **32**(6): 988-992.

Summary: This study found that despite strong correlations and small mean biases for VO_2 , VCO_2 and REE obtained by the Vmax® and E-COVX®, the limits of agreement were beyond the clinically acceptable range. These devices should not be used interchangeably for gas exchange measurements in mechanically ventilated children.

Smallwood, C. D., *et al.* (2017). "Accuracy of Oxygen Consumption and Carbon Dioxide Elimination Measurements in 2 Breath-by-Breath Devices." *Respir Care* **62**(4): 475-480.

Summary: Of the two breath-by-breath devices tested, only the newest module demonstrated a bias and limits of agreement that were within an a priori determined clinically acceptable range of $\pm 20\%$ for VO_2 and VCO_2 (E-sCAiOVX). The limits of agreement were clinically acceptable from 40 to 100 mL/min. This range corresponds to approximate patient weights of 5 to 16 kg. The older device (E-COVX) did not demonstrate agreement with the simulated values and therefore is not clinically acceptable for use in pediatric patients.

Veldscholte, K., S. Verbruggen, D. Kerklaan, L. Langouche, I. Vanhorebeek, G. Van Den Berghe and K. Joosten (2020). "The usefulness of the respiratory quotient as a non-invasive marker of under- or overfeeding." *Clinical Nutrition ESPEN* **40**: 443.

Summary: Secondary analysis was conducted in the PEPaNIC RCT where 131 patients' reliable IC measurements were within the timeframe of analysis. Day 3 was selected for analysis, and there was a positive correlation between energy intake/measured resting energy expenditure (EI/mREE), with indirect calorimetry determined RQ ($\rho=0.396$, $p<0.001$). Furthermore, the authors concluded that energy intake less than 90% of mREE may result in a fasting response that is reflected by an $\text{RQ} < 0.80$.

COVID-19

De Waele, E., J. Demol and J. Jonckheer (2020). "Resting energy expenditure measured by indirect calorimetry: Ventilated Covid-19 patients are normometabolic." *Clinical Nutrition ESPEN* **40**: 631-632.

Summary: This limited study evaluated IC in the management of COVID-19 patients. In total, 6 patients were evaluated with a total of 19 measurements between day 1 and day 26. The mean REE was 2,021 kcal/day (21 kcal/kg/day). Contrary to other observations, there was no evidence of ebb and flood phases.

Di Filippo, L., R. De Lorenzo, M. D'Amico, V. Sofia, L. Roveri, R. Mele, A. Saibene, P. Rovere-Querini and C. Conte (2020). "COVID-19 is associated with clinically significant weight loss and risk of malnutrition, independent of hospitalisation: A post-hoc analysis of a prospective cohort study." *Clin Nutr.*

Summary: This study does not have implications pertaining indirect calorimetry or energy expenditure determinations. However it serves as a foundation to understand that COVID-19 infected patients are at risk of malnutrition. The study illustrated that nearly 30% of patients lost >5% of baseline body weight and more than half were at risk of malnutrition; this finding was independent of hospitalization.

Li, G., C. L. Zhou, Y. M. Ba, Y. M. Wang, B. Song, X. B. Cheng, Q. F. Dong, L. L. Wang and S. S. You (2020). "Nutritional risk and therapy for severe and critical COVID-19 patients: A multicenter retrospective observational study." *Clin Nutr.*

Summary: The primary focus of this study was to evaluate nutritional metabolism in COVID-19 patients upon admission and to evaluate the prognostic value of nutrition screening tools. In total, 523 patients were studied, and 211 were managed in the ICU. The NUTRIC score can independently predict the risk of death in the hospital (OR = 1.197, p = 0.006) and high NRS-score patients have a higher risk of poor outcome in the ICU (OR = 1.880, p = 0.012). The authors observed that severe and critical patients with COVID-19 have a high risk of malnutrition. Furthermore, "Patients with low BMI and protein levels were significantly associated with adverse events."

Schuijs, J. M., R. D. Eveleens, B. van der Hoven, P. L. M. Lakenman, J. van Bommel, D. A. M. P. J. Gommers, K. F. M. Joosten and J. F. Olieman (2020). "Feeding practises and REE in critically ill COVID-19 patients." *Clinical Nutrition ESPEN* **40**: 440.

Summary: (IC: Q-NRG+): This observational study evaluated REE during the acute (day 1-7) and late (>7 days) of critically ill mechanically ventilated patients with COVID-19. 35 patients were enrolled with 42 IC measurements performed (20 acute phase; 22 late phase). During the acute phase, the REE was 1,956 kcal and RQ 0.72. In the late phase, the REE was 2374 kcal with an RQ 0.81. During the acute phase, hypocaloric feeding (64% of REE) was noted, while normal caloric feeding (92% of REE) occurred predominantly during the late phase. This illustrated that during both phases of illness, the majority of COVID-19 patients were hypermetabolic

Whittle, J., J. Molinger, D. MacLeod, K. Haines and P. E. Wischmeyer (2020). "Persistent hypermetabolism and longitudinal energy expenditure in critically ill patients with COVID-19." *Critical care (London, England)* **24**(1).

Summary: IC: Q-NRG (Cosmed/Baxter): In this research letter, the authors evaluated EE via IC in preliminary results from the LEEP-COVID study. Data from 22 patients was evaluated with mREE to range between 15-20 kcal/kg/d. Increasing hypermetabolism and wider variability in mREE was observed following the first week in the ICU stay and persisted during the third ICU week.

Yu, P.-J., H. Cassiere, K. Bocchieri, S. DeRosa, S. Yar and A. Hartman (2020). "Hypermetabolism in critically ill patients with COVID-19 and the effects of hypothermia: A case series." *Metabolism open* **7**: 100046.

Summary: IC: CCM-Express (MGC Diagnostics): This study involved a limited case series of COVID-19 patients with respiratory failure and managed with hypothermia. Indirect calorimetry was used to measure the magnitude of the hypermetabolic state. In total, four cases were illustrated and consistently showed the presence of a hypermetabolic state. The use of hypothermia may attenuate some of this metabolic stress – mild hypothermia decreased REE on average of 27% and led to decreases in VCO₂ and VO₂ of 29.2% and 25.7%, respectively.

Sepsis

Hoeyer-Nielsen, A. K., M. J. Holmberg, A. V. GrosseStreuer, T. Yankama, J. P. Branton, M. W. Donnino and K. M. Berg (2020). "Association Between the Oxygen Consumption: Lactate Ratio and Survival in Critically Ill Patients With Sepsis." *Shock*.

Summary: This retrospective study evaluated a prospective sepsis study in which VCO₂ and VO₂ were measured continuously for 48 hours to find out whether any association with survival could be determined. The VO₂: lactate ratio was significantly higher in survivors. There was a significant difference in VCO₂ change over time between survivors (+11.6%) and non-survivors (-8.3%, p=0.03). No association was found between median VO₂ and survival.

Meneguetti, M. G., T. R. de Araújo, A. M. Laus, O. A. Martins-Filho, A. Basile-Filho and M. Auxiliadora-Martins (2019). "Resting Energy Expenditure and Oxygen Consumption in Critically Ill Patients With vs Without Sepsis." *American Journal of Critical Care* **28**(2): 136-141.

Summary: This study evaluated whether REE, RQ and oxygen consumption and carbon dioxide production (measured by indirect calorimetry) differed between critically ill patients with and without sepsis. In total, 205 patients were evaluated with 91 (44%) having sepsis. Analysis of receiver operating characteristic curves showed no significant differences between patients with and without sepsis for any of the indirect calorimetry variables.

Burns

Guo, F., H. Zhou, J. Wu, Y. Huang, G. Lv, Y. Wu, H. Qiu, Y. Xu and Y. Yang (2021). "Prospective Study on Energy Expenditure in Patients With Severe Burns." *JPEN. Journal of parenteral and enteral nutrition* **45**(1): 146-151.

Summary: IC: Vmax Spectra 229 (SensorMedics): This prospective, multicenter study evaluated the burn-related changes in metabolism via IC measurements and compared the utility of predictive equations. 43 severe-burn patients were enrolled with a median APACHE II score 20 ± 2.5 , with body-surface burn involvement of 50-98%. The mean energy expenditure on the seventh day after severe burns was as high as 65 kcal/kg, which was 267% (range, 236% to 293%) of the basal metabolic rate (BMR). Prediction formulas were not precise in evaluating energy requirements in this hypermetabolic patient type.

Obesity

Marra, M., R. Sammarco, I. Cioffi, D. Morlino, O. Di Vincenzo, E. Speranza and F. Pasanisi (2021). "New predictive equations for estimating resting energy expenditure in subjects with normal weight and overweight." *Nutrition* **84**: 111105.

Summary: IC: Vmax 29 and Vmax Encore (Sensor Medics): This study evaluated predictive equations to measure REE by leveraging bioimpedance analysis (BIA) in subjects with normal weight and overweight. The equation was developed and validated using data from 2,483 adult patients. The predictive equation was compared to IC. Compared to other predictive equations, this novel equation showed slightly improved accuracy when BIA was included (70.3% male, 72.3% female). The authors concluded that this predictive equation may serve as a viable alternative when indirect calorimetry measurements are not available.

Jeon, J., D. Kym, Y. S. Cho, Y. Kim, J. Yoon, H. Yim, J. Hur and W. Chun (2019). "Reliability of resting energy expenditure in major burns: Comparison between measured and predictive equations." *Clinical Nutrition* **38**(6): 2763-2769.

Summary: IC: Vmax 29 (Sensor-Medics): This study evaluated 215 patients with burns involving > 20% body surface area and involved a total of 418 IC measurements. The purpose of this study was to evaluate IC versus predictive equations for REE and to derive a new predictive equation (Hangang equation). The novel equation showed the highest level of correlation with calorimetry compared to the other predictive equations used. The Hangang equation is unique in that it considers time (post-burn days) and the ventilator status of the patient, while other predictive equations do not.

Popp, C. J., M. Butler, M. Curran, P. Illiano, M. A. Sevvick and D. E. St-Jules (2020). "Evaluating steady-state resting energy expenditure using indirect calorimetry in adults with overweight and obesity." *Clinical nutrition (Edinburgh, Scotland)* **39**(7): 2220-2226.

Summary: IC: Quark RMR (Cosmed): This study assessed the importance of attaining steady state while measuring EE via indirect calorimetry. This was a cross-over design with 63 total subjects enrolled with a mean BMI of 35 ± 5 kg/m². 54/63 (84%) were able to achieve 5-minute steady-state REE. Of note, lower thresholds of 4- and 3-minute steady state were practical alternatives to measuring REE.

Ridley, E. J., A. Tierney, S. King, E. Ainslie, A. Udy, C. Scheinkestel and I. Nyulasi (2020). "Measured Energy Expenditure Compared With Best-Practice Recommendations for Obese, Critically Ill Patients-A Prospective Observational Study." *JPEN. Journal of parenteral and enteral nutrition* **44**(6): 1144-1149.

Summary: IC: Quark RMR (Cosmed): This study evaluated EE in critically ill obese patients, comparing measured versus predicted EE. In addition, a comparison between measured EE and recommendations from the American Society for Parenteral and Enteral Nutrition (ASPEN) Guidelines was conducted. A total of 19 patients were evaluated, with a BMI range of 30.5 – 64.5 kg/m². Clinically significant variation was observed between measured EE, predictive estimates, and guideline recommendations at all time points in these patients.

Vest, M. T., E. Newell, M. Shapero, P. McGraw, C. Jurkovitz, S. L. Lennon and J. Trabulsi (2019). "Energy balance in obese, mechanically ventilated intensive care unit patients." *Nutrition* **66**: 48-53.

Summary: IC: CCM Express (MedGraphics): This prospective cohort-controlled study evaluated predictive versus indirect calorimetry-measured energy requirements in obese, critically ill patients. In total, 25 patients had REE measurements obtained, spanning a BMI range of 30-50 kg/m². The mean predicted energy requirement was 1,227 kcal/day, compared with a mean measured target energy requirement of 1,691 kcal/day. The results showed that predictive equations consistently underestimated REE in this obese patient population.

Weaning

Miwa, K., M. Mitsuoka, S. Takamori, A. Hayashi and K. Shirouzu "Continuous Monitoring of Oxygen Consumption in Patients Undergoing Weaning from Mechanical Ventilation."

Summary: IC: Puritan-Bennett 7250 Metabolic Monitor: Among 20 patients evaluated in this study, a total of 208 weaning trials were performed, including 145 that were successful. A statistical difference in oxygen cost of breathing (OCOB, respiratory frequency/tidal volume), Δ RR, and Δ EE was found between successful and failed weaning trials. OCOB <30% showed the greatest accuracy among these three measures. The authors added, "Continuous monitoring of VO₂ is useful to predict success or failure of trials attempting to reduce mechanical ventilatory support."

El-Khatib, M., P. Bou-Khalil, S. Zeineldine, N. Kanj, G. Abi-Saad and G. Jamaledine (2009). "Metabolic and Respiratory Variables during Pressure Support versus Synchronized Intermittent Mandatory Ventilation." *Respiration* **77**(2): 154-159.

Summary: IC: Deltatrac II: This study evaluated the impact of REE during two differing modes of respiratory support: pressure support ventilation (PSV) or volume-cycled synchronized intermittent mandatory ventilation (SIMV). In total, 14 patients were enrolled. The study found that changes in VO₂, VCO₂ and measured EE were significantly smaller during comparable ventilatory support changes in PSV versus volume-cycled SIMV. The authors concluded, "PSV may be more suitable for progressive respiratory muscle reloading."

Lago, A. F., E. C. Goncalves, E. C. Silva, M. G. Meneguetti, E. A. Nicolini, M. Auxiliadora-Martins, E. Z. Martinez, A. C. Gastaldi and A. Basile-Filho (2015). "Comparison of Energy Expenditure and Oxygen Consumption of Spontaneous Breathing Trial Conducted With and Without Automatic Tube Compensation." *Journal of Clinical Medicine Research* **7**(9): 700-705.

Summary: IC: Deltatrac II (GE Healthcare): This randomized crossover-design study evaluated spontaneous breathing trials of CPAP with automatic tube compensation (ATC) or CPAP without ATC. The authors concluded that VO₂ and EE obtained during SBT with and without ATC were not different.

dos Santos, L. J., F. C. Hoff, R. L. Condessa, M. L. Kaufmann and S. R. Vieira (2011). "Energy expenditure during weaning from mechanical ventilation: is there any difference between pressure support and T-tube?" *J Crit Care* **26**(1): 34-41.

Summary: M-COVX model (GE Healthcare): This study compared the EE measured by IC of patients in pressure support (PS) and T-tube (TT) weaning from MV. This was a randomized, cross-over designed study with 40 patients included. The mean EE of patients in TT (1782 ± 375 kcal/d) was 14.4% higher than in PS (1558 ± 304 kcal/d; P < 0.001).

Guillaume, M., N. Nicolas, E. Sandrine, J. Philippe and E. Guillaume (2018). "CO-68 Indirect calorimetry as a tool to assess the work of breathing in critically ill children." *Annals of Intensive Care* **8**(Proceedings of Réanimation 2018, the French Intensive Care Society International Congress).

Summary: In this study, work of breathing (WOB) was assessed via differing methods, and comparison was made to IC-based utility to assess WOB. Oxygen consumption obtained by IC was higher during the spontaneous breathing test as compared to conventional ventilation (3.8 [3.0–5.2] vs 3.6 [3.1–4.6] ml kg min) but not significantly. Changes in WOB as assessed by VO₂ were poorly correlated with measurements from esophageal pressure and electrical activity of the diaphragm. The authors concluded: "oxygen consumption measured by IC does not seem to be a reliable tool to assess work of breathing in mechanically ventilated children."

Perioperative Care

Shepherd, Stephen J. and Rupert M. Pearse (2009). "Role of Central and Mixed Venous Oxygen Saturation Measurement in Perioperative Care." *Anesthesiology* **111**(3): 649-656.

Summary: Venous oxygen saturation reflects the balance between global oxygen delivery and oxygen consumption, which may be affected by a wide range of factors during the perioperative period. This article describes the physiology and measurement of mixed and central venous oxygen saturation and explores the findings of clinical investigations of their use in perioperative care. Some highlights pertaining to VO_2 :

- Few studies have explored the relationship between VO_2 and venous saturation during the perioperative period. This may reflect poor recognition of the importance of VO_2 as a determinant of venous saturation.
- Increases in VO_2 resulting from pain, anxiety, or shivering may all result in a decrease in venous saturation. General anesthesia results in a decrease in VO_2 as a result of decreased work of breathing, motor activity and body temperature.

Jakobsson, J., S. Vadman, E. Hagel, S. Kalman and E. Bartha (2019). "The effects of general anaesthesia on oxygen consumption: A meta-analysis guiding future studies on perioperative oxygen transport." *Acta Anaesthesiologica Scandinavica* **63**(2): 144-153.

Summary: Oxygen consumption (VO_2) can change in several ways in the perioperative period, but is seldom monitored directly in routine care. This study investigates the effects of general anesthesia on VO_2 .

- Twenty-four studies including 453 patients were analyzed for VO_2 changes induced by anesthesia. Studies were published during 1969-2000 and the mean age of patients ranged from 28 70 years. VO_2 decreased after anesthesia induction by -65 (-75 ; -55 , 95% CI) mL min^{-1} .
- This meta-analysis demonstrates that general anesthesia reduces the global oxygen consumption, but the exact size estimate and its distribution are uncertain.
- In all included studies, oxygen consumption was assessed either by breathing gas analysis, such as indirect calorimetry, or calculated by the reverse Fick method using thermodilution cardiac output by a pulmonary artery or right ventricle catheter.

The authors suggest that oxygen consumption be included in both observational studies and trials on hemodynamic optimization strategies in high-risk surgical patients and related outcomes. Preferably, oxygen consumption changes should be monitored continuously throughout the perioperative period. This requires monitoring methods with high time resolution feasible for pre-, intra- and post-operative settings, or reliable estimation methods.

General Review and Editorial Articles

Berg, K. M., *et al.* (2018). "Looking for CO(2): Exploring the Novel Finding of Low Respiratory Quotient After Cardiac Arrest." *J Am Heart Assoc* **7**(13).

Summary: In this editorial in response to a rat-model published in the same journal, the author made extrapolations to human care in cardiac arrest. If accurate measurements can be obtained, however, bedside monitoring of VO₂, VCO₂, and RQ in post-arrest patients can reflect the state of aerobic cellular metabolism and mitochondrial function in real time. These parameters are both potential prognostic indicators and targets of treatment. Subsequent experiments can address whether the altered VO₂, VCO₂, and RQ relate to human recovery from cardiac arrest and explore the mechanisms behind the phenomena.

De Waele, E., *et al.* (2018). "Does the use of indirect calorimetry change outcome in the ICU? Yes it does." *Curr Opin Clin Nutr Metab Care* **21**(2): 126-129.

SUMMARY: Metabolic monitoring by indirect calorimetry is achieving a level in which it can be implemented in critical care practice. Evidence is available to prove that by guiding your nutritional therapy by measured values, it will change outcome of critically ill patients.

Summary: The highlights of this review article include:

- 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 devices. Agreement could exist on the fact that indirect calorimetry is needed to optimize nutritional therapy, which can improve patients' outcome.
- It is about time to consider nutritional therapy in the critically ill as a sort of 'medication' helping the healing process. As such, it might be beneficial to consider the four Ds of nutritional therapy in an analogy of how to deal with antibiotics and fluids: drug (type of feeding), dose (caloric and protein load), duration (when and how long) and de-escalation (stop enteral nutrition and/or parenteral nutrition when oral intake improves).
- In analogy to 'antibiotic stewardship,' the authors suggest coining the term 'nutrition stewardship.'

Donaldson, L., *et al.* (2003). "Clinical evaluation of a continuous oxygen consumption monitor in mechanically ventilated patients." *Anaesthesia* **58**(5): 455-460.

Summary: This study used M-COVX to measure VO₂ and concluded that there were small errors between M-COVX VO₂ and calculated values.

Epstein, C. D., *et al.* (2000). "Comparison of methods of measurements of oxygen consumption in mechanically ventilated patients with multiple trauma: the Fick method versus indirect calorimetry." *Crit Care Med* **28**(5): 1363-1369.

Summary: This study concluded that IC was superior to the Fick method of calorimetry in multiple trauma patients.

Haugen, H. A., *et al.* (2007). "Indirect calorimetry: a practical guide for clinicians." *Nutr Clin Pract* **22**(4): 377-388.

Summary: This review gives clinicians a comprehensive overview of indirect calorimetry. Indirect calorimetry offers a scientifically-based approach to customize a patient's energy needs and nutrient delivery to maximize the benefits of nutrition therapy. With recent advances in technology, indirect calorimeters are easier to operate, more portable, and affordable. Increased utilization of indirect calorimetry would facilitate individualized patient care and should lead to improved treatment outcomes.

Moreira, E., *et al.* (2018). "Update on metabolism and nutrition therapy in critically ill burned patients."

Summary: This review article applicable to burn patients observed that calorie deficit, negative protein balance and antioxidant micronutrient deficiency after thermal injury have been associated with poor clinical outcomes. In this context, personalized nutrition therapy with early enteral feeding from the start of resuscitation is indicated.

Oshima, T., *et al.* (2017). "Indirect calorimetry in nutritional therapy. A position paper by the ICALIC study group." *Clin Nutr* **36**(3): 651-662.

Summary: Highlights of this review article include:

- The Deltatrac Metabolic Monitor® produced 35 years ago is often viewed as the reference device.
- Devices with a mixing chamber generate more stable measurements because the gases are physically averaged before being analyzed, allowing the gas analyzers to generate very accurate analysis. The capacity to make reliable measurements in a short duration is also limited, as it takes just as much time for the gas concentrations in the mixing chamber to stabilize.
- Patients in the ICU for > 4 days or those after major surgery are good candidates for IC as they undergo severe stress related to variable metabolic needs. Indeed, these patients are at high nutritional risk, as they are unable to resume sufficient oral intake.
- Obese patients constitute an increasing proportion of the ICU patient population. Their energy requirements are particularly poorly addressed by predictive equations. IC is the only way to determine their metabolic requirements accurately.

Parker, E. A., *et al.* (2017). "Considerations when using predictive equations to estimate energy needs among older, hospitalized patients: a narrative review." **6**(2): 102-110.

Summary: In this review article, the authors observed that as the evidence demonstrating the importance of nutritional supplementation in older, hospitalized adults grows, more accurate energy assessment methods that account for age-related conditions are needed to predict nutritional requirements.

Pielmeier, U. and S. J. C. C. Andreassen (2016). "VCO₂ calorimetry is a convenient method for improved assessment of energy expenditure in the intensive care unit." **20**(1): 224.

Summary: This editorial argued that IC remains the gold standard for assessment of EE in ventilated critically ill patients. However, the best validated system, the Deltatrac, is no longer on the market. and new indirect calorimeters have not yet proven to be accurate. More important, predictive equations are inaccurate, and their use should be avoided. VCO₂-based EE provides the best alternative.

Smallwood, C. D. and B. K. Walsh (2017). "Noninvasive Monitoring of Oxygen and Ventilation." *Respir Care* **62**(6): 751-764.

Summary: This comprehensive review article looked at diverse clinical applications for non-invasive monitoring beyond indirect calorimetry (IC). As it pertains to IC, the author highlighted several use cases:

- Nutrition, to detect during mechanical ventilation, spontaneous respirations and non-invasive ventilation. It is recommended to titrate energy prescriptions in critically ill children. Recent evidence suggests VCO₂ can serve as a surrogate for EE
- Potential uses include: titration of end-expiratory pressure during critical illness; titration of minute ventilation during severe obstruction; and assessment of response to pulmonary vasodilatory therapy.
- The optimization of VCO₂ can potentially guide clinicians to the optimal balance between atelectasis and over-distention.

Taylor, B. E., *et al.* (2016). "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.)." *Crit Care Med* **44**(2): 390-438.

Summary: ASPEN Guidelines provide several key recommendations:

- 1) Based on expert consensus, determine nutrition risk on all patients admitted to the ICU for whom volitional intake is anticipated to be insufficient.
- 2) Use indirect calorimetry (IC) to determine energy requirements when available and in the absence of variables that affect the accuracy of measurement.

Use cases highlighted include sepsis, trauma and traumatic brain injury, burns and obesity in critical illness.

Teigen, L. M., *et al.* (2018). "Use of both quantitative and qualitative methods to improve assessment of resting energy expenditure equation performance in hospitalized adults."

Summary: A large amount of variability was observed with all estimated equations (EE). As the mean calorie level increased, the degree of under-estimation of EE worsened.

Achamrah, N., M. Delsoglio, E. De Waele, M. M. Berger and C. Pichard (2021). "Indirect calorimetry: The 6 main issues." *Clinical Nutrition* **40**(1): 4-14.

Summary: This review article aims at informing and educating clinicians on the routine use of indirect calorimetry and how to interpret the results.

Barrocas, A. (2019). "Demonstrating the Value of the Nutrition Support Team to the C-Suite in a Value-Based Environment: Rise or Demise of Nutrition Support Teams?" *Nutr Clin Pract* **34**(6): 806-821.

Summary: This review article focuses on the economic impacts associated with the use of nutrition support teams.

Bendavid, I., D. N. Lobo, R. Barazzoni, T. Cederholm, M. Coëffier, M. de van der Schueren, E. Fontaine, M. Hiesmayr, A. Laviano, C. Pichard and P. Singer (2021). "The centenary of the Harris-Benedict equations: How to assess energy requirements best? Recommendations from the ESPEN expert group." *Clinical Nutrition* **40**(3): 690-701.

Summary: This review article provides details around the evolution of the Harris-Benedict equation, which was first introduced over a century ago. This review details the accuracy of predictive equations and the relationship of predictive equations and indirect calorimetry. There is dedicated commentary on selected disease states/populations, including obese, elderly, cancer and surgical patients.

Berger, M. M. and C. Pichard (2019). "Feeding should be individualized in the critically ill patients." *Current opinion in critical care* **25**(4): 307-313.

Summary: An excerpt from the abstract of this review article states, "Accurate and repeated indirect calorimetry is becoming possible thanks to the recent development of a reliable, easy-to-use and affordable indirect calorimeter. The optimal timing of the prescription of the measured energy expenditure values as a goal remains to be determined. Optimal protein prescription remains difficult as no clinically available tool has yet been identified reflecting the body needs."

Bruenderman, E. H., J. J. Webb and M. C. Bozeman (2020). "Burns as the Outlier in Early Enteral Nutrition in Critical Illness." *Current Surgery Reports* **8**(1).

Summary: This review article takes aim at the literature pertaining early enteral feeding in burn patients. The hypermetabolic response and inflammatory changes that result from severe burn injury are greater than those seen in any other disease process. The current literature reinforces the belief that early enteral nutrition improves outcomes after burn injury.

Cekici, H. and N. Acar Tek (2020). "Determining energy requirement and evaluating energy expenditure in neurological diseases." *Nutritional neuroscience* **23**(7): 543-553.

Summary: This review article describes the science around energy expenditure across sundry neurological conditions including Parkinson's disease, Alzheimer's disease, multiple sclerosis and others. In general, a consensus is lacking on the optimal means to assess nutritional requirements in this subset of critically ill patients.

Cordoza, M., L.-N. Chan, E. Bridges and H. Thompson (2020). "Methods for Estimating Energy Expenditure in Critically Ill Adults." *AACN Advanced Critical Care* **31**(3): 254-264.

Summary: This review article looks at methods of evaluating EE in critically ill adults and the benefits and limitations of each method, with practical considerations for use.

Delsoglio, M., N. Achamrah and M. M. Berger (2019). "Indirect Calorimetry in Clinical Practice." *Journal of Clinical Medicine* **8**(9): 1387.

Summary: This review article serves as a refresher that details the practicalities of IC implementation and illustrates the limitations of its use. The article discusses alternative methods to IC.

De Waele, E., M. L. N. G. Malbrain and H. Spapen (2020). "Nutrition in Sepsis: A Bench-to-Bedside Review." *Nutrients* **12**(2).

Summary: This review article discusses the nutritional principles involved in management of patients with sepsis. It also covers practical recommendations pertaining to all aspects of nutritional therapy in the setting of sepsis.

Doley, J. and W. Phillips (2019). "Coding for Malnutrition in the Hospital: Does It Change Reimbursement?" *Nutr Clin Pract* **34**(6): 823-831.

Summary: This review article discusses the clinical and financial implications associated with protein calorie malnutrition (PCM).

Lambell, K. J., O. A. Tatucu-Babet, L. A. Chapple, D. Gantner and E. J. Ridley (2020). "Nutrition therapy in critical illness: a review of the literature for clinicians." *Crit Care* **24**(1): 35.

Summary: This review article outlines nutritional therapy in the management of critically ill patients.

Macdonald, I. A. (2020). "Editorial for Clinical Nutrition: Issues to consider when using ventilated hood indirect calorimetry to estimate energy expenditure and substrate utilisation." *Clinical nutrition (Edinburgh, Scotland)* **39**(6): 1643-1644.

Summary: This article is a point-counterpoint discussion based on an accompanying publication by Oshima that comments on the issues to consider when using a ventilated hood to measure EE with IC.

Moonen, H., K. J. H. Beckers and A. R. H. van Zanten (2021). "Energy expenditure and indirect calorimetry in critical illness and convalescence: current evidence and practical considerations." *J Intensive Care* **9**(1): 8.

Summary: This review article details the use of IC in critical illness with a focus on the acute, chronic and convalescent phases of illness. The transitions between these three phases remain unidentifiable. The author illustrates a listing of on-market devices designed to perform IC measurements, including but not limited to Deltatrak, Quark RMR, E-COVX and CCM Express. The article reiterates that energy requirements are best determined via use of IC, rather than reliance on predictive equations, which can result in over- or under-feeding.

Mtaweh, H., M. J. Soto Aguero, M. Campbell, J. P. Allard, P. Pencharz, E. Pullenayegum and C. S. Parshuram (2019). "Systematic review of factors associated with energy expenditure in the critically ill." *Clinical nutrition ESPEN* **33**: 111-124.

Summary: This systematic literature review identified 103 articles included in analysis. In this analysis, 95 clinical factors were evaluated for association with EE in critically ill patients. Of note, groups of factors were significant in different patient populations. The data presented is expansive and beyond the scope of this summary.

Oshima, T., M. Delsoglio, Y. M. Dupertuis, P. Singer, E. De Waele, C. Veraar, C. P. Heidegger, J. Wernermann, P. E. Wischmeyer, M. M. Berger and C. Pichard (2020). "The clinical evaluation of the new indirect calorimeter developed by the ICALIC project." *Clin Nutr* **39**(10): 3105-3111.

Summary: This study evaluated the time required to obtain EE with use of Q-NRG® versus currently used ICs, including Deltatrak and E-COVX. The Q-NRG® required a much shorter time than most other ICs to determine EE in mechanically ventilated ICU patients. The authors concluded, "Q-NRG® is the only commercially available IC tested against mass spectrometry to ensure gas accuracy, while being very easy-to use."

Plauth, M., W. Bernal, S. Dasarathy, M. Merli, L. D. Plank, T. Schütz and S. C. Bischoff (2019). "ESPEN guideline on clinical nutrition in liver disease." *Clinical Nutrition* **38**(2): 485-521.

Summary: This item presents the ESPEN guidelines on clinical nutrition in liver disease. It spans acute liver failure, non-alcoholic fatty liver disease, liver cirrhosis, and liver surgery, plus transplantation.

Rattanachaiwong, S. and P. Singer (2019). "Indirect calorimetry as point of care testing." *Clinical Nutrition* **38**(6): 2531-2544.

Summary: This review article addresses the background and utility of indirect calorimetry with a special emphasis on point-of-care (POC) testing. Of note, POC does not refer to novel technologies that are portable (i.e. hand-held) but rather conventional technology that provides information to the clinician at the bedside.

Singer, P. (2019). "Preserving the quality of life: nutrition in the ICU." *Crit Care* **23**(Suppl 1): 139.

Summary: This review article focuses on nutrition therapy in the ICU, including the catabolic response to stress, energy requirements and prescription, and nutrition in recovery from critical illness.

Singer, P., C. Pichard and E. De Waele (2020). "Practical guidance for the use of indirect calorimetry during COVID 19 pandemic." *Clinical Nutrition Experimental* **33**: 18-23.

Summary: This review article provides practical guidance to healthcare professionals in the management of patients with COVID-19. This includes practical guidance in the use of the QNRG+ (Cosmed) and E-sCOVX/E-sCAiOVX (GE Healthcare).

Singer, P., C. Pichard and S. Rattanachaiwong (2020). "Evaluating the TARGET and EAT-ICU trials: how important are accurate caloric goals? Point-counterpoint." *Current Opinion in Clinical Nutrition and Metabolic Care* **23**(2): 91-95.

Summary: Controversies about the adequate amount of energy to deliver to critically ill patients continue, and trying to find if a hypocaloric or normocaloric regimen is beneficial in this population. The authors reviewed recent studies in which indirect calorimetry was and was not used.

van Zanten, A. R. H., E. De Waele and P. E. Wischmeyer (2019). "Nutrition therapy and critical illness: practical guidance for the ICU, post-ICU, and long-term convalescence phases." *Crit Care* **23**(1): 368.

Summary: This review article summarizes the latest scientific insights and guidelines on ICU nutrition delivery. Specifically, the article provides practical guidance on the delivery of optimal nutrition during the three phases of the patient journey.

Wise, A. K., K. A. Hromatka and K. R. Miller (2019). "Energy Expenditure and Protein Requirements Following Burn Injury." *Nutrition in Clinical Practice* **34**(5): 673-680.

Summary: This review article focuses on the energy expenditure associated with burn patients. The authors state, "Following transition from the resuscitative phase, IC remains the standard with regard to determination of caloric requirements."

Yatabe, T. (2019). "Strategies for optimal calorie administration in critically ill patients." *Journal of Intensive Care* **7**(1).

Summary: This review article outlines the use of indirect calorimetry in critically ill patients and the strategies required for optimal calorie administration.

Pediatrics

Zhang, J., Y. Q. Cui, Z. M. Ma Md, Y. Luo, X. X. Chen and J. Li (2019). "Energy and Protein Requirements in Children Undergoing Cardiopulmonary Bypass Surgery: Current Problems and Future Direction." *Journal of Parenteral and Enteral Nutrition* **43**(1): 54-62.

Summary: This review article addresses energy and protein requirements in children undergoing cardiopulmonary bypass surgery. Topics addressed include poor preoperative nutritional status, difficulty in assessing nutrition, lack of studies measuring REE following cardiopulmonary bypass, and protein requirements in these patients.

Ringel, J. B., D. Jannat-Khah, R. Chambers, E. Russo, L. Merriman and R. Gupta (2019). "Impact of gaps in care for malnourished patients on length of stay and hospital readmission." *BMC Health Serv Res* **19**(1): 87.

Summary: This study evaluated the presence of gaps in care that follow malnutrition diagnosis and their effects on length of stay and 90-day readmission. The hypothesis is that these gaps are associated with increased length of stay and increased readmission. A retrospective chart review was conducted by two registered dietitians, evaluating 22 malnourished patients. Gaps in care were categorized as related to communication, testing/procedure, and discharge. The average participant with any gap in care had a 2.5-day longer LOS compared to those without any gap. Of note, those with a testing/procedure gap had a 6-day increase in LOS.

Serrano Valles, C., J. J. Lopez Gomez, S. Garcia Calvo, R. Jimenez Sahagun, B. Torres Torres, E. Gomez Hoyos, A. Ortola Buigues and D. de Luis Roman (2020). "Influence of nutritional status on hospital length of stay in patients with type 2 diabetes." *Endocrinol Diabetes Nutr* **67**(10): 617-624.

Summary: This study evaluated the impact of diabetes on hospitalized patients and whether they had a poorer nutritional status. This transverse study involved 1,017 patients between 2014 and 2016.

ARTICLES BY ALPHABETICAL ORDER

Acar-Tek, N., *et al.* (2017). "Estimation of Resting Energy Expenditure: Validation of Previous and New Predictive Equations in Obese Children and Adolescents." *J Am Coll Nutr* **36**(6): 470-480.

Summary: Previously developed predictive equations mostly provided inaccurate and biased estimates of REE. However, the new predictive equations allow clinicians to estimate REE in obese children and adolescents with sufficient and acceptable accuracy.

Achamrah, N., M. Delsoglio, E. De Waele, M. M. Berger and C. Pichard (2021). "Indirect calorimetry: The 6 main issues." *Clinical Nutrition* **40**(1): 4-14.

Summary: This review article aims at informing and educating clinicians on the routine use of indirect calorimetry and how to interpret the results.

Allingstrup, M. J., *et al.* (2017). "Indirect Calorimetry in Mechanically Ventilated Patients: A Prospective, Randomized, Clinical Validation of 2 Devices Against a Gold Standard." *JPEN J Parenter Enteral Nutr* **41**(8): 1272-1277.

Summary: In this study, the QUARK RMR ICU indirect calorimeter compared better with the gold standard (modified Tissot bell-spirometer method) for values of VO_2 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.

Ang, D., R. Chari, A. Garcia, J. Clark, J. Farrah, J. Hagan, C. Watson, W. Richards, H. Liu, D. Donaldson, J. Barde and T. Alderman (2019). "Optimizing energy expenditure and oxygenation toward ventilator tolerance is associated with lower ventilator and intensive care unit days." *J Trauma Acute Care Surg* **87**(3): 559-565.

Summary: IC: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): The hypothesis of this study was that if both EE and oxygenation are optimized toward ventilator tolerance ($\text{RQ} = 0.7$ to 1.0); this would provide patients with the best condition to be liberated from the ventilator. In this single-center prospective study of trauma patients requiring mechanical ventilation, 1,090 patients were included in a primary analysis of ventilator days between the intervention arm and historical controls. The primary outcome favored the intervention arm by approximately three days. In this study, all patients achieved the RQ goal (between 0.7 - 1.0) and over 95% met their REE nutritional goal.

Bae, E., *et al.* (2018). "Increased energy expenditure using indirect calorimetry among acute phase patients in neurosurgical intensive care unit." **37**: S52.

Summary: This study evaluated IC measured using the CARESCAPE B650 compared to predictive equations in neurosurgical critically ill patients. Predictive equations were found to underestimate EE in both acute (<14 day LOS) neurosurgical patients, and to a lesser extent, in chronically ill (>14 day LOS) patients. IC should be used to assess EE in neurosurgical patients, notably during the acute phase of disease.

Baek, J. K., S. J. Lee, H. J. Lee, Y. J. Jung and S. K. Hong (2019). "OR04: Assessing the Appropriate Energy Expenditure Requirement Using Indirect Calorimetry for Liver Transplant Recipients." *Clinical Nutrition* **38**: S5-S6.

Summary: This study compared predictive equations with indirect calorimetry to identify the appropriate energy expenditure requirement of liver transplant recipients. 46 patients were enrolled, and the REE with the strongest agreement was the Penn State 1988 equation (65%) followed by the Harris-Benedict method (56%, $P < 0.001$). All three predictive equations evaluated showed unsatisfactory agreement with measured REE.

Barrocas, A. (2019). "Demonstrating the Value of the Nutrition Support Team to the C-Suite in a Value-Based Environment: Rise or Demise of Nutrition Support Teams?" *Nutr Clin Pract* **34**(6): 806-821.

Summary: This review article focuses on the economic impacts associated with the use of nutrition support teams.

Beggs, M. R., *et al.* (2016). "Do PICU patients meet technical criteria for performing indirect calorimetry?" *Clin Nutr ESPEN* **15**: 80-84.

Summary: Indirect calorimetry is the gold standard for measuring energy expenditure. However, in this current study, technical criteria for IC were met on only one third of total patient days. Moreover, criteria were met on only 29% of days for infants 6 months and younger. Children 24 months of age and older still only met criteria on 40% of patient days. This study highlights a major gap in the feasibility of current recommendations for the care of this population, particularly vulnerable infants. Future studies are needed to develop improved methods to accurately predict and measure energy requirements in critically ill children who do not meet current criteria for indirect calorimetry.

Bendavid, I., D. N. Lobo, R. Barazzoni, T. Cederholm, M. Coëffier, M. de van der Schueren, E. Fontaine, M. Hiesmayr, A. Laviano, C. Pichard and P. Singer (2021). "The centenary of the Harris-Benedict equations: How to assess energy requirements best? Recommendations from the ESPEN expert group." *Clinical Nutrition* **40**(3): 690-701.

Summary: This review article provides details around the evolution of the Harris-Benedict equation, which was first introduced over a century ago. This review details the accuracy of predictive equations and the relationship of predictive equations and indirect calorimetry. There is dedicated commentary on selected disease states/populations, including obese, elderly, cancer and surgical patients.

Berg, K. M., et al. (2018). "Looking for CO(2): Exploring the Novel Finding of Low Respiratory Quotient After Cardiac Arrest." *J Am Heart Assoc* **7**(13).

Summary: In this editorial in response to a rat-model published in the same journal, the author made extrapolations to human care in cardiac arrest. If accurate measurements can be obtained, however, bedside monitoring of VO₂, VCO₂, and RQ in post-arrest patients can reflect the state of aerobic cellular metabolism and mitochondrial function in real time. These parameters are both potential prognostic indicators and targets of treatment. Subsequent experiments can address whether the altered VO₂, VCO₂, and RQ relate to human recovery from cardiac arrest and explore the mechanisms behind the phenomena.

Berger, M. M. and C. Pichard (2019). "Feeding should be individualized in the critically ill patients." *Current opinion in critical care* **25**(4): 307-313.

Summary: An excerpt from the abstract of this review article states, "Accurate and repeated indirect calorimetry is becoming possible thanks to the recent development of a reliable, easy-to-use and affordable indirect calorimeter. The optimal timing of the prescription of the measured energy expenditure values as a goal remains to be determined. Optimal protein prescription remains difficult as no clinically available tool has yet been identified reflecting the body needs."

Berger, M. M., et al. (2017). "Impact of the reduction of the recommended energy target in the ICU on protein delivery and clinical outcomes." *Clin Nutr* **36**(1): 281-287.

Summary: Energy targets are a matter of debate for ICU patients. As the guidelines have evolved, energy targets have been reduced, while protein intake objectives have increased. The impact of these changes remains largely unknown. This quality study investigated the clinical impact of these changes in patients with an ICU stay > 3 days. A linear reduction in energy target recommendation without changing the feed composition led to an unplanned and significant reduction in protein delivery, which was associated with a prolonged duration of ventilation and an extended hospital stay.

Briassoulis, G., et al. (2009). "Influence of different ventilator modes on VO(2) and VCO(2) measurements using a compact metabolic monitor." *Nutrition* **25**(11-12): 1106-1114.

Summary: The influence of different ventilator modes on VO₂ and VCO₂ measurements in adequately sedated critically ill children is not significant. The E-COVX metabolic module is suitable for repeated measurements in well-sedated mechanically ventilated children with stable respiratory patterns.

Briassoulis, G., et al. (2009). "The effects of endotracheal suctioning on the accuracy of oxygen consumption and carbon dioxide production measurements and pulmonary mechanics calculated by a compact metabolic monitor." *Anesth Analg* **109**(3): 873-879.

Summary: E-COVX indirect calorimetry measurements in pediatric sepsis or head injury were not affected by endotracheal suctioning (ETS). Metabolics were reliably measured within 5 minutes following ETS.

Bruenderman, E. H., J. J. Webb and M. C. Bozeman (2020). "Burns as the Outlier in Early Enteral Nutrition in Critical Illness." *Current Surgery Reports* **8**(1).

Summary: This review article takes aim at the literature pertaining early enteral feeding in burn patients. The hypermetabolic response and inflammatory changes that result from severe burn injury are greater than those seen in any other disease process. The current literature reinforces the belief that early enteral nutrition improves outcomes after burn injury.

CARDIA, L., et al. (2017). "Resting Metabolic Rate In Patients Submitted To Bariatric Surgery: Comparison of Indirect Calorimetry With Predictive Equations." *Surgery for Obesity and Related Diseases* **13**(10): S141.

Summary: In this study, IC was measured with Ultima CPX (MedGraphics). Gastric bypass patients were evaluated before surgery, peri-operative, and 6 months and 36 months after. The study displayed descriptive statistics only and no conclusions on the application of IC before during or after bariatric surgery were offered.

Carpenter, A., *et al.* (2017). "Predictive Equations Are Inaccurate in the Estimation of the Resting Energy Expenditure of Children With End-Stage Liver Disease." *JPEN J Parenter Enteral Nutr* **41**(3): 507-511.

Summary: This study found that commonly used predictive equations perform poorly in infants and young children with ESLD. Indirect calorimetry should be used when available to guide energy provision, particularly in children who are already malnourished.

Cekici, H. and N. Acar Tek (2020). "Determining energy requirement and evaluating energy expenditure in neurological diseases." *Nutritional neuroscience* **23**(7): 543-553.

Summary: This review article describes the science around energy expenditure across sundry neurological conditions including Parkinson's disease, Alzheimer's disease, multiple sclerosis and others. In general, a consensus is lacking on the optimal means to assess nutritional requirements in this subset of critically ill patients.

Chen, Y. H., *et al.* Comparison of the Metabolic Load in Patient Ventilated with Pressure Support Ventilation and Adaptive Support Ventilation Mode with the Same Minute Ventilation. A104. CRITICAL CARE: INVASIVE, NON-INVASIVE, CONVENTIONAL, AND NON-CONVENTIONAL VENTILATION IN ACUTE RESPIRATORY FAILURE: A2550-A2550.

Summary: The Engström CareStation was used to evaluate VO_2 and VCO_2 during pressure-support ventilation (PSV) and adaptive support ventilation (ASV). Metabolic load was significantly lower during ASV versus PSV, as were VO_2 and VCO_2 . It is suggested that this lower metabolic load is the result of reduced work of breathing.

Clark, A., *et al.* (2017). "Nutrition and metabolism in burn patients." *Burns Trauma* **5**: 11.

Summary: This review article involving nutritional support for burn patients listed a few highlights. 1) Nutritional support is critical in the treatment of burn patients, in whom the metabolic rate can be greater than twice the normal rate. 2) The primary goal of nutritional support in burn patients is to fulfill the increased caloric requirements caused by the hypermetabolic state while avoiding overfeeding. 3) IC is considered the gold standard with a great concern about overfeeding, which is commonly associated with difficulty in weaning from the mechanical ventilator.

Cordoza, M., L.-N. Chan, E. Bridges and H. Thompson (2020). "Methods for Estimating Energy Expenditure in Critically Ill Adults." *AACN Advanced Critical Care* **31**(3): 254-264.

Summary: This review article looks at methods of evaluating EE in critically ill adults and the benefits and limitations of each method, with practical considerations for use.

De Waele, E., *et al.* (2015). "Measuring resting energy expenditure during extracorporeal membrane oxygenation: preliminary clinical experience with a proposed theoretical model." *Acta Anaesthesiol Scand* **59**(10): 1296-1302.

Summary: This pilot study evaluated the use of IC in patients with severe respiratory failure undergoing ECMO. [Unknown IC device]

De Waele, E., *et al.* (2016). " VCO_2 calorimetry: stop tossing stones, it's time for building!". *Acta Anaesthesiol Scand*. **20**(1): 399.

Summary: The commenters concurred that VO_2 is the most relevant variable for EE measurement. However, the most accurate and precise estimation of EE in a critically ill population can only be obtained by sampling of inspired and expired oxygen/carbon dioxide concentrations and by measuring expired gas flow. This is the core task of indirect calorimetry.

De Waele, E., *et al.* (2018). "Does the use of indirect calorimetry change outcome in the ICU? Yes it does." *Curr Opin Clin Nutr Metab Care* **21**(2): 126-129.

SUMMARY: Metabolic monitoring by indirect calorimetry is achieving a level in which it can be implemented in critical care practice. Evidence is available to prove that by guiding your nutritional therapy by measured values, it will change outcome of critically ill patients.

Summary: The highlights of this review article include:

- 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 devices. Agreement could exist on the fact that indirect calorimetry is needed to optimize nutritional therapy, which can improve patients' outcome.
- It is about time to consider nutritional therapy in the critically ill as a sort of 'medication' helping the healing process. As such, it might be beneficial to consider the four Ds of nutritional therapy in an analogy of how to deal with antibiotics and fluids: drug (type of feeding), dose (caloric and protein load), duration (when and how long) and de-escalation (stop enteral nutrition and/or parenteral nutrition when oral intake improves).
- In analogy to 'antibiotic stewardship,' the authors suggest coining the term 'nutrition stewardship.'

De Waele, E., *et al.* (2018). "The CoCoS trial: Caloric Control in Cardiac Surgery patients promotes survival, an interventional trial with retrospective control." *Clinical Nutrition* **37**(3): 864-869.

Summary: Malnutrition is an often overlooked comorbid condition in patients scheduled for cardiac surgery and affects 10-25% of patients. The patients are often considered to have higher in-hospital mortality, have increased length of intensive care and hospital stay, need longer antibiotic and vasopressor treatment and more frequently have positive blood cultures. IC was measured using Vmax™ Encore 29n. Targeted nutrition therapy conferred a survival benefit in female patients, but not in male patients. In addition, there were significantly fewer cardiac arrhythmias in males following surgery that were in the nutrition therapy group. The authors conclude that nutrition therapy can largely benefit elective cardiac surgery patients and deserves to be implemented as a standard-of-care supportive therapy in this setting.

De Waele, E., J. Demol and J. Jonckheer (2020). "Resting energy expenditure measured by indirect calorimetry: Ventilated Covid-19 patients are normometabolic." *Clinical Nutrition ESPEN* **40**: 631-632.

Summary: This limited study evaluated IC in the management of COVID-19 patients. In total, 6 patients were evaluated with a total of 19 measurements between day 1 and day 26. The mean REE was 2,021 kcal/day (21 kcal/kg/day). Contrary to other observations, there was no evidence of ebb and flood phases.

De Waele, E., M. L. N. G. Malbrain and H. Spapen (2020). "Nutrition in Sepsis: A Bench-to-Bedside Review." *Nutrients* **12**(2).

Summary: This review article discusses the nutritional principles involved in management of patients with sepsis. It also covers practical recommendations pertaining to all aspects of nutritional therapy in the setting of sepsis.

Delsoglio, M., N. Achamrah and M. M. Berger (2019). "Indirect Calorimetry in Clinical Practice." *Journal of Clinical Medicine* **8**(9): 1387.

Summary: This review article serves as a refresher that details the practicalities of IC implementation and illustrates the limitations of its use. The article discusses alternative methods to IC.

Di Filippo, L., R. De Lorenzo, M. D'Amico, V. Sofia, L. Roveri, R. Mele, A. Saibene, P. Rovere-Querini and C. Conte (2020). "COVID-19 is associated with clinically significant weight loss and risk of malnutrition, independent of hospitalisation: A post-hoc analysis of a prospective cohort study." *Clin Nutr*.

Summary: This study does not have implications pertaining indirect calorimetry or energy expenditure determinations. However it serves as a foundation to understand that COVID-19 infected patients are at risk of malnutrition. The study illustrated that nearly 30% of patients lost >5% of baseline body weight and more than half were at risk of malnutrition; this finding was independent of hospitalization.

Diehl, J. L., N. Peron, R. Chocron, B. Debuc, E. Guerot, C. Hauw-Berlemont, B. Hermann, J. L. Augy, R. Younan, A. Novara, J. Langlais, L. Khider, N. Gendron, G. Goudot, J. F. Fagon, T. Mirault and D. M. Smadja (2020). "Respiratory mechanics and gas exchanges in the early course of COVID-19 ARDS: a hypothesis-generating study." *Ann Intensive Care* **10**(1): 95.

Summary: IC: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): This study evaluated the respiratory mechanics and gas exchange associated with COVID-19 infected patients with ARDS. A total of 22 patients were evaluated, and gas exchange was characterized by hypercapnia and high physiological dead space. The ventilatory ratio was 2.9.

Doley, J. and W. Phillips (2019). "Coding for Malnutrition in the Hospital: Does It Change Reimbursement?" *Nutr Clin Pract* **34**(6): 823-831.

Summary: This review article discusses the clinical and financial implications associated with protein calorie malnutrition (PCM).

Donaldson, L., et al. (2003). "Clinical evaluation of a continuous oxygen consumption monitor in mechanically ventilated patients." *Anaesthesia* **58**(5): 455-460.

Summary: This study used M-COVX to measure VO_2 and concluded that there were small errors between M-COVX VO_2 and calculated values.

dos Santos, L. J., F. C. Hoff, R. L. Condessa, M. L. Kaufmann and S. R. Vieira (2011). "Energy expenditure during weaning from mechanical ventilation: is there any difference between pressure support and T-tube?" *J Crit Care* **26**(1): 34-41.

Summary: M-COVX model (GE Healthcare): This study compared the EE measured by IC of patients in pressure support (PS) and T-tube (TT) weaning from MV. This was a randomized, cross-over designed study with 40 patients included. The mean EE of patients in TT (1782 ± 375 kcal/d) was 14.4% higher than in PS (1558 ± 304 kcal/d; $P < 0.001$).

Ebihara, T., et al. (2018). "Low energy expenditure among elderly patients in acute, sepsis." *Clinical Nutrition* **37**: S174.

Summary: REE is typically increased in septic patients, but it is unknown if that applies to the elderly (>65 yoa). Comparisons were made in REE (measured) and BEE (estimated) in the elderly and in control (<65 yoa) population. A BEE/REE < 80% was only observed in the elderly population. A BEE/REE > 120% was associated with a high likelihood of death (66.7% in elderly, 0% in controls). In summary, low energy expenditure was only observed in the elderly population and conferred a survival benefit.

El-Khatib, M., P. Bou-Khalil, S. Zeineldine, N. Kanj, G. Abi-Saad and G. Jamaledine (2009). "Metabolic and Respiratory Variables during Pressure Support versus Synchronized Intermittent Mandatory Ventilation." *Respiration* **77**(2): 154-159.

Summary: IC: Deltatrac II: This study evaluated the impact of REE during two differing modes of respiratory support: pressure support ventilation (PSV) or volume-cycled synchronized intermittent mandatory ventilation (SIMV). In total, 14 patients were enrolled. The study found that changes in VO_2 , VCO_2 and measured EE were significantly smaller during comparable ventilatory support changes in PSV versus volume-cycled SIMV. The authors concluded, "PSV may be more suitable for progressive respiratory muscle reloading."

Epstein, C. D., et al. (2000). "Comparison of methods of measurements of oxygen consumption in mechanically ventilated patients with multiple trauma: the Fick method versus indirect calorimetry." *Crit Care Med* **28**(5): 1363-1369.

Summary: This study concluded that IC was superior to the Fick method of calorimetry in multiple trauma patients.

Fabiano Alves, V. G., E. E. M. da Rocha, M. C. Gonzalez, R. B. Vieira da Fonseca and M. H. do Nascimento Silva (2019). "Resting Energy Expenditure Measured by Indirect Calorimetry in Obese Patients: Variation Within Different BMI Ranges." *Journal of Parenteral and Enteral Nutrition* **44**(1): 129-137.

Summary (IC: Deltatrac II): This study aimed to determine if there was an appreciable difference in REE in obese patients between the fasted and fed state. In total, 97 IC measurements were obtained from 63 patients during 2009 - 2012 with a BMI range of 27.3 to 53.4 kg/m². There was no difference in measured REE between fasted and fed states across three BMI groups (overweight, obese, morbidly obese). Additionally, there was a negative correlation between REE and progression of BMI from overweight through morbidly obese ($r = -0.35$, $p = 0.04$). The authors concluded that no method can be recommended to estimate REE in extremely obese patients given the risk of underestimating energy requirements.

Ferreruela, M., et al. (2017). "Effect of FiO₂ in the measurement of VO₂ and VCO₂ using the E-COXV metabolic monitor." *Med Intensiva* **41**(8): 461-467.

Summary: This study demonstrated good precision for VO₂ and VCO₂ with the GE Healthcare E-COVX module with FiO₂ up to 0.40. There was no clinically significant bias observed with FiO₂ 0.40-0.80. Precision was vulnerable to increased FiO₂, with clinically inadequate VO₂ observed when FiO₂ exceeded 0.6. Measurement of VCO₂ was not affected by changes in FiO₂.

Fetterplace, K., et al. (2018). "Targeted Full Energy and Protein Delivery in Critically Ill Patients: A Pilot Randomized Controlled Trial (FEED Trial)." *JPEN J Parenter Enteral Nutr.*

Summary: This pilot study looked at protocol-based care (volume target enteral feeding) versus the standard of care. No IC measurement was mentioned to support the protocol treatment arm. The results show that protocol-based feeding resulted in significant improvements in skeletal muscle mass. However, there were no differences in outcomes (mortality and LOS) between the two groups.

Graf, S., et al. (2017). "Energy expenditure in mechanically ventilated patients: The weight of body weight!" *Clin Nutr* **36**(1): 224-228.

Summary: This study aimed to determine the best prediction strategy when IC is not available. Correlations between estimated EE? and IC were poor regardless of body weight, and agreement was also poor.

Graham, J. (2018). "Oxygen Consumption in Sepsis.", *University of San Diego*

Summary: This study (a dissertation) evaluated metabolics between septic and non-septic patients. There was a difference in oxygen consumption between the two groups of cases [VO₂ (t 3.919, p 0.001), VCO₂ (η = 608, p = 0.003), and lactate (η = 621, p = 0.003)]. The authors stated that future research is needed using larger samples to test predictive models for sepsis so that nurses can intervene to prevent the deterioration of these patients

Graham, J. and E. Goulette (2019). "Accurate determination of resting energy expenditure in the critically ill adult." *Critical Care Medicine* **47**(1).

Summary: This prospective evaluation of mechanically ventilated critically ill patients compared the PENN predictive equation to indirect calorimetry assessment of REE. A total of 21 patients were enrolled, and a statistically significant difference was noted between the predictive and measured REE, where PENN underestimated IC (P<0.001). This study supports the growing evidence that use of predictive equations increases the risk of overfeeding.

Guillaume, M., N. Nicolas, E. Sandrine, J. Philippe and E. Guillaume (2018). "CO-68 Indirect calorimetry as a tool to assess the work of breathing in critically ill children." *Annals of Intensive Care* **8**(Proceedings of Réanimation 2018, the French Intensive Care Society International Congress).

Summary: In this study, work of breathing (WOB) was assessed via differing methods, and comparison was made to IC-based utility to assess WOB. Oxygen consumption obtained by IC was higher during the spontaneous breathing test as compared to conventional ventilation (3.8 [3.0–5.2] vs 3.6 [3.1–4.6] ml kg min) but not significantly. Changes in WOB as assessed by VO₂ were poorly correlated with measurements from esophageal pressure and electrical activity of the diaphragm. The authors concluded: "oxygen consumption measured by IC does not seem to be a reliable tool to assess work of breathing in mechanically ventilated children."

Guo, F., H. Zhou, J. Wu, Y. Huang, G. Lv, Y. Wu, H. Qiu, Y. Xu and Y. Yang (2021). "Prospective Study on Energy Expenditure in Patients With Severe Burns." *JPEN. Journal of parenteral and enteral nutrition* **45**(1): 146-151.

Summary: IC: Vmax Spectra 229 (SensorMedics): This prospective, multicenter study evaluated the burn-related changes in metabolism via IC measurements and compared the utility of predictive equations. 43 severe-burn patients were enrolled with a median APACHE II score 20 ± 2.5, with body-surface burn involvement of 50-98%. The mean energy expenditure on the seventh day after severe burns was as high as 65 kcal/kg, which was 267% (range, 236% to 293%) of the basal metabolic rate (BMR). Prediction formulas were not precise in evaluating energy requirements in this hypermetabolic patient type.

Haugen, H. A., et al. (2007). "Indirect calorimetry: a practical guide for clinicians." *Nutr Clin Pract* **22**(4): 377-388.

Summary: This review gives clinicians a comprehensive overview of indirect calorimetry. Indirect calorimetry offers a scientifically-based approach to customize a patient's energy needs and nutrient delivery to maximize the benefits of nutrition therapy. With recent advances in technology, indirect calorimeters are easier to operate, more portable, and affordable. Increased utilization of indirect calorimetry would facilitate individualized patient care and should lead to improved treatment outcomes.

Hoeyer-Nielsen, A. K., M. J. Holmberg, A. V. Grossestreuer, T. Yankama, J. P. Branton, M. W. Donnino and K. M. Berg (2020). "Association Between the Oxygen Consumption: Lactate Ratio and Survival in Critically Ill Patients With Sepsis." *Shock*.

Summary: This retrospective study evaluated a prospective sepsis study in which VCO_2 and VO_2 were measured continuously for 48 hours to find out whether any association with survival could be determined. The VO_2 : lactate ratio was significantly higher in survivors. There was a significant difference in VCO_2 change over time between survivors (+11.6%) and non-survivors (-8.3%, $p=0.03$). No association was found between median VO_2 and survival.

Hung, R., et al. (2017). "Comparison of estimates of resting energy expenditure equations in haemodialysis patients." *Int J Artif Organs* **40**(3): 96-101.

Summary: In hemodialysis patients, standard equations underestimated REE.

Inadomi, C., et al. (2008). "Comparison of oxygen consumption calculated by Fick's principle (using a central venous catheter) and measured by indirect calorimetry." *J Anesth* **22**(2): 163-166.

Summary: This study investigated the clinical usefulness of the Fick method using central venous oxygen saturation (ScvO_2) and cardiac output (CO) measured by Pulse Dye -Densitometry (PDD) for monitoring oxygen consumption (VO_2). This prospective clinical study was performed in 28 mechanically ventilated postoperative patients after major abdominal surgery. VO_2 values determined by the Fick method were significantly lower than those measured by indirect calorimetry.

Ismail, J., A. Bansal, M. Jayashree, K. Nallasamy and S. V. Attri (2019). "Energy Balance in Critically Ill Children With Severe Sepsis Using Indirect Calorimetry: A Prospective Cohort Study." *Journal of pediatric gastroenterology and nutrition* **68**(6): 868-873.

Summary: This study evaluated the daily energy balance in children with severe sepsis. IC was measured with the Quark RMR (Cosmed) metabolic cart. 40 patients were evaluated and the study demonstrated a persistent negative energy balance from days 1 to 7. Furthermore, a persistent negative nitrogen balance was observed from day 1 to 5. There also was poor agreement between predicted and measured REE. The authors concluded: "Predictive equations are inaccurate in estimating the REE in critically ill children with severe sepsis. IC remains the criterion standard for accurate assessment of energy intake, and it should be considered in all patients with metabolic disturbances."

Jakobsson, J., S. Vadman, E. Hagel, S. Kalman and E. Bartha (2019). "The effects of general anaesthesia on oxygen consumption: A meta-analysis guiding future studies on perioperative oxygen transport." *Acta Anaesthesiologica Scandinavica* **63**(2): 144-153.

Summary: Oxygen consumption (VO_2) can change in several ways in the perioperative period, but is seldom monitored directly in routine care. This study investigates the effects of general anesthesia on VO_2 .

- Twenty-four studies including 453 patients were analyzed for VO_2 changes induced by anesthesia. Studies were published during 1969-2000 and the mean age of patients ranged from 28 to 70 years. VO_2 decreased after anesthesia induction by -65 (-75 ; -55 , 95% CI) mL min^{-1} .
- This meta-analysis demonstrates that general anesthesia reduces the global oxygen consumption, but the exact size estimate and its distribution are uncertain.
- In all included studies, oxygen consumption was assessed either by breathing gas analysis, such as indirect calorimetry, or calculated by the reverse Fick method using thermodilution cardiac output by a pulmonary artery or right ventricle catheter.

The authors suggest that oxygen consumption be included in both observational studies and trials on hemodynamic optimization strategies in high-risk surgical patients and related outcomes. Preferably, oxygen consumption changes should be monitored continuously throughout the perioperative period. This requires monitoring methods with high time resolution feasible for pre-, intra- and post-operative settings, or reliable estimation methods.

Jeon, J., D. Kym, Y. S. Cho, Y. Kim, J. Yoon, H. Yim, J. Hur and W. Chun (2019). "Reliability of resting energy expenditure in major burns: Comparison between measured and predictive equations." *Clinical Nutrition* **38**(6): 2763-2769.

Summary: IC: Vmax 29 (Sensor-Medics): This study evaluated 215 patients with burns involving > 20% body surface area and involved a total of 418 IC measurements. The purpose of this study was to evaluate IC versus predictive equations for REE and to derive a new predictive equation (Hangang equation). The novel equation showed the highest level of correlation with calorimetry compared to the other predictive equations used. The Hangang equation is unique in that it considers time (post-burn days) and the ventilator status of the patient, while other predictive equations do not.

Jhang, W. K. and S. J. Park (2020). "Energy Expenditure in Mechanically Ventilated Korean Children: Single-Center Evaluation of a New Estimation Equation." *Pediatric Critical Care Medicine Publish Ahead of Print* **(8)**: e522-e529.

Summary: This study aimed at developing a novel energy expenditure equation compared to EE measured via IC. This predictive equation performs better than other equations used. There is a need to further validate the use of this equation in pediatric ICU patients.

Jimenez, L., et al. (2017). "Timing of the initiation of parenteral nutrition in critically ill children." *Curr Opin Clin Nutr Metab Care* **20**(3): 227-231.

Summary: This review article is very good for background understanding of parenteral nutrition in critically ill children. The authors summarize guidelines for parenteral nutrition initiation, relying on risk stratification of malnutrition and the ability to accurately assess energy expenditure via indirect calorimetry

Jotterand Chaparro, C., et al. (2017). "Performance of Predictive Equations Specifically Developed to Estimate Resting Energy Expenditure in Ventilated Critically Ill Children." *J Pediatr* **184**: 220-226.e225.

Summary: 15 predictive equations were used to estimate REE. None of the predictive equations tested met the performance criteria for the entire range of REE between 200 and 1,000 kcal/day. Even the equations with the smallest bias may entail a risk of underfeeding or overfeeding, especially in the youngest children. The authors concluded that indirect calorimetry measurement must be preferred in this patient population.

Jotterand Chaparro, C., et al. (2018). "Estimation of Resting Energy Expenditure Using Predictive Equations in Critically Ill Children: Results of a Systematic Review." *JPEN J Parenter Enteral Nutr* **42**(6): 976-986.

Summary: This meta analysis included 22 studies with 21 equations that estimate REE in children. Only six equations were evaluated by at least three studies in critically ill children; no equation predicted REE within $\pm 10\%$ of MEE in >50% of observations. The Schofield equations and Talbot tables were the least inaccurate of the predictive equations. The author concluded that there is an urgent need for a new validated IC measurement for pediatric ICU patients.

Kagan, I., et al. (2018). "Validation of carbon dioxide production (VCO_2) as a tool to calculate resting energy expenditure (REE) in mechanically ventilated critically ill patients: a retrospective observational study." *Crit Care* **22**(1): 186.

Summary: A retrospective observational study involving ventilated patients compared the REE derived from VCO_2 (REE- VCO_2) with the REE derived from IC (REE-IC). REE and RQ were calculated using the Weir equation. 497 measurements were conducted with a median of three measurements per patient. Results showed that there was wide variability without a consistent bias, suggesting that the VCO_2 measurement could widely under- and over-estimate REE. Therefore, REE via IC remains the best tool to estimate caloric needs.

Kamel, A., L. Robayo, D. Liang, M. Rosenthal, S. Voils and P. Efron (2019). "Estimated versus measured energy expenditure in ventilated surgical trauma critically ill patients." *Critical Care Medicine* **47**(1).

Summary: This study evaluated the REE via predictive equations compared to indirect calorimetry in surgical trauma patients. A total of 10 predictive equations were used. 104 patients were analyzed. and the closest estimate to IC-REE was the modified Harris-Benedict equation ($r=0.6515$). The authors concluded that predictive equations offer limited effectiveness for estimating REE in this patient population.

Karlsson, M., et al. (2017). "Ability to predict resting energy expenditure with six equations compared to indirect calorimetry in octogenarian men." **92**: 52-55.

Summary: The accuracy of predictive equations for calculating resting energy expenditure (REE) in elderly people has been questioned. Aging is associated with progressive declines in REE, which is partly explained by loss of fat-free mass (FFM). The Mifflin-St Jeor equation (using FFM) is the most accurate equation for estimating REE in these octogenarian men. The Harris-Benedict or WHO equations are potential alternatives if information on FFM is unavailable, although their accuracy on an individual level is limited. (An unknown IC device used in this study.)

Koekkoek, W. A. C., G. Xiaochen, D. van Dijk and A. R. H. van Zanten (2020). "Resting energy expenditure by indirect calorimetry versus the ventilator-VCO₂ derived method in critically ill patients: The DREAM-VCO₂ prospective comparative study." *Clinical Nutrition ESPEN* **39**: 137-143.

Summary: IC: Quark RMR (Cosmed); VCO₂: Hamilton-S1 mechanical ventilator, Hamilton Medical AG): This study compared energy expenditure via measurement of expired gases (EEVCO₂) against the reference standard of indirect calorimetry in a prospective observational study involving critically ill patients. EEVCO₂ was derived from CO₂ using an adjusted version of Weir's equation, and RQ estimated at 0.86. In total, 31 patients were included for analysis. The mean EEVCO₂ was 2,134 kcal/d compared to a mean EE from IC of 1,623 kcal/d. EEVCO₂ overestimated EE in 92.8% of cases and underestimated in 0.2% of cases. The authors concluded that predictive equations, albeit inaccurate, may even predict EE better compared with the EEVCO₂ method.

Kovachev, I., et al. (2002). "[Assessment of oxygen delivery (DO₂) and oxygen consumption (VO₂) in severe pre-eclamptic patients]." *Akush Ginekol (Sofia)* **41**(3): 18-23.

Summary: No results can be determined except for demonstration of use of VO₂ in management of preeclampsia.

Ladd, A. K., et al. (2018). "Preventing Underfeeding and Overfeeding: A Clinician's Guide to the Acquisition and Implementation of Indirect Calorimetry." *Nutr Clin Pract* **33**(2): 198-205.

Summary: In this quality improvement (QI) initiative around IC implementation in a PICU, 69% of measurements resulted in adjustments to energy delivery. 47% of energy prescriptions decreased by a mean of 27%, and 22% increased by a mean of 17%. The authors concluded that their QI initiative demonstrated the implementation and application of IC in the critically ill population and the ability to target energy provision to prevent energy imbalances.

Lago, A. F., E. C. Goncalves, E. C. Silva, M. G. Meneguetti, E. A. Nicolini, M. Auxiliadora-Martins, E. Z. Martinez, A. C. Gastaldi and A. Basile-Filho (2015). "Comparison of Energy Expenditure and Oxygen Consumption of Spontaneous Breathing Trial Conducted With and Without Automatic Tube Compensation." *Journal of Clinical Medicine Research* **7**(9): 700-705.

Summary: IC: Deltatrac II (GE Healthcare): This randomized crossover-design study evaluated spontaneous breathing trials of CPAP with automatic tube compensation (ATC) or CPAP without ATC. The authors concluded that VO₂ and EE obtained during SBT with and without ATC were not different.

Lambell, K. J., O. A. Tatucu-Babet, L. A. Chapple, D. Gantner and E. J. Ridley (2020). "Nutrition therapy in critical illness: a review of the literature for clinicians." *Crit Care* **24**(1): 35.

Summary: This review article outlines nutritional therapy in the management of critically ill patients.

Larsen, B. M. K., et al. (2018). "Can energy intake alter clinical and hospital outcomes in PICU?" *Clin Nutr ESPEN* **24**: 41-46.

Summary: This study aimed to determine the incidence of over- and under-feeding and to compare hospital outcomes between these feeding categories in children admitted to the PICU. It found that only 12% of critically ill children were appropriately fed, while 53% were overfed and 35% underfed. Those that were overfed had longer hospital and PICU LOS than those appropriately fed, while those that were underfed had shorter hospital and PICU LOS than those appropriately fed.

Ławiński, M., M. K. Skroński, A. Ukleja, M. Andrzejewska, P. Nyckowski, M. Słodkowski, M. Theilla and P. Singer (2019). "MON-PO600: Indirect Calorimetry in Oncological Surgery Liver Patients – Comparison of Resting Energy Expenditure with Prediction Equations." *Clinical Nutrition* **38**: S281-S282.

Summary: This study evaluated the utility of predictive equations compared to calorimetry in patients undergoing liver resection surgery. In total, 100 patients were enrolled. There was no appreciable difference in the resting metabolic rate between Day 0 and Day 7 following surgery. If IC not available, the Mifflin formula offered the best correlation with IC during pre-surgery evaluation (R=0.85). However, there is no optimal predictive formula for REE evaluation for this surgical patient group.

Lee, I. H., Y.-W. Kuo, F.-C. Lin, C.-W. Wu, J.-S. Jerng, P.-H. Kuo, J.-C. Cheng, Y.-C. Chien, C.-K. Huang and H.-D. Wu (2020). "Kinetics of oxygen uptake during unassisted breathing trials in prolonged mechanical ventilation: a prospective pilot study." *Scientific Reports* **10**(1): 14301.

Summary: GE Healthcare CARESCAPE Monitor B650 and Engström Carestation: This pilot study investigated the kinetics of VO_2 during unassisted breathing trials (UBT) in patients with prolonged mechanical ventilation. 49 patients were evaluated in a prospective observational trial. The median VO_2 increased significantly (from 235.8 to 298.2 ml/min; $P = 0.025$) in the failure group, but there was no significant change in the success group (from 223.1 to 221.6 ml/min; $P = 0.505$). In multivariate logistic regression analysis, an increase in $\text{VO}_2 > 17\%$ from the beginning period and a peak inspiratory pressure greater than -30 cm H_2O were significantly associated with the success of 120-minute UBT. The authors concluded, "Our findings show the potential of monitoring VO_2 in the final phase of weaning in tracheostomized patients with prolonged mechanical ventilation."

Lee, P. S.-P., *et al.* (2017). "Metabolic Requirement of Septic Shock Patients Before and After Liberation From Mechanical Ventilation." **41**(6): 993-999.

Summary: This study identified the difference in energy expenditure and substrate utilization of patients during and upon liberation from mechanical ventilation. The authors concluded that measured energy expenditure was higher during than upon liberation from mechanical ventilation. This could be the increase in work of breathing from the continuous positive pressure support, repeated weaning cycles from mechanical ventilation, and/or the asynchronization between patients' respiration and ventilator support. Future studies should examine whether more appropriately matching energy expenditure with energy intake would promote positive health outcomes. (An unknown IC device used in this study.)

Lee, S. J., H.-J. Lee, Y.-J. Jung, M. Han, S.-G. Lee and S.-K. Hong (2020). "Comparison of Measured Energy Expenditure Using Indirect Calorimetry vs Predictive Equations for Liver Transplant Recipients." *Journal of Parenteral and Enteral Nutrition* n/a(n/a).

Summary (IC: GE Healthcare, specific device not specified): In this study, commonly used predictive equations were compared to EE measured via IC in patients undergoing liver transplantation. The four predictive methods evaluated were the simple weight-based equation (25 kcal/kg/day, rule of thumb) and Harris-Benedict, Ireton-Jones (for ventilated patients), and Penn State 1988 equations. In total, 46 patients were evaluated. The predicted REE calculated using the Penn State 1988 method agreed with the measured REE. All four predictive equations showed a fixed bias and appeared to be inaccurate for predicting REE in this cohort of liver transplant recipients. The authors concluded that precise measurements using IC may be helpful when treating critically ill patients to avoid underestimating or overestimating their metabolic needs.

Li, G., C. L. Zhou, Y. M. Ba, Y. M. Wang, B. Song, X. B. Cheng, Q. F. Dong, L. L. Wang and S. S. You (2020). "Nutritional risk and therapy for severe and critical COVID-19 patients: A multicenter retrospective observational study." *Clin Nutr.*

Summary: The primary focus of this study was to evaluate nutritional metabolism in COVID-19 patients upon admission and to evaluate the prognostic value of nutrition screening tools. In total, 523 patients were studied, and 211 were managed in the ICU. The NUTRIC score can independently predict the risk of death in the hospital ($\text{OR} = 1.197$, $p = 0.006$) and high NRS-score patients have a higher risk of poor outcome in the ICU ($\text{OR} = 1.880$, $p = 0.012$). The authors observed that severe and critical patients with COVID-19 have a high risk of malnutrition. Furthermore, "Patients with low BMI and protein levels were significantly associated with adverse events."

Liu, W., *et al.* (2017). "Measurements of resting energy expenditure in surgical critically ill patients with mechanical ventilator." **44**(7): 452-455.

Summary: This study compared the differences between measured resting energy expenditure calculated by the indirect calorimetry and the resting energy expenditure calculated by the Harris-Benedict formula. Resting energy expenditure by the Harris-Benedict formula was significantly higher than calculated from indirect calorimetry ($P < 0.05$). Resting energy expenditure by the weight formula was significantly lower than calculated from indirect calorimetry ($p < 0.05$). Although the Harris-Benedict formula and weight formula are convenient in clinical use, the results calculated by them is significantly different from the results calculated by indirect calorimetry. So clinical nutrition support should rely on indirect calorimetry as far as possible. (An unknown IC device used in this study.)

Macdonald, I. A. (2020). "Editorial for Clinical Nutrition: Issues to consider when using ventilated hood indirect calorimetry to estimate energy expenditure and substrate utilisation." *Clinical nutrition (Edinburgh, Scotland)* **39**(6): 1643-1644.

Summary: This article is a point-counterpoint discussion based on an accompanying publication by Oshima that comments on the issues to consider when using a ventilated hood to measure EE with IC.

Marra, M., R. Sammarco, I. Cioffi, D. Morlino, O. Di Vincenzo, E. Speranza and F. Pasanisi (2021). "New predictive equations for estimating resting energy expenditure in subjects with normal weight and overweight." *Nutrition* **84**: 111105.

Summary: IC: Vmax 29 and Vmax Encore (Sensor Medics): This study evaluated predictive equations to measure REE by leveraging bioimpedance analysis (BIA) in subjects with normal weight and overweight. The equation was developed and validated using data from 2,483 adult patients. The predictive equation was compared to IC. Compared to other predictive equations, this novel equation showed slightly improved accuracy when BIA was included (70.3% male, 72.3% female). The authors concluded that this predictive equation may serve as a viable alternative when indirect calorimetry measurements are not available.

Martinez, E. E., et al. (2017). "Energy and Protein Delivery in Overweight and Obese Children in the Pediatric Intensive Care Unit." *Nutr Clin Pract* **32**(3): 414-419.

Summary: In this investigation involving overweight and obese children, the study cohort had suboptimal nutrition assessments (34%) and macronutrient delivery during their PICU course. Mortality and duration of PICU stay were greater when compared with the general PICU population. PICU duration was 8 days vs 5 days for obese patients compared to the general PICU population. The mortality rate was 7.2% vs 3.3% ($P = .045$) between obese and general PICU populations. Nutritional assessments were conducted in only 60% of obese patients. There is a need to improve nutritional assessments, utilization of indirect calorimetry-guided energy prescriptions, and optimization of energy and protein delivery in this pediatric population.

Menegueti, M. G., T. R. de Araújo, A. M. Laus, O. A. Martins-Filho, A. Basile-Filho and M. Auxiliadora-Martins (2019). "Resting Energy Expenditure and Oxygen Consumption in Critically Ill Patients With vs Without Sepsis." *American Journal of Critical Care* **28**(2): 136-141.

Summary: This study evaluated whether REE, RQ and oxygen consumption and carbon dioxide production (measured by indirect calorimetry) differed between critically ill patients with and without sepsis. In total, 205 patients were evaluated with 91 (44%) having sepsis. Analysis of receiver operating characteristic curves showed no significant differences between patients with and without sepsis for any of the indirect calorimetry variables.

Miwa, K., M. Mitsuoka, S. Takamori, A. Hayashi and K. Shirouzu "Continuous Monitoring of Oxygen Consumption in Patients Undergoing Weaning from Mechanical Ventilation."

Summary: IC: Puritan-Bennett 7250 Metabolic Monitor: Among 20 patients evaluated in this study, a total of 208 weaning trials were performed, including 145 that were successful. A statistical difference in oxygen cost of breathing (OCOB, respiratory frequency/tidal volume), ΔRR , and ΔEE was found between successful and failed weaning trials. OCOB <30% showed the greatest accuracy among these three measures. The authors added, "Continuous monitoring of VO_2 is useful to predict success or failure of trials attempting to reduce mechanical ventilatory support."

Moonen, H., K. J. H. Beckers and A. R. H. van Zanten (2021). "Energy expenditure and indirect calorimetry in critical illness and convalescence: current evidence and practical considerations." *J Intensive Care* **9**(1): 8.

Summary: This review article details the use of IC in critical illness with a focus on the acute, chronic and convalescent phases of illness. The transitions between these three phases remain unidentifiable. The author illustrates a listing of on-market devices designed to perform IC measurements, including but not limited to Deltatrac, Quark RMR, E-COVX and CCM Express. The article reiterates that energy requirements are best determined via use of IC, rather than reliance on predictive equations, which can result in over- or under-feeding.

Moreira, E., et al. (2018). "Update on metabolism and nutrition therapy in critically ill burned patients."

Summary: This review article applicable to burn patients observed that calorie deficit, negative protein balance and antioxidant micronutrient deficiency after thermal injury have been associated with poor clinical outcomes. In this context, personalized nutrition therapy with early enteral feeding from the start of resuscitation is indicated.

Moreno, Y. M., et al. (2016). "Problems With Optimal Energy and Protein Delivery in the Pediatric Intensive Care Unit." *Nutr Clin Pract* **31**(5): 673-680.

Summary: On average, actual energy intake in critically ill children was 47% of the predicted energy expenditure, and 68% of patients were underfed. Significant gaps in predicted energy requirements combined with prescription and delivery of energy and protein resulted in underfeeding in this PICU population.

Mouzaki, M., *et al.* (2017). "Can VCO₂-Based Estimates of Resting Energy Expenditure Replace the Need for Indirect Calorimetry in Critically Ill Children?" *JPEN J Parenter Enteral Nutr* **41**(4): 619-624.

Summary: This study found that in pediatric patients undergoing cardiopulmonary bypass, indirect calorimetry was the most accurate method (compared to VCO₂-derived estimates) to determine REE. The authors noted that further evaluation is needed to assess the utility of VCO₂-derived REE estimation.

Mtaweh, H., C. Garros, A. Ashkin, L. Tuira, J. P. Allard, P. Pencharz, E. Pullenayegum, A. Joffe and C. S. Parshuram (2020). "An Exploratory Retrospective Study of Factors Affecting Energy Expenditure in Critically Ill Children." *Journal of Parenteral and Enteral Nutrition* **44**(3): 507-515.

Summary: This study in pediatric patients aimed to evaluate the factors available at the bedside and to determine any association with EE. IC was measured at this multicenter study with the Vmax Encore 29n metabolic cart (Vyair medical). The authors identified significant associations between EE and factors representative of body size, cardiac output, minute ventilation, and administered sedatives. Future prospective evaluations are warranted to determine the true predictive nature of these variables.

Mtaweh, H., M. J. Soto Agüero, M. Campbell, J. P. Allard, P. Pencharz, E. Pullenayegum and C. S. Parshuram (2019). "Systematic review of factors associated with energy expenditure in the critically ill." *Clinical nutrition ESPEN* **33**: 111-124.

Summary: This systematic literature review identified 103 articles included in analysis. In this analysis, 95 clinical factors were evaluated for association with EE in critically ill patients. Of note, groups of factors were significant in different patient populations. The data presented is expansive and beyond the scope of this summary.

Oliveira, A., C. C. de Oliveira, M. T. de Jesus, N. N. B. Menezes, F. N. de Gois, J. T. da Silva and L. M. Santos (2020). "Comparison of Equations to Predict Energy Requirements with Indirect Calorimetry in Hospitalized Patients." *Journal of Parenteral and Enteral Nutrition*.

Summary: IC: CCM Express (MedGraphics): This study evaluated the degree of agreement between the REE measurement via IC (REE-IC) and REE estimated by predictive equations in ICU patients. There was a significant difference in REE measured by IC as compared to predictive equations (Harris-Benedict and Ireton Jones).

Oshima, T., *et al.* (2017). "Indirect calorimetry in nutritional therapy. A position paper by the ICALIC study group." *Clin Nutr* **36**(3): 651-662.

Summary: Highlights of this review article include:

- The Deltatrac Metabolic Monitor® produced 35 years ago is often viewed as the reference device.
- Devices with a mixing chamber generate more stable measurements because the gases are physically averaged before being analyzed, allowing the gas analyzers to generate very accurate analysis. The capacity to make reliable measurements in a short duration is also limited, as it takes just as much time for the gas concentrations in the mixing chamber to stabilize.
- Patients in the ICU for > 4 days or those after major surgery are good candidates for IC as they undergo severe stress related to variable metabolic needs. Indeed, these patients are at high nutritional risk, as they are unable to resume sufficient oral intake.
- Obese patients constitute an increasing proportion of the ICU patient population. Their energy requirements are particularly poorly addressed by predictive equations. IC is the only way to determine their metabolic requirements accurately.

Oshima, T., M. Delsoglio, Y. M. Dupertuis, P. Singer, E. De Waele, C. Veraar, C. P. Heidegger, J. Wernermann, P. E. Wischmeyer, M. M. Berger and C. Pichard (2020). "The clinical evaluation of the new indirect calorimeter developed by the ICALIC project." *Clin Nutr* **39**(10): 3105-3111.

Summary: This study evaluated the time required to obtain EE with use of Q-NRG® versus currently used ICs, including Deltatrac and E-COVX. The Q-NRG® required a much shorter time than most other ICs to determine EE in mechanically ventilated ICU patients. The authors concluded, "Q-NRG® is the only commercially available IC tested against mass spectrometry to ensure gas accuracy, while being very easy-to use."

Panitchote, A., et al. (2017). "Energy expenditure in severe sepsis or septic shock in a Thai Medical Intensive Care Unit." *Asia Pac J Clin Nutr* **26**(5): 794-797.

Summary: This study aimed to measure energy expenditure in severe sepsis/septic shock patients by indirect calorimetry and to assess the correlation of energy expenditures between indirect calorimetry and predictive equations. IC was measured using an Engström Carestation mechanical ventilator. There was poor agreement and correlation between EE using predictive equations versus EE using IC. The Bland-Altman analysis showed a mean difference (limits of agreement) of -757 kcal/day between EE using IC and EE using predictive equations.

Parker, E. A., et al. (2017). "Considerations when using predictive equations to estimate energy needs among older, hospitalized patients: a narrative review." **6**(2): 102-110.

Summary: In this review article, the authors observed that as the evidence demonstrating the importance of nutritional supplementation in older, hospitalized adults grows, more accurate energy assessment methods that account for age-related conditions are needed to predict nutritional requirements.

Patkova, A., et al. (2018). "Prognostic value of respiratory quotients in severe polytrauma patients with nutritional support." **49**: 90-95.

Summary: This study aimed to evaluate the association between energy metabolism and prognosis in polytrauma patients. IC was performed on the fourth ICU day in order to evaluate the impact of EE on outcomes. RQ was significantly lower in fasted polytrauma patients than in those receiving nutritional support (parenteral nutrition). Significant association was demonstrated between ICU LOS and duration of mechanical ventilation for those receiving nutritional support.

Patt, P. L., et al. (2007). "Estimation of resting energy expenditure in children with spinal cord injuries." *J Spinal Cord Med* **30 Suppl 1**: S83-87.

Summary: This study found that measured REE was lower than the results of prediction equations in pediatric patients with spinal cord injuries. Further validation studies are needed.

Peerless, J. R., et al. (2000). "Oxygen consumption in the early postinjury period: use of continuous, on-line indirect calorimetry." *Crit Care Med* **28**(2): 395-401.

Summary: This study aimed to determine patterns of oxygen consumption (VO_2) using indirect calorimetry (IC) for the first 24 hours after serious blunt traumatic injury. The authors found that seriously injured patients are hypermetabolic in the early post-injury period. The level of VO_2 was unrelated to injury severity and did not predict the onset of multiorgan dysfunction.

Pelekhaty, S. L., C. L. Ramirez, J. M. Massetti, D. Gaetani, K. Riggin, G. Schwartzbauer and D. M. Stein (2020). "Measured vs Predicted Energy Expenditure in Mechanically Ventilated Adults With Acute, Traumatic Spinal Cord Injuries." *Nutrition in Clinical Practice*.

Summary: IC: Vmax 229 (SensorMedics): This study evaluated measured energy expenditure from indirect calorimetry versus predicted energy expenditure in critically ill patients with acute spinal cord injuries. A total of 115 IC studies were conducted in 51 patients. Penn State 2003b predicted within 10% of measured energy expenditure most frequently. All equations were biased toward overfeeding, except for PS 2003b in the obese subset. Therefore, in the absence of IC, the Penn State or the derived Weir equation may be acceptable predictive equations in this patient population.

Pereira-da-Silva, L., S. Barradas, A. C. Moreira, M. Alves, A. L. Papoila, D. Virella and G. Cordeiro-Ferreira (2020). "Evolution of Resting Energy Expenditure, Respiratory Quotient, and Adiposity in Infants Recovering from Corrective Surgery of Major Congenital Gastrointestinal Tract Anomalies: A Cohort Study." *Nutrients* **12**(10): 1-17.

Summary (IC: Deltatrac II): This study aimed at quantifying the evolution of REE, RQ, and adiposity of infants during the late anabolic phase after corrective surgery of major congenital gastrointestinal tract anomalies and to explore the determinants associated with these components of energy balance. 29 neonates were included for analysis, which included 15 pre-term infants. In total, 317 longitudinal calorimetry measurements were performed. In infants born pre-term, the median REE varied between 55.7 and 67.4 kcal/kg/day, and median RQ changed from 0.70 to 0.86-0.92 between 34 and 42 weeks. In infants born at term, the median REE varied between 57.3 and 67.9 kcal/kg/day while the median RQ increased from 0.63 to 0.84-0.88 from 38 to 44 weeks PMA (post-menopausal age).

Pereira-da-Silva, L., S. Barradas, A. C. Moreira, M. Alves, A. L. Papoila, D. Virella and G. Cordeiro-Ferreira (2020). "Evolution of Resting Energy Expenditure, Respiratory Quotient, and Adiposity in Infants Recovering from Corrective Surgery of Major Congenital Gastrointestinal Tract Anomalies: A Cohort Study." *Nutrients* **12**(10): 1-17.

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Peyton, P. J. and G. J. Robinson (2005). "Measured pulmonary oxygen consumption: difference between systemic oxygen uptake measured by the reverse Fick method and indirect calorimetry in cardiac surgery." *Anaesthesia* **60**(2): 146-150.

Summary: Measurement of oxygen uptake by indirect calorimetry was compared with the reverse Fick method in a series of patients undergoing cardiac surgery. IC was performed with non-GE technology. Indirect calorimetry overestimated the reverse Fick value by 11.3% ($p < 0.001$), a finding consistent with the results of previous studies with similar patient groups.

Piccolo, M. F., et al. (2016). "Harris-Benedict Equation and Resting Energy Expenditure Estimates in Critically Ill Ventilator Patients." *Am J Crit Care* **25**(1): e21-29.

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

Pielmeier, U. and S. J. C. C. Andreassen (2016). "VCO₂ calorimetry is a convenient method for improved assessment of energy expenditure in the intensive care unit." **20**(1): 224.

Summary: This editorial argued that IC remains the gold standard for assessment of EE in ventilated critically ill patients. However, the best validated system, the Deltatrac, is no longer on the market, and new indirect calorimeters have not yet proven to be accurate. More important, predictive equations are inaccurate, and their use should be avoided. VCO₂-based EE provides the best alternative.

Piot, J., et al. (2018). "An elevated respiratory quotient predicts complications after cardiac surgery under extracorporeal circulation: an observational pilot study." *J Clin Monit Comput*.

Summary: Following cardiac surgery, hyperlactatemia due to anaerobic metabolism is associated with an increase in both morbidity and mortality. Researchers previously found that an elevated respiratory quotient (RQ) predicted anaerobic metabolism. In the present study, the authors aimed to demonstrate that increased RQ is associated with poor outcomes following cardiac surgery. This was confirmed.

Plauth, M., W. Bernal, S. Dasarathy, M. Merli, L. D. Plank, T. Schütz and S. C. Bischoff (2019). "ESPEN guideline on clinical nutrition in liver disease." *Clinical Nutrition* **38**(2): 485-521.

Summary: This item presents the ESPEN guidelines on clinical nutrition in liver disease. It spans acute liver failure, non-alcoholic fatty liver disease, liver cirrhosis, and liver surgery, plus transplantation.

Popp, C. J., M. Butler, M. Curran, P. Illiano, M. A. Sevvick and D. E. St-Jules (2020). "Evaluating steady-state resting energy expenditure using indirect calorimetry in adults with overweight and obesity." *Clinical nutrition (Edinburgh, Scotland)* **39**(7): 2220-2226.

Summary: IC: Quark RMR (Cosmed): This study assessed the importance of attaining steady state while measuring EE via indirect calorimetry. This was a cross-over design with 63 total subjects enrolled with a mean BMI of 35 ± 5 kg/m². 54/63 (84%) were able to achieve 5-minute steady-state REE. Of note, lower thresholds of 4- and 3-minute steady state were practical alternatives to measuring REE.

Poulsen, M. K., L. P. Thomsen, S. Kjærgaard, S. E. Rees and D. S. Karbing (2019). "Reliability of, and Agreement Between, two Breath-by-Breath Indirect Calorimeters at Varying Levels of Inspiratory Oxygen." *Nutrition in Clinical Practice* **34**(5): 767-774.

Summary: IC: Beacon 3 (Mermaid Care, device 2) and ECOVX (GE Healthcare, device 1), reference method): This study investigated whether measurements of EE, VO₂, and VCO₂ by breath-by-breath IC devices 1 and 2 were within-day reliable under conditions of varying FiO₂, and whether the two systems measured in agreement. (Device 2 does not use the Haldane transformation). The study was conducted in 20 healthy male subjects and IC was measured while breathing through a ventilator facemask, conscious and sitting. Both systems measured EE, VO₂, and VCO₂ at 21%-85% FiO₂ reliably, but with bias at 85% FiO₂. The devices were in agreement at 21% and 50% FiO₂, but further studies need to confirm accuracy at high FiO₂.

Ramos, F., et al. (2017). "Comparison of predictive equations of resting energy expenditure in older adults with chronic obstructive pulmonary disease." **23**(1): 40-42.

Summary: The authors concluded that the majority of equations underestimated the REE and all equations showed low association with IC. Therefore, they suggested that the REE equations used at present study should not be used in older adults with COPD. The main limitation of this study was that the small sample size constituted mainly by male patients does not permit speculation about these results in general COPD population and more studies evaluating higher number of older adults with COPD are needed.

Rattanachaiwong, S. and P. Singer (2019). "Indirect calorimetry as point of care testing." *Clinical Nutrition* **38**(6): 2531-2544.

Summary: This review article addresses the background and utility of indirect calorimetry with a special emphasis on point-of-care (POC) testing. Of note, POC does not refer to novel technologies that are portable (i.e. hand-held) but rather conventional technology that provides information to the clinician at the bedside.

Reneau, J., B. Obi, A. Moosreiner and S. Kidambi (2019). "Do we need race-specific resting metabolic rate prediction equations?" *Nutrition & Diabetes* **9**(1).

Summary: IC: Parvo TrueOne2400: This study aimed to evaluate racial impacts on REE between predictive and calorimetry-based measurements. A total of 114 healthy subjects were enrolled. The authors determined that the formula using height, weight, gender and age systematically overestimated REE and hence predicted higher caloric needs among African-American patients.

Ridley, E. J., A. Tierney, S. King, E. Ainslie, A. Udy, C. Scheinkestel and I. Nyulasi (2020). "Measured Energy Expenditure Compared With Best-Practice Recommendations for Obese, Critically Ill Patients-A Prospective Observational Study." *JPEN. Journal of parenteral and enteral nutrition* **44**(6): 1144-1149.

Summary: IC: Quark RMR (Cosmed): This study evaluated EE in critically ill obese patients, comparing measured versus predicted EE. In addition, a comparison between measured EE and recommendations from the American Society for Parenteral and Enteral Nutrition (ASPEN) Guidelines was conducted. A total of 19 patients were evaluated, with a BMI range of 30.5 – 64.5 kg/m². Clinically significant variation was observed between measured EE, predictive estimates, and guideline recommendations at all time points in these patients.

Ringel, J. B., D. Jannat-Khah, R. Chambers, E. Russo, L. Merriman and R. Gupta (2019). "Impact of gaps in care for malnourished patients on length of stay and hospital readmission." *BMC Health Serv Res* **19**(1): 87.

Summary: This study evaluated the presence of gaps in care that follow malnutrition diagnosis and their effects on length of stay and 90-day readmission. The hypothesis is that these gaps are associated with increased length of stay and increased readmission. A retrospective chart review was conducted by two registered dietitians, evaluating 22 malnourished patients. Gaps in care were categorized as related to communication, testing/procedure, and discharge. The average participant with any gap in care had a 2.5-day longer LOS compared to those without any gap. Of note, those with a testing/procedure gap had a 6-day increase in LOS.

Roebuck, N., C. P. S. Fan, A. Floh, Z. L. Harris and M. L. Mazwi (2020). "A Comparative Analysis of Equations to Estimate Patient Energy Requirements Following Cardiopulmonary Bypass for Correction of Congenital Heart Disease." *JPEN. Journal of parenteral and enteral nutrition* **44**(3): 444-453.

Summary: This study used a novel method to determine REE in pediatric patients following cardiopulmonary bypass for repair of congenital heart disease. IC was measured leveraging respiratory mass spectrometry (AMIS 2000, Innovision A/S). In total, 107 patients were evaluated with no predictive equation showing suitable accuracy compared to IC measurement of REE.

Satoh, D., et al. (2018). "Effects of intraoperative nutrients administration on energy expenditure during general anesthesia." *Nutrition* **45**: 37-40.

Summary: This study explored the physiological benefits of the administration of exogenous nutrients during general anesthesia. Recent reports have indicated that intraoperative infusions of glucose and amino acids exert anticatabolic effects. IC was measured with the GE Healthcare E-COVX module. The number of days of intubation and the length of the ICU stay did not differ among the three patient groups studied. The lengths of hospital stay were shorter in the groups receiving intraoperative glucose and amino acids, compared to the control group. Additionally, these results indicate that the infusion of glucose and amino acids during general anesthesia increases REE and exerts a thermogenic effect.

Schuijs, J. M., R. D. Eveleens, B. van der Hoven, P. L. M. Lakenman, J. van Bommel, D. A. M. P. J. Gommers, K. F. M. Joosten and J. F. Olieman (2020). "Feeding practises and REE in critically ill COVID-19 patients." *Clinical Nutrition ESPEN* **40**: 440.

Summary: (IC: Q-NRG+): This observational study evaluated REE during the acute (day 1-7) and late (>7 days) of critically ill mechanically ventilated patients with COVID-19. 35 patients were enrolled with 42 IC measurements performed (20 acute phase; 22 late phase). During the acute phase, the REE was 1,956 kcal and RQ 0.72. In the late phase, the REE was 2374 kcal with an RQ 0.81. During the acute phase, hypocaloric feeding (64% of REE) was noted, while normal caloric feeding (92% of REE) occurred predominantly during the late phase. This illustrated that during both phases of illness, the majority of COVID-19 patients were hypermetabolic

Segadilha, N., et al. (2017). "Energy Expenditure in Critically Ill Elderly Patients: Indirect Calorimetry vs Predictive Equations." *JPEN J Parenter Enteral Nutr* **41**(5): 776-784.

Summary: This study evaluated the degree of agreement between and the accuracy of the REE measured by IC (REE-IC) and REE estimated by predictive equations (REE-PE) in mechanically ventilated elderly patients. The authors concluded that estimated REE showed limited effectiveness in this patient population.

Serrano Valles, C., J. J. Lopez Gomez, S. Garcia Calvo, R. Jimenez Sahagun, B. Torres Torres, E. Gomez Hoyos, A. Ortolá Buigues and D. de Luis Roman (2020). "Influence of nutritional status on hospital length of stay in patients with type 2 diabetes." *Endocrinol Diabetes Nutr* **67**(10): 617-624.

Summary: This study evaluated the impact of diabetes on hospitalized patients and whether they had a poorer nutritional status. This transverse study involved 1,017 patients between 2014 and 2016.

Shepherd, Stephen J. and Rupert M. Pearce (2009). "Role of Central and Mixed Venous Oxygen Saturation Measurement in Perioperative Care." *Anesthesiology* **111**(3): 649-656.

Summary: Venous oxygen saturation reflects the balance between global oxygen delivery and oxygen consumption, which may be affected by a wide range of factors during the perioperative period. This article describes the physiology and measurement of mixed and central venous oxygen saturation and explores the findings of clinical investigations of their use in perioperative care. Some highlights pertaining to VO₂:

- Few studies have explored the relationship between VO₂ and venous saturation during the perioperative period. This may reflect poor recognition of the importance of VO₂ as a determinant of venous saturation.
- Increases in VO₂ resulting from pain, anxiety, or shivering may all result in a decrease in venous saturation. General anesthesia results in a decrease in VO₂ as a result of decreased work of breathing, motor activity and body temperature.

Silva, T. A., F. d. C. P. Maia, M. C. A. Zocrato, S. F. Mauricio, M. I. T. D. Correia and S. d. V. Generoso (2021). "Preoperative and Postoperative Resting Energy Expenditure of Patients Undergoing Major Abdominal Operations." *Journal of Parenteral and Enteral Nutrition* **45**(1): 152-157.

Summary: IC: Quark RMR (Cosmed): This study assessed REE after major abdominal procedures and its associated factors. In total, 54 patients were included in the analysis. There were no significant changes in REE at any of the assessed periods in the pre-operative or post-operative periods. There was a decrease in the RQ during the post-operative period when compared with the pre-operative assessment, accompanied by a decrease in carbohydrate oxidation and an increase in lipid oxidation.

Singer, P. (2019). "Preserving the quality of life: nutrition in the ICU." *Crit Care* **23**(Suppl 1): 139.

Summary: This review article focuses on nutrition therapy in the ICU, including the catabolic response to stress, energy requirements and prescription, and nutrition in recovery from critical illness.

Singer, P., C. Pichard and E. De Waele (2020). "Practical guidance for the use of indirect calorimetry during COVID 19 pandemic." *Clinical Nutrition Experimental* **33**: 18-23.

Summary: This review article provides practical guidance to healthcare professionals in the management of patients with COVID-19. This includes practical guidance in the use of the QNRG+ (Cosmed) and E-sCOVX/E-sCAiOVX (GE Healthcare).

Singer, P., C. Pichard and S. Rattanachaiwong (2020). "Evaluating the TARGET and EAT-ICU trials: how important are accurate caloric goals? Point-counterpoint." *Current Opinion in Clinical Nutrition and Metabolic Care* **23**(2): 91-95.

Summary: Controversies about the adequate amount of energy to deliver to critically ill patients continue, and trying to find if a hypocaloric or normocaloric regimen is beneficial in this population. The authors reviewed recent studies in which indirect calorimetry was and was not used.

Singer, P., E. De Waele, C. Sanchez, S. Ruiz Santana, J. C. Montejó, P. F. Laterre, A. Soroksky, E. Moscovici and I. Kagan (2021). "TICACOS international: A multi-center, randomized, prospective controlled study comparing tight calorie control versus Liberal calorie administration study." *Clinical nutrition (Edinburgh, Scotland)* **40**(2): 380-387.

Summary: IC: Deltatrac II, COVX (both GE Healthcare) and Quark (Cosmed): This follow-on to the compendium of TICACOS studies completed to date evaluated the impact of measuring daily REE and the impact on infection rates in critically ill patients. In total 332 patients were allocated into a control or study intervention arm; but the study failed to achieve the targeted enrollment numbers. The primary outcome of infection was not significantly decreased between the study and control groups. There was a trend for decreased hospital mortality in the study arm that did not reach statistical significance. The authors concluded, "these results together with other prospective randomized studies using indirect calorimetry might give a signal toward improved survival when patients' medical nutritional therapy is guided by indirect calorimetry."

Smallwood, C. D. and B. K. Walsh (2017). "Noninvasive Monitoring of Oxygen and Ventilation." *Respir Care* **62**(6): 751-764.

Summary: This comprehensive review article looked at diverse clinical applications for non-invasive monitoring beyond indirect calorimetry (IC). As it pertains to IC, the author highlighted several use cases:

- Nutrition, to detect during mechanical ventilation, spontaneous respirations and non-invasive ventilation. It is recommended to titrate energy prescriptions in critically ill children. Recent evidence suggests VCO_2 can serve as a surrogate for EE
- Potential uses include: titration of end-expiratory pressure during critical illness; titration of minute ventilation during severe obstruction; and assessment of response to pulmonary vasodilatory therapy.
- The optimization of VCO_2 can potentially guide clinicians to the optimal balance between atelectasis and over-distention.

Smallwood, C. D. and N. M. Mehta (2013). "Gas exchange measurement during pediatric mechanical ventilation--agreement between gas sampling at the airway and the ventilator exhaust." *Clin Nutr* **32**(6): 988-992.

Summary: This investigation compared oxygen consumption (VO_2), carbon dioxide elimination (VCO_2), Resting Energy Expenditure (REE) and respiratory quotient (RQ) in mechanically ventilated children, obtained by two devices using distinct gas sampling methods. Despite strong correlations and small mean biases for VO_2 , VCO_2 and REE obtained by the Viasys Healthcare Vmax® and GE Healthcare E-COVX®, the limits of agreement were beyond the clinically acceptable range. These devices should not be used interchangeably for gas exchange measurements in mechanically ventilated children.

Smallwood, C. D. and N. M. Mehta (2013). "Gas exchange measurement during pediatric mechanical ventilation--agreement between gas sampling at the airway and the ventilator exhaust." *Clin Nutr* **32**(6): 988-992.

Summary: This study found that despite strong correlations and small mean biases for VO_2 , VCO_2 and REE obtained by the Vmax® and E-COVX®, the limits of agreement were beyond the clinically acceptable range. These devices should not be used interchangeably for gas exchange measurements in mechanically ventilated children.

Smallwood, C. D., et al. (2017). "Accuracy of Oxygen Consumption and Carbon Dioxide Elimination Measurements in 2 Breath-by-Breath Devices." *Respir Care* **62**(4): 475-480.

Summary: Of the two breath-by-breath devices tested, only the newest module demonstrated a bias and limits of agreement that were within an a priori determined clinically acceptable range of $\pm 20\%$ for VO_2 and VCO_2 (E-sCAiOVX). The limits of agreement were clinically acceptable from 40 to 100 mL/min. This range corresponds to approximate patient weights of 5 to 16 kg. The older device (E-COVX) did not demonstrate agreement with the simulated values and therefore is not clinically acceptable for use in pediatric patients.

Smallwood, C. D., et al. (2017). "Accuracy of Oxygen Consumption and Carbon Dioxide Elimination Measurements in 2 Breath-by-Breath Devices." *Respir Care* **62**(4): 475-480.

Summary: This study assessed the accuracy and agreement of two devices used to quantify oxygen consumption (VO_2) and carbon dioxide elimination (VCO_2) in children, using a pediatric in vitro model of gas exchange. Of the two devices tested, only the newest module demonstrated a bias and limits of agreement that were within an a priori determined clinically acceptable range of $\pm 20\%$ for VO_2 and VCO_2 (E-sCAiOVX). The limits of agreement were clinically acceptable from 40 to 100 mL/min. This range corresponds to approximate patient weights of 5-16 kg. The older device (E-COVX) did not demonstrate agreement with the simulated values and therefore is not clinically acceptable for use in pediatric patients.

Smetana, K. S., Y. Hannawi and C. C. May (2020). "Indirect Calorimetry Measurements Compared With Guideline Weight-Based Energy Calculations in Critically Ill Stroke Patients." *JPEN. Journal of parenteral and enteral nutrition*.

Summary: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): The energy requirements of neuro-critical care patients are largely unknown. This study in critically ill stroke patients evaluated the energy requirements during the acute disease process. In this single-center, retrospective, observational study, IC was obtained at the baseline of the critical-care journey and low-weight and high-weight-based energy estimates were compared. The low-weight-based group was significantly lower than the REE target measured by IC, while high-weight-based group was similar to IC REE targets. Linear regression analysis showed that weight, height, and hemorrhagic stroke subtype were associated with IC.

Soussi, S., et al. (2017). "Measurement of Oxygen Consumption Variations in Critically Ill Burns Patients: Are the Fick Method and Indirect Calorimetry Interchangeable?" *Shock* **48**(5): 532-538.

Summary: This study conducted in 23 critically ill burn patients evaluated the interchangeability of oxygen consumption variations measured with the Fick equation versus indirect calorimetry. The results demonstrated poor agreement, and therefore VO_2 measurements by means of IC are not interchangeable with VO_2 obtained by Fick.

Stapel, S. N., et al. (2018). "Indirect calorimetry in critically ill mechanically ventilated patients: Comparison of E-sCOVX with the deltatrac." *Clin Nutr*.

Summary: In this prospective study with Deltatrac and E-sCOVX, measurements of energy expenditure (EE) in critically ill, mechanically ventilated patients were performed simultaneously. Mean EE-E-sCOVX was higher than EE-Deltatrac, with a bias of 235 ± 149 kcal/day, corresponding to a percentage error of 12.1% of the reference method. EE, VCO_2 and VO_2 measured by E-sCOVX and Deltatrac were significantly correlated. RQ was not. The authors concluded –that the E-sCOVX is not accurate and its use is therefore not recommended in critically ill patients. Because maintenance of the Deltatrac is no longer supported, there is a need for a new and reliable device.

Sundström Rehal, M., et al. (2016). "Measuring energy expenditure in the intensive care unit: a comparison of indirect calorimetry by E-sCOVX and Quark RMR with Deltatrac II in mechanically ventilated critically ill patients." **20**(1): 54.

Summary: The aim of this study was to determine the level of agreement in gas exchange measurements between the E-sCOVX, Quark RMR and the Deltatrac II in mechanically ventilated ICU patients. There was a significant bias toward higher VO_2 and VCO_2 values with both E-sCOVX and Quark RMR as compared to Deltatrac; that corresponded to 10% overestimation of REE.

Sungurtekin, H., S. Karakuzu and S. Serin (2019). "Energy Expenditure in Mechanically Ventilated Patients: Indirect Calorimetry vs Predictive Equations." *Dahili ve Cerrahi Bilimler Yoğun Bakım Dergisi* **10**(1): 7-12.

Summary: IC: M-CAiOVX (GE Healthcare): This prospective study evaluated multiple predictive equations compared to indirect calorimetry measurements in mechanically ventilated critically ill patients. In total, 114 patients were evaluated. All of the predictive equations showed moderate correlation among themselves ($P < 0.05$). The Harris- Benedict and Penn State equations showed the better agreement with IC, compared to other equations. The authors concluded: "Predictive equations are not reliable in determining EE; the confidence intervals are very high and can lead to inadequate feeding or overfeeding."

Tah, P. C., V. R. Hakumat-Rai, B. K. Poh, M. B. Mat Nor, H. Abdul Majid, C. C. Kee, M. K. Zaman, Z. Y. Lee and M. S. Hasan (2019). "MON-PO621: Validity of Predictive Equations for Estimation of Resting Energy Expenditure Among Mechanically Ventilated Critically Ill Patients at Different Phases of Critical Illness." *Clinical Nutrition* **38**: S289-S290.

Summary: This study evaluated predictive equations compared to indirect calorimetry in critically ill patients amongst Southeast Asian populations. Comparison methodology was applied during the acute, late and chronic phases of the ICU stay. In the acute phase, the Penn State equation showed the highest level of agreement. During the late phase, the Brandi equation was the best, and during the chronic phase, the Faisy equation had the highest agreement. Based on the Bland-Altman test, good agreement was also observed between REE-PE and REE-IC, which was characterized by a narrow interval.

Tah, P. C., Z.-Y. Lee, B. K. Poh, H. Abdul Majid, V.-R. Hakumat-Rai, M. B. Mat Nor, C. C. Kee, M. Kamarul Zaman and M. S. Hasan (2020). "A Single-Center Prospective Observational Study Comparing Resting Energy Expenditure in Different Phases of Critical Illness: Indirect Calorimetry Versus Predictive Equations." *Critical Care Medicine* **48**(5): e380-e390.

Summary: This single center prospective observational study evaluated REE during different phases of critical illness. The main evaluation was accuracy of predictive equations compared to indirect calorimetry. In brief, none of the resting energy expenditure calculations from predictive equations showed very good agreement or accuracy.

Tamura, T., T. Yatabe and M. Yokoyama (2019). "Energy expenditure measured using indirect calorimetry after elective cardiac surgery in ventilated postoperative patients: A prospective observational study." *Clinical Nutrition Experimental* **24**: 15-23.

Summary: IC: CARESTATION Engstrom ventilator (GE Healthcare): This study evaluated REE in patients undergoing cardiac surgery during the post-operative period. This prospective observational study enrolled 47 patients. Bland-Altman analysis was conducted. The mean difference was 116.6 kcal/day between REE measured and REE estimated by Harris-Benedict. Secondary analysis determined no significant difference in REE between on-pump and off-pump groups.

Tan, J., et al. (2018). "Pilot experience with use of continuous indirect calorimetry in ICU." **37**: S53.

Summary: This pilot study evaluated the GE Healthcare R860 ventilator for determining REE. The technology was easy to use by staff. REE was not affected by time of day and therefore measurement can be obtained daily.

Taylor, B. E., et al. (2016). "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.)." *Crit Care Med* **44**(2): 390-438.

Summary: ASPEN Guidelines provide several key recommendations:

- 1) Based on expert consensus, determine nutrition risk on all patients admitted to the ICU for whom volitional intake is anticipated to be insufficient.
- 2) Use indirect calorimetry (IC) to determine energy requirements when available and in the absence of variables that affect the accuracy of measurement.

Use cases highlighted include sepsis, trauma and traumatic brain injury, burns and obesity in critical illness.

Teigen, L. M., et al. (2018). "Use of both quantitative and qualitative methods to improve assessment of resting energy expenditure equation performance in hospitalized adults."

Summary: A large amount of variability was observed with all estimated equations (EE). As the mean calorie level increased, the degree of under-estimation of EE worsened.

Tignanelli, C. J., A. G. Andrews, K. M. Sieloff, M. R. Pleva, H. A. Reichert, J. A. Wooley, L. M. Napolitano and J. R. Cherry-Bukowiec (2017). "Are Predictive Energy Expenditure Equations in Ventilating Surgery Patients Accurate?" *J Intensive Care Med*: 885066617702077.

Summary: This study compared the REE measured by IC with REE calculated using specific calorie goals or predictive equations for nutritional support in ventilated adult SICU patients. 419 patients were evaluated in this retrospective study. The HBE, 20, 25, and 30 kcal/kg/d estimates of REE were found to be inaccurate regardless of age, gender, or weight. The HBE and 20 kcal/kg/d underestimated REE, while 25 and 30 kcal/kg/d overestimated REE.

Tignanelli, C. J., et al. (2017). "Are Predictive Energy Expenditure Equations in Ventilating Surgery Patients Accurate?": 0885066617702077.

Summary: Prior studies suggest these equations frequently misjudge actual resting energy expenditure (REE) in medical and mixed intensive care unit (ICU) patients; however, their utility for surgical ICU (SICU) patients has not been fully evaluated. In SICU patients with nutrition requirements essential to recovery, REE was found to be inaccurate and IC measurement should be performed to guide clinicians in determining goal caloric requirements.

Uber, A., et al. (2018). "Preliminary observations in systemic oxygen consumption during targeted temperature management after cardiac arrest." **127**: 89-94.

Summary: Cardiac arrest patients receiving targeted temperature management were evaluated. Continuous VO_2 and VCO_2 measurements were obtained with the GE Healthcare CARESCAPE™ B650 monitor and the CARESCAPE E-sCOVX respiratory module. In a post-hoc analysis of the first 12 hours after return of spontaneous circulation, VO_2 was associated with survival (median VO_2 in survivors 3.35 mL/kg/min [2.98, 3.88] vs. non-survivors 2.61 mL/kg/min $p=0.039$). There was no cut-off value for VO_2 that differentiated survivors and non-survivors. There was no association between VCO_2 and survival. The RQ was higher in survivors -- patients whose first measured RQ was <0.7 had a survival rate of 17%, compared to 64% in patients whose initial RQ was ≥ 0.7 . Venous hyperoxia may offer future prognostic benefit in this population - venous hyperoxia as a state in which central venous oxygen saturation remains elevated despite low-to-normal cardiac output suggests a cellular inability to utilize oxygen and portends a poor prognosis.

van Zanten, A. R. H., E. De Waele and P. E. Wischmeyer (2019). "Nutrition therapy and critical illness: practical guidance for the ICU, post-ICU, and long-term convalescence phases." *Crit Care* **23**(1): 368.

Summary: This review article summarizes the latest scientific insights and guidelines on ICU nutrition delivery. Specifically, the article provides practical guidance on the delivery of optimal nutrition during the three phases of the patient journey.

Vasileiou, G., M. B. Mulder, S. Qian, R. Iyengar, L. M. Gass, J. Parks, E. Lineen, P. Byers and D. D. Yeh (2020). "Continuous Indirect Calorimetry in Critically Injured Patients Reveals Significant Daily Variability and Delayed, Sustained Hypermetabolism." *JPEN J Parenter Enteral Nutr* **44**(5): 889-894.

Summary: IC: E-sCOVX or E-COVX (GE Healthcare): This study evaluated the use of continuous indirect calorimetry over a two-week period among trauma patients in the ICU. Data from multiple 10-minute periods was collected daily during steady state and was used to calculate REE daily maximum, REE daily minimum, REE daily average and REE variability. 55 patients comprised the final analysis, the majority with blunt injuries (69%). A 25% increase in average REE was noted on Day 7 that was sustained through Day 14. The authors concluded: "Isolated REE measurements may not accurately reflect the true metabolic requirements (especially during early hospitalization), and continuous REE measurements, if available, are recommended for capturing the variations of metabolism as they occur on a day-to-day basis."

Vasileiou, G., S. Qian, R. Iyengar, M. B. Mulder, L. M. Gass, J. Parks, G. D. Pust, R. Rattan, E. Lineen, P. Byers and D. D. Yeh (2019). "Use of Predictive Equations for Energy Prescription Results in Inaccurate Estimation in Trauma Patients." *Nutrition in Clinical Practice* **35**(5): 927-932.

Summary: CARESCAPE R860 with integrated IC: This study of 55 mechanically ventilated trauma ICU patients showed that predictive equations (e.g. Harris-Benedict) overestimated REE compared to IC. On the first day of REE measurement, overestimation was 26%; over seven days, the overestimation was 13%, and at 14 days, the overestimation remained greater than IC at 7%. The study concluded that "The use of weight-based equations and formulas fails to account for the continuous metabolic changes that occur in this population during the first days after injury."

Veldscholte, K., S. Verbruggen, D. Kerklaan, L. Langouche, I. Vanhorebeek, G. Van Den Berghe and K. Joosten (2020). "The usefulness of the respiratory quotient as a non-invasive marker of under- or overfeeding." *Clinical Nutrition ESPEN* **40**: 443.

Summary: Secondary analysis was conducted in the PEPaNIC RCT where 131 patients' reliable IC measurements were within the timeframe of analysis. Day 3 was selected for analysis, and there was a positive correlation between energy intake/measured resting energy expenditure (EI/mREE), with indirect calorimetry determined RQ ($\rho=0.396$, $p<0.001$). Furthermore, the authors concluded that energy intake less than 90% of mREE may result in a fasting response that is reflected by an RQ < 0.80.

Vest, M. T., E. Newell, M. Shapero, P. McGraw, C. Jurkovitz, S. L. Lennon and J. Trabulsi (2019). "Energy balance in obese, mechanically ventilated intensive care unit patients." *Nutrition* **66**: 48-53.

Summary: IC: CCM Express (MedGraphics): This prospective cohort-controlled study evaluated predictive versus indirect calorimetry-measured energy requirements in obese, critically ill patients. In total, 25 patients had REE measurements obtained, spanning a BMI range of 30-50 kg/m². The mean predicted energy requirement was 1,227 kcal/day, compared with a mean measured target energy requirement of 1,691 kcal/day. The results showed that predictive equations consistently underestimated REE in this obese patient population.

Weintraub, V., F. B. Mimouni and S. Dollberg (2007). "Changes in energy expenditure in preterm infants during weaning: a randomized comparison of two weaning methods from an incubator." *Pediatr Res* **61**(3): 341-344.

Summary: IC: Deltatrac II (GE Healthcare): In this study, 42 preterm infants were assessed in an RCT with one of two weaning methods to assess the impact on REE. REE increased significantly at the time an infant was weaned from the incubator, regardless of weaning method. A comparison of the six infants who failed weaning with the 36 that had a successful weaning from the incubator revealed that mode of weaning was not significantly influential (two failures/19 infants (10.5%) in the warming bassinet group versus 4/23 (17.4%) in the incubator group, $p=0.67$). Baseline REE was almost significantly lower ($p=0.06$) in the failed group (219 ± 11 kJ/kg/d) than in the successful group (236 ± 7 kJ/kg/d).

Wen-Yi, C., et al. (2017). "PT07. 3: The Clinical Outcomes and Medical Costs in Chronic Obstructive Pulmonary Disease Patients on Prolonged Mechanical Ventilation with and without Malnutrition." **36**: S44.

Summary: In patients with chronic obstructive pulmonary disease on prolonged mechanical ventilation, malnutrition was associated with worse clinical outcomes: increased mortality rate and 30-day readmission rates. In addition, hospital charges were 1.7 greater in the malnutrition cohort.

Wen-Yi, C., *et al.* (2017). "PT07.4: The Clinical Outcomes and Medical Costs in Non-Dialysis Chronic Kidney Disease Patients with and without Malnutrition." *Clinical Nutrition* **36**: S44-S45.

Summary: In patients with non-dialysis chronic kidney disease, malnutrition was associated with worse clinical outcomes: increased mortality rate and 30-day readmission rates.

Whittle, J., J. Molinger, D. MacLeod, K. Haines and P. E. Wischmeyer (2020). "Persistent hypermetabolism and longitudinal energy expenditure in critically ill patients with COVID-19." *Critical care (London, England)* **24**(1).

Summary: IC: Q-NRG (Cosmed/Baxter): In this research letter, the authors evaluated EE via IC in preliminary results from the LEEP-COVID study. Data from 22 patients was evaluated with mREE to range between 15-20 kcal/kg/d. Increasing hypermetabolism and wider variability in mREE was observed following the first week in the ICU stay and persisted during the third ICU week.

Wise, A. K., K. A. Hromatka and K. R. Miller (2019). "Energy Expenditure and Protein Requirements Following Burn Injury." *Nutrition in Clinical Practice* **34**(5): 673-680.

Summary: This review article focuses on the energy expenditure associated with burn patients. The authors state, "Following transition from the resuscitative phase, IC remains the standard with regard to determination of caloric requirements."

Yatabe, T. (2019). "Strategies for optimal calorie administration in critically ill patients." *Journal of Intensive Care* **7**(1).

Summary: This review article outlines the use of indirect calorimetry in critically ill patients and the strategies required for optimal calorie administration.

Yoshimura, S., *et al.* (2015). "A short period of fasting before surgery conserves basal metabolism and suppresses catabolism according to indirect calorimetry performed under general anesthesia." *J Anesth* **29**(3): 453-456.

Summary: The authors' findings suggest that a short period of fasting (<8 h) before surgery is more strongly associated with the conservation of basal metabolism.

Yu, P.-J., H. Cassiere, K. Bocchieri, S. DeRosa, S. Yar and A. Hartman (2020). "Hypermetabolism in critically ill patients with COVID-19 and the effects of hypothermia: A case series." *Metabolism open* **7**: 100046.

Summary: IC: CCM-Express (MGC Diagnostics): This study involved a limited case series of COVID-19 patients with respiratory failure and managed with hypothermia. Indirect calorimetry was used to measure the magnitude of the hypermetabolic state. In total, four cases were illustrated and consistently showed the presence of a hypermetabolic state. The use of hypothermia may attenuate some of this metabolic stress – mild hypothermia decreased REE on average of 27% and led to decreases in VCO₂ and VO₂ of 29.2% and 25.7%, respectively.

Zhang, J., Y. Q. Cui, Z. M. Ma Md, Y. Luo, X. X. Chen and J. Li (2019). "Energy and Protein Requirements in Children Undergoing Cardiopulmonary Bypass Surgery: Current Problems and Future Direction." *Journal of Parenteral and Enteral Nutrition* **43**(1): 54-62.

Summary: This review article addresses energy and protein requirements in children undergoing cardiopulmonary bypass surgery. Topics addressed include poor preoperative nutritional status, difficulty in assessing nutrition, lack of studies measuring REE following cardiopulmonary bypass, and protein requirements in these patients.

Zusman, O., *et al.* (2016). "Resting energy expenditure, calorie and protein consumption in critically ill patients: a retrospective cohort study." *Crit Care* **20**(1): 367.

Summary: This study, the largest retrospective study (n=6994) completed using indirect calorimetry as opposed to predictive equations to determine energy requirements in mechanically ventilated, critically ill patients, demonstrated a non-linear, significant association between the percent Administered Calories/REE and mortality by 60 days. The findings suggest that both underfeeding and overfeeding appear to be harmful to mechanically ventilated, critically ill patients. Intuitively, achieving a goal of 100 % calories administered would be optimal; in fact, the ideal goal for calories administered with the most favorable survival was achieved at 70%.

Zusman, O., *et al.* (2018). "Predictive equations versus measured energy expenditure by indirect calorimetry: A retrospective validation." *Clin Nutr*.

Summary: A retrospective study in ICU patients evaluating REE estimates compared to IC (Deltatrac) was conducted on 1,565 patients, for a total of 5,847 measurements. This is the largest study evaluating REE versus predictive equations. The results confirm what has been observed in many smaller studies as well as a systematic review, showing a large variability and poor accuracy of predictive equations. The level of accuracy never exceeded 50%.

ARTICLES BY YEAR OF PUBLICATION

Achamrah, N., M. Delsoglio, E. De Waele, M. M. Berger and C. Pichard (2021). "Indirect calorimetry: The 6 main issues." *Clinical Nutrition* **40**(1): 4-14.

Summary: This review article aims at informing and educating clinicians on the routine use of indirect calorimetry and how to interpret the results.

Bendavid, I., D. N. Lobo, R. Barazzoni, T. Cederholm, M. Coëffier, M. de van der Schueren, E. Fontaine, M. Hiesmayr, A. Laviano, C. Pichard and P. Singer (2021). "The centenary of the Harris-Benedict equations: How to assess energy requirements best? Recommendations from the ESPEN expert group." *Clinical Nutrition* **40**(3): 690-701.

Summary: This review article provides details around the evolution of the Harris-Benedict equation, which was first introduced over a century ago. This review details the accuracy of predictive equations and the relationship of predictive equations and indirect calorimetry. There is dedicated commentary on selected disease states/populations, including obese, elderly, cancer and surgical patients.

Guo, F., H. Zhou, J. Wu, Y. Huang, G. Lv, Y. Wu, H. Qiu, Y. Xu and Y. Yang (2021). "Prospective Study on Energy Expenditure in Patients With Severe Burns." *JPEN. Journal of parenteral and enteral nutrition* **45**(1): 146-151.

Summary: IC: Vmax Spectra 229 (SensorMedics): This prospective, multicenter study evaluated the burn-related changes in metabolism via IC measurements and compared the utility of predictive equations. 43 severe-burn patients were enrolled with a median APACHE II score 20 ± 2.5 , with body-surface burn involvement of 50-98%. The mean energy expenditure on the seventh day after severe burns was as high as 65 kcal/kg, which was 267% (range, 236% to 293%) of the basal metabolic rate (BMR). Prediction formulas were not precise in evaluating energy requirements in this hypermetabolic patient type.

Marra, M., R. Sammarco, I. Cioffi, D. Morlino, O. Di Vincenzo, E. Speranza and F. Pisanisi (2021). "New predictive equations for estimating resting energy expenditure in subjects with normal weight and overweight." *Nutrition* **84**: 111105.

Summary: IC: Vmax 29 and Vmax Encore (Sensor Medics): This study evaluated predictive equations to measure REE by leveraging bioimpedance analysis (BIA) in subjects with normal weight and overweight. The equation was developed and validated using data from 2,483 adult patients. The predictive equation was compared to IC. Compared to other predictive equations, this novel equation showed slightly improved accuracy when BIA was included (70.3% male, 72.3% female). The authors concluded that this predictive equation may serve as a viable alternative when indirect calorimetry measurements are not available.

Moonen, H., K. J. H. Beckers and A. R. H. van Zanten (2021). "Energy expenditure and indirect calorimetry in critical illness and convalescence: current evidence and practical considerations." *J Intensive Care* **9**(1): 8.

Summary: This review article details the use of IC in critical illness with a focus on the acute, chronic and convalescent phases of illness. The transitions between these three phases remain unidentifiable. The author illustrates a listing of on-market devices designed to perform IC measurements, including but not limited to Deltatrac, Quark RMR, E-COVX and CCM Express. The article reiterates that energy requirements are best determined via use of IC, rather than reliance on predictive equations, which can result in over- or under-feeding.

Silva, T. A., F. d. C. P. Maia, M. C. A. Zocrato, S. F. Mauricio, M. I. T. D. Correia and S. d. V. Generoso (2021). "Preoperative and Postoperative Resting Energy Expenditure of Patients Undergoing Major Abdominal Operations." *Journal of Parenteral and Enteral Nutrition* **45**(1): 152-157.

Summary: IC: Quark RMR (Cosmed): This study assessed REE after major abdominal procedures and its associated factors. In total, 54 patients were included in the analysis. There were no significant changes in REE at any of the assessed periods in the pre-operative or post-operative periods. There was a decrease in the RQ during the post-operative period when compared with the pre-operative assessment, accompanied by a decrease in carbohydrate oxidation and an increase in lipid oxidation.

Singer, P., E. De Waele, C. Sanchez, S. Ruiz Santana, J. C. Montejo, P. F. Laterre, A. Soroksky, E. Moscovici and I. Kagan (2021). "TICACOS international: A multi-center, randomized, prospective controlled study comparing tight calorie control versus Liberal calorie administration study." *Clinical nutrition (Edinburgh, Scotland)* **40**(2): 380-387.

Summary: IC: Deltatrac II, COVX (both GE Healthcare) and Quark (Cosmed): This follow-on to the compendium of TICACOS studies completed to date evaluated the impact of measuring daily REE and the impact on infection rates in critically ill patients. In total 332 patients were allocated into a control or study intervention arm; but the study failed to achieve the targeted enrollment numbers. The primary outcome of infection was not significantly decreased between the study and control groups. There was a trend for decreased hospital mortality in the study arm that did not reach statistical significance. The authors concluded, "these results together with other prospective randomized studies using indirect calorimetry might give a signal toward improved survival when patients' medical nutritional therapy is guided by indirect calorimetry."

Bruenderman, E. H., J. J. Webb and M. C. Bozeman (2020). "Burns as the Outlier in Early Enteral Nutrition in Critical Illness." *Current Surgery Reports* **8**(1).

Summary: This review article takes aim at the literature pertaining early enteral feeding in burn patients. The hypermetabolic response and inflammatory changes that result from severe burn injury are greater than those seen in any other disease process. The current literature reinforces the belief that early enteral nutrition improves outcomes after burn injury.

Cekici, H. and N. Acar Tek (2020). "Determining energy requirement and evaluating energy expenditure in neurological diseases." *Nutritional neuroscience* **23**(7): 543-553.

Summary: This review article describes the science around energy expenditure across sundry neurological conditions including Parkinson's disease, Alzheimer's disease, multiple sclerosis and others. In general, a consensus is lacking on the optimal means to assess nutritional requirements in this subset of critically ill patients.

Cordoza, M., L.-N. Chan, E. Bridges and H. Thompson (2020). "Methods for Estimating Energy Expenditure in Critically Ill Adults." *AACN Advanced Critical Care* **31**(3): 254-264.

Summary: This review article looks at methods of evaluating EE in critically ill adults and the benefits and limitations of each method, with practical considerations for use.

De Waele, E., J. Demol and J. Jonckheer (2020). "Resting energy expenditure measured by indirect calorimetry: Ventilated Covid-19 patients are normometabolic." *Clinical Nutrition ESPEN* **40**: 631-632.

Summary: This limited study evaluated IC in the management of COVID-19 patients. In total, 6 patients were evaluated with a total of 19 measurements between day 1 and day 26. The mean REE was 2,021 kcal/day (21 kcal/kg/day). Contrary to other observations, there was no evidence of ebb and flood phases.

De Waele, E., M. L. N. G. Malbrain and H. Spapen (2020). "Nutrition in Sepsis: A Bench-to-Bedside Review." *Nutrients* **12**(2).

Summary: This review article discusses the nutritional principles involved in management of patients with sepsis. It also covers practical recommendations pertaining to all aspects of nutritional therapy in the setting of sepsis.

Di Filippo, L., R. De Lorenzo, M. D'Amico, V. Sofia, L. Roveri, R. Mele, A. Saibene, P. Rovere-Querini and C. Conte (2020). "COVID-19 is associated with clinically significant weight loss and risk of malnutrition, independent of hospitalisation: A post-hoc analysis of a prospective cohort study." *Clin Nutr.*

Summary: This study does not have implications pertaining indirect calorimetry or energy expenditure determinations. However it serves as a foundation to understand that COVID-19 infected patients are at risk of malnutrition. The study illustrated that nearly 30% of patients lost >5% of baseline body weight and more than half were at risk of malnutrition; this finding was independent of hospitalization.

Diehl, J. L., N. Peron, R. Chocron, B. Debuc, E. Guerot, C. Hauw-Berlemont, B. Hermann, J. L. Augy, R. Younan, A. Novara, J. Langlais, L. Khider, N. Gendron, G. Goudot, J. F. Fagon, T. Mirault and D. M. Smadja (2020). "Respiratory mechanics and gas exchanges in the early course of COVID-19 ARDS: a hypothesis-generating study." *Ann Intensive Care* **10**(1): 95.

Summary: IC: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): This study evaluated the respiratory mechanics and gas exchange associated with COVID-19 infected patients with ARDS. A total of 22 patients were evaluated, and gas exchange was characterized by hypercapnia and high physiological dead space. The ventilatory ratio was 2.9.

Hoeyer-Nielsen, A. K., M. J. Holmberg, A. V. Grossestreuer, T. Yankama, J. P. Branton, M. W. Donnino and K. M. Berg (2020). "Association Between the Oxygen Consumption: Lactate Ratio and Survival in Critically Ill Patients With Sepsis." *Shock*.

Summary: This retrospective study evaluated a prospective sepsis study in which VCO_2 and VO_2 were measured continuously for 48 hours to find out whether any association with survival could be determined. The VO_2 : lactate ratio was significantly higher in survivors. There was a significant difference in VCO_2 change over time between survivors (+11.6%) and non-survivors (-8.3%, $p=0.03$). No association was found between median VO_2 and survival.

Jhang, W. K. and S. J. Park (2020). "Energy Expenditure in Mechanically Ventilated Korean Children: Single-Center Evaluation of a New Estimation Equation." *Pediatric Critical Care Medicine Publish Ahead of Print* **(8)**: e522-e529.

Summary: This study aimed at developing a novel energy expenditure equation compared to EE measured via IC. This predictive equation performs better than other equations used. There is a need to further validate the use of this equation in pediatric ICU patients.

Koekkoek, W. A. C., G. Xiaochen, D. van Dijk and A. R. H. van Zanten (2020). "Resting energy expenditure by indirect calorimetry versus the ventilator- VCO_2 derived method in critically ill patients: The DREAM- VCO_2 prospective comparative study." *Clinical Nutrition ESPEN* **39**: 137-143.

Summary: IC: Quark RMR (Cosmed); VCO_2 : Hamilton-S1 mechanical ventilator, Hamilton Medical AG): This study compared energy expenditure via measurement of expired gases (EE VCO_2) against the reference standard of indirect calorimetry in a prospective observational study involving critically ill patients. EE VCO_2 was derived from CO_2 using an adjusted version of Weir's equation, and RQ estimated at 0.86. In total, 31 patients were included for analysis. The mean EE VCO_2 was 2,134 kcal/d compared to a mean EE from IC of 1,623 kcal/d. EE VCO_2 overestimated EE in 92.8% of cases and underestimated in 0.2% of cases. The authors concluded that predictive equations, albeit inaccurate, may even predict EE better compared with the EE VCO_2 method.

Lambell, K. J., O. A. Tatucu-Babet, L. A. Chapple, D. Gantner and E. J. Ridley (2020). "Nutrition therapy in critical illness: a review of the literature for clinicians." *Crit Care* **24**(1): 35.

Summary: This review article outlines nutritional therapy in the management of critically ill patients.

Lee, I. H., Y.-W. Kuo, F.-C. Lin, C.-W. Wu, J.-S. Jerng, P.-H. Kuo, J.-C. Cheng, Y.-C. Chien, C.-K. Huang and H.-D. Wu (2020). "Kinetics of oxygen uptake during unassisted breathing trials in prolonged mechanical ventilation: a prospective pilot study." *Scientific Reports* **10**(1): 14301.

Summary: GE Healthcare CARESCAPE Monitor B650 and Engström Carestation: This pilot study investigated the kinetics of VO_2 during unassisted breathing trials (UBT) in patients with prolonged mechanical ventilation. 49 patients were evaluated in a prospective observational trial. The median VO_2 increased significantly (from 235.8 to 298.2 ml/min; $P = 0.025$) in the failure group, but there was no significant change in the success group (from 223.1 to 221.6 ml/min; $P = 0.505$). In multivariate logistic regression analysis, an increase in $\text{VO}_2 > 17\%$ from the beginning period and a peak inspiratory pressure greater than -30 cm H₂O were significantly associated with the success of 120-minute UBT. The authors concluded, "Our findings show the potential of monitoring VO_2 in the final phase of weaning in tracheostomized patients with prolonged mechanical ventilation.

Lee, S. J., H.-J. Lee, Y.-J. Jung, M. Han, S.-G. Lee and S.-K. Hong (2020). "Comparison of Measured Energy Expenditure Using Indirect Calorimetry vs Predictive Equations for Liver Transplant Recipients." *Journal of Parenteral and Enteral Nutrition* n/a(n/a).

Summary (IC: GE Healthcare, specific device not specified): In this study, commonly used predictive equations were compared to EE measured via IC in patients undergoing liver transplantation. The four predictive methods evaluated were the simple weight-based equation (25 kcal/kg/day, rule of thumb) and Harris-Benedict, Ireton-Jones (for ventilated patients), and Penn State 1988 equations. In total, 46 patients were evaluated. The predicted REE calculated using the Penn State 1988 method agreed with the measured REE. All four predictive equations showed a fixed bias and appeared to be inaccurate for predicting REE in this cohort of liver transplant recipients. The authors concluded that precise measurements using IC may be helpful when treating critically ill patients to avoid underestimating or overestimating their metabolic needs.

Li, G., C. L. Zhou, Y. M. Ba, Y. M. Wang, B. Song, X. B. Cheng, Q. F. Dong, L. L. Wang and S. S. You (2020). "Nutritional risk and therapy for severe and critical COVID-19 patients: A multicenter retrospective observational study." *Clin Nutr*.

Summary: The primary focus of this study was to evaluate nutritional metabolism in COVID-19 patients upon admission and to evaluate the prognostic value of nutrition screening tools. In total, 523 patients were studied, and 211 were managed in the ICU. The NUTRIC score can independently predict the risk of death in the hospital (OR = 1.197, $p = 0.006$) and high NRS-score patients have a higher risk of poor outcome in the ICU (OR = 1.880, $p = 0.012$). The authors observed that severe and critical patients with COVID-19 have a high risk of malnutrition. Furthermore, "Patients with low BMI and protein levels were significantly associated with adverse events."

Macdonald, I. A. (2020). "Editorial for Clinical Nutrition: Issues to consider when using ventilated hood indirect calorimetry to estimate energy expenditure and substrate utilisation." *Clinical nutrition (Edinburgh, Scotland)* **39**(6): 1643-1644.

Summary: This article is a point-counterpoint discussion based on an accompanying publication by Oshima that comments on the issues to consider when using a ventilated hood to measure EE with IC.

Mtaweh, H., C. Garros, A. Ashkin, L. Tuira, J. P. Allard, P. Pencharz, E. Pullenayegum, A. Joffe and C. S. Parshuram (2020). "An Exploratory Retrospective Study of Factors Affecting Energy Expenditure in Critically Ill Children." *Journal of Parenteral and Enteral Nutrition* **44**(3): 507-515.

Summary: This study in pediatric patients aimed to evaluate the factors available at the bedside and to determine any association with EE. IC was measured at this multicenter study with the Vmax Encore 29n metabolic cart (Vyaire medical). The authors identified significant associations between EE and factors representative of body size, cardiac output, minute ventilation, and administered sedatives. Future prospective evaluations are warranted to determine the true predictive nature of these variables.

Oliveira, A., C. C. de Oliveira, M. T. de Jesus, N. N. B. Menezes, F. N. de Gois, J. T. da Silva and L. M. Santos (2020). "Comparison of Equations to Predict Energy Requirements with Indirect Calorimetry in Hospitalized Patients." *Journal of Parenteral and Enteral Nutrition*.

Summary: IC: CCM Express (MedGraphics): This study evaluated the degree of agreement between the REE measurement via IC (REE-IC) and REE estimated by predictive equations in ICU patients. There was a significant difference in REE measured by IC as compared to predictive equations (Harris-Benedict and Ireton Jones).

Oshima, T., M. Delsoglio, Y. M. Dupertuis, P. Singer, E. De Waele, C. Veraar, C. P. Heidegger, J. Wernermann, P. E. Wischmeyer, M. M. Berger and C. Pichard (2020). "The clinical evaluation of the new indirect calorimeter developed by the ICALIC project." *Clin Nutr* **39**(10): 3105-3111.

Summary: This study evaluated the time required to obtain EE with use of Q-NRG[®] versus currently used ICs, including Deltatrac and E-COVX. The Q-NRG[®] required a much shorter time than most other ICs to determine EE in mechanically ventilated ICU patients. The authors concluded, "Q-NRG[®] is the only commercially available IC tested against mass spectrometry to ensure gas accuracy, while being very easy-to use."

Pelekhaty, S. L., C. L. Ramirez, J. M. Massetti, D. Gaetani, K. Riggan, G. Schwartzbauer and D. M. Stein (2020). "Measured vs Predicted Energy Expenditure in Mechanically Ventilated Adults With Acute, Traumatic Spinal Cord Injuries." *Nutrition in Clinical Practice*.

Summary: IC: Vmax 229 (SensorMedics): This study evaluated measured energy expenditure from indirect calorimetry versus predicted energy expenditure in critically ill patients with acute spinal cord injuries. A total of 115 IC studies were conducted in 51 patients. Penn State 2003b predicted within 10% of measured energy expenditure most frequently. All equations were biased toward overfeeding, except for PS 2003b in the obese subset. Therefore, in the absence of IC, the Penn State or the derived Weir equation may be acceptable predictive equations in this patient population.

Pereira-da-Silva, L., S. Barradas, A. C. Moreira, M. Alves, A. L. Papoila, D. Virella and G. Cordeiro-Ferreira (2020). "Evolution of Resting Energy Expenditure, Respiratory Quotient, and Adiposity in Infants Recovering from Corrective Surgery of Major Congenital Gastrointestinal Tract Anomalies: A Cohort Study." *Nutrients* **12**(10): 1-17.

Summary (IC: Deltatrac II): This study aimed at quantifying the evolution of REE, RQ, and adiposity of infants during the late anabolic phase after corrective surgery of major congenital gastrointestinal tract anomalies and to explore the determinants associated with these components of energy balance. 29 neonates were included for analysis, which included 15 pre-term infants. In total, 317 longitudinal calorimetry measurements were performed. In infants born pre-term, the median REE varied between 55.7 and 67.4 kcal/kg/day, and median RQ changed from 0.70 to 0.86-0.92 between 34 and 42 weeks. In infants born at term, the median REE varied between 57.3 and 67.9 kcal/kg/day while the median RQ increased from 0.63 to 0.84-0.88 from 38 to 44 weeks PMA (post-menopausal age).

Pereira-da-Silva, L., S. Barradas, A. C. Moreira, M. Alves, A. L. Papoila, D. Virella and G. Cordeiro-Ferreira (2020). "Evolution of Resting Energy Expenditure, Respiratory Quotient, and Adiposity in Infants Recovering from Corrective Surgery of Major Congenital Gastrointestinal Tract Anomalies: A Cohort Study." *Nutrients* **12**(10): 1-17.

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Popp, C. J., M. Butler, M. Curran, P. Illiano, M. A. Sevvick and D. E. St-Jules (2020). "Evaluating steady-state resting energy expenditure using indirect calorimetry in adults with overweight and obesity." *Clinical nutrition (Edinburgh, Scotland)* **39**(7): 2220-2226.

Summary: IC: Quark RMR (Cosmed): This study assessed the importance of attaining steady state while measuring EE via indirect calorimetry. This was a cross-over design with 63 total subjects enrolled with a mean BMI of 35 ± 5 kg/m². 54/63 (84%) were able to achieve 5-minute steady-state REE. Of note, lower thresholds of 4- and 3-minute steady state were practical alternatives to measuring REE.

Ridley, E. J., A. Tierney, S. King, E. Ainslie, A. Udy, C. Scheinkestel and I. Nyulasi (2020). "Measured Energy Expenditure Compared With Best-Practice Recommendations for Obese, Critically Ill Patients-A Prospective Observational Study." *JPEN. Journal of parenteral and enteral nutrition* **44**(6): 1144-1149.

Summary: IC: Quark RMR (Cosmed): This study evaluated EE in critically ill obese patients, comparing measured versus predicted EE. In addition, a comparison between measured EE and recommendations from the American Society for Parenteral and Enteral Nutrition (ASPEN) Guidelines was conducted. A total of 19 patients were evaluated, with a BMI range of 30.5 – 64.5 kg/m². Clinically significant variation was observed between measured EE, predictive estimates, and guideline recommendations at all time points in these patients.

Roebuck, N., C. P. S. Fan, A. Floh, Z. L. Harris and M. L. Mazwi (2020). "A Comparative Analysis of Equations to Estimate Patient Energy Requirements Following Cardiopulmonary Bypass for Correction of Congenital Heart Disease." *JPEN. Journal of parenteral and enteral nutrition* **44**(3): 444-453.

Summary: This study used a novel method to determine REE in pediatric patients following cardiopulmonary bypass for repair of congenital heart disease. IC was measured leveraging respiratory mass spectrometry (AMIS 2000, Innovision A/S). In total, 107 patients were evaluated with no predictive equation showing suitable accuracy compared to IC measurement of REE.

Schuijs, J. M., R. D. Eveleens, B. van der Hoven, P. L. M. Lakenman, J. van Bommel, D. A. M. P. J. Gommers, K. F. M. Joosten and J. F. Olieman (2020). "Feeding practises and REE in critically ill COVID-19 patients." *Clinical Nutrition ESPEN* **40**: 440.

Summary: (IC: Q-NRG+): This observational study evaluated REE during the acute (day 1-7) and late (>7 days) of critically ill mechanically ventilated patients with COVID-19. 35 patients were enrolled with 42 IC measurements performed (20 acute phase; 22 late phase). During the acute phase, the REE was 1,956 kcal and RQ 0.72. In the late phase, the REE was 2374 kcal with an RQ 0.81. During the acute phase, hypocaloric feeding (64% of REE) was noted, while normal caloric feeding (92% of REE) occurred predominantly during the late phase. This illustrated that during both phases of illness, the majority of COVID-19 patients were hypermetabolic

Serrano Valles, C., J. J. Lopez Gomez, S. Garcia Calvo, R. Jimenez Sahagun, B. Torres Torres, E. Gomez Hoyos, A. Ortola Buigues and D. de Luis Roman (2020). "Influence of nutritional status on hospital length of stay in patients with type 2 diabetes." *Endocrinol Diabetes Nutr* **67**(10): 617-624.

Summary: This study evaluated the impact of diabetes on hospitalized patients and whether they had a poorer nutritional status. This transverse study involved 1,017 patients between 2014 and 2016.

Singer, P., C. Pichard and E. De Waele (2020). "Practical guidance for the use of indirect calorimetry during COVID 19 pandemic." *Clinical Nutrition Experimental* **33**: 18-23.

Summary: This review article provides practical guidance to healthcare professionals in the management of patients with COVID-19. This includes practical guidance in the use of the QNRG+ (Cosmed) and E-sCOVX/E-sCAiOVX (GE Healthcare).

Singer, P., C. Pichard and S. Rattanachaiwong (2020). "Evaluating the TARGET and EAT-ICU trials: how important are accurate caloric goals? Point-counterpoint." *Current Opinion in Clinical Nutrition and Metabolic Care* **23**(2): 91-95.

Summary: Controversies about the adequate amount of energy to deliver to critically ill patients continue, and trying to find if a hypocaloric or normocaloric regimen is beneficial in this population. The authors reviewed recent studies in which indirect calorimetry was and was not used.

Smetana, K. S., Y. Hannawi and C. C. May (2020). "Indirect Calorimetry Measurements Compared With Guideline Weight-Based Energy Calculations in Critically Ill Stroke Patients." *JPEN. Journal of parenteral and enteral nutrition*.

Summary: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): The energy requirements of neuro-critical care patients are largely unknown. This study in critically ill stroke patients evaluated the energy requirements during the acute disease process. In this single-center, retrospective, observational study, IC was obtained at the baseline of the critical-care journey and low-weight and high-weight-based energy estimates were compared. The low-weight-based group was significantly lower than the REE target measured by IC, while high-weight-based group was similar to IC REE targets. Linear regression analysis showed that weight, height, and hemorrhagic stroke subtype were associated with IC.

Tah, P. C., Z.-Y. Lee, B. K. Poh, H. Abdul Majid, V.-R. Hakumat-Rai, M. B. Mat Nor, C. C. Kee, M. Kamarul Zaman and M. S. Hasan (2020). "A Single-Center Prospective Observational Study Comparing Resting Energy Expenditure in Different Phases of Critical Illness: Indirect Calorimetry Versus Predictive Equations." *Critical Care Medicine* **48**(5): e380-e390.

Summary: This single center prospective observational study evaluated REE during different phases of critical illness. The main evaluation was accuracy of predictive equations compared to indirect calorimetry. In brief, none of the resting energy expenditure calculations from predictive equations showed very good agreement or accuracy.

Vasileiou, G., M. B. Mulder, S. Qian, R. Iyengar, L. M. Gass, J. Parks, E. Lineen, P. Byers and D. D. Yeh (2020). "Continuous Indirect Calorimetry in Critically Injured Patients Reveals Significant Daily Variability and Delayed, Sustained Hypermetabolism." *JPEN J Parenter Enteral Nutr* **44**(5): 889-894.

Summary: IC: E-sCOVX or E-COVX (GE Healthcare): This study evaluated the use of continuous indirect calorimetry over a two-week period among trauma patients in the ICU. Data from multiple 10-minute periods was collected daily during steady state and was used to calculate REE daily maximum, REE daily minimum, REE daily average and REE variability. 55 patients comprised the final analysis, the majority with blunt injuries (69%). A 25% increase in average REE was noted on Day 7 that was sustained through Day 14. The authors concluded: "Isolated REE measurements may not accurately reflect the true metabolic requirements (especially during early hospitalization), and continuous REE measurements, if available, are recommended for capturing the variations of metabolism as they occur on a day-to-day basis."

Veldscholte, K., S. Verbruggen, D. Kerklaan, L. Langouche, I. Vanhorebeek, G. Van Den Berghe and K. Joosten (2020). "The usefulness of the respiratory quotient as a non-invasive marker of under- or overfeeding." *Clinical Nutrition ESPEN* **40**: 443.

Summary: Secondary analysis was conducted in the PEPaNIC RCT where 131 patients' reliable IC measurements were within the timeframe of analysis. Day 3 was selected for analysis, and there was a positive correlation between energy intake/measured resting energy expenditure (EI/mREE), with indirect calorimetry determined RQ ($\rho=0.396$, $p<0.001$). Furthermore, the authors concluded that energy intake less than 90% of mREE may result in a fasting response that is reflected by an RQ < 0.80.

Whittle, J., J. Molinger, D. MacLeod, K. Haines and P. E. Wischmeyer (2020). "Persistent hypermetabolism and longitudinal energy expenditure in critically ill patients with COVID-19." *Critical care (London, England)* **24**(1).

Summary: IC: Q-NRG (Cosmed/Baxter): In this research letter, the authors evaluated EE via IC in preliminary results from the LEEP-COVID study. Data from 22 patients was evaluated with mREE to range between 15-20 kcal/kg/d. Increasing hypermetabolism and wider variability in mREE was observed following the first week in the ICU stay and persisted during the third ICU week.

Yu, P.-J., H. Cassiere, K. Bocchieri, S. DeRosa, S. Yar and A. Hartman (2020). "Hypermetabolism in critically ill patients with COVID-19 and the effects of hypothermia: A case series." *Metabolism open* **7**: 100046.

Summary: IC: CCM-Express (MGC Diagnostics): This study involved a limited case series of COVID-19 patients with respiratory failure and managed with hypothermia. Indirect calorimetry was used to measure the magnitude of the hypermetabolic state. In total, four cases were illustrated and consistently showed the presence of a hypermetabolic state. The use of hypothermia may attenuate some of this metabolic stress – mild hypothermia decreased REE on average of 27% and led to decreases in VCO₂ and VO₂ of 29.2% and 25.7%, respectively.

Ang, D., R. Chari, A. Garcia, J. Clark, J. Farrah, J. Hagan, C. Watson, W. Richards, H. Liu, D. Donaldson, J. Barde and T. Alderman (2019). "Optimizing energy expenditure and oxygenation toward ventilator tolerance is associated with lower ventilator and intensive care unit days." *J Trauma Acute Care Surg* **87**(3): 559-565.

Summary: IC: CARESCAPE R860 ventilator with E-sCOVX respiratory module (GE Healthcare): The hypothesis of this study was that if both EE and oxygenation are optimized toward ventilator tolerance (RQ = 0.7 to 1.0); this would provide patients with the best condition to be liberated from the ventilator. In this single-center prospective study of trauma patients requiring mechanical ventilation, 1,090 patients were included in a primary analysis of ventilator days between the intervention arm and historical controls. The primary outcome favored the intervention arm by approximately three days. In this study, all patients achieved the RQ goal (between 0.7-1.0) and over 95% met their REE nutritional goal.

Baek, J. K., S. J. Lee, H. J. Lee, Y. J. Jung and S. K. Hong (2019). "OR04: Assessing the Appropriate Energy Expenditure Requirement Using Indirect Calorimetry for Liver Transplant Recipients." *Clinical Nutrition* **38**: S5-S6.

Summary: This study compared predictive equations with indirect calorimetry to identify the appropriate energy expenditure requirement of liver transplant recipients. 46 patients were enrolled, and the REE with the strongest agreement was the Penn State 1988 equation (65%) followed by the Harris-Benedict method (56%, $P < 0.001$). All three predictive equations evaluated showed unsatisfactory agreement with measured REE.

Barrocas, A. (2019). "Demonstrating the Value of the Nutrition Support Team to the C-Suite in a Value-Based Environment: Rise or Demise of Nutrition Support Teams?" *Nutr Clin Pract* **34**(6): 806-821.

Summary: This review article focuses on the economic impacts associated with the use of nutrition support teams.

Berger, M. M. and C. Pichard (2019). "Feeding should be individualized in the critically ill patients." *Current opinion in critical care* **25**(4): 307-313.

Summary: An excerpt from the abstract of this review article states, "Accurate and repeated indirect calorimetry is becoming possible thanks to the recent development of a reliable, easy-to-use and affordable indirect calorimeter. The optimal timing of the prescription of the measured energy expenditure values as a goal remains to be determined. Optimal protein prescription remains difficult as no clinically available tool has yet been identified reflecting the body needs."

Delsoglio, M., N. Achamrah and M. M. Berger (2019). "Indirect Calorimetry in Clinical Practice." *Journal of Clinical Medicine* **8**(9): 1387.

Summary: This review article serves as a refresher that details the practicalities of IC implementation and illustrates the limitations of its use. The article discusses alternative methods to IC.

Doley, J. and W. Phillips (2019). "Coding for Malnutrition in the Hospital: Does It Change Reimbursement?" *Nutr Clin Pract* **34**(6): 823-831.

Summary: This review article discusses the clinical and financial implications associated with protein calorie malnutrition (PCM).

Fabiano Alves, V. G., E. E. M. da Rocha, M. C. Gonzalez, R. B. Vieira da Fonseca and M. H. do Nascimento Silva (2019). "Resting Energy Expenditure Measured by Indirect Calorimetry in Obese Patients: Variation Within Different BMI Ranges." *Journal of Parenteral and Enteral Nutrition* **44**(1): 129-137.

Summary (IC: Deltatrac II): This study aimed to determine if there was an appreciable difference in REE in obese patients between the fasted and fed state. In total, 97 IC measurements were obtained from 63 patients during 2009 - 2012 with a BMI range of 27.3 to 53.4 kg/m². There was no difference in measured REE between fasted and fed states across three BMI groups (overweight, obese, morbidly obese). Additionally, there was a negative correlation between REE and progression of BMI from overweight through morbidly obese ($r = -0.35$, $p = 0.04$). The authors concluded that no method can be recommended to estimate REE in extremely obese patients given the risk of underestimating energy requirements.

Graham, J. and E. Goulette (2019). "Accurate determination of resting energy expenditure in the critically ill adult." *Critical Care Medicine* **47**(1).

Summary: This prospective evaluation of mechanically ventilated critically ill patients compared the PENN predictive equation to indirect calorimetry assessment of REE. A total of 21 patients were enrolled, and a statistically significant difference was noted between the predictive and measured REE, where PENN underestimated IC ($P < 0.001$). This study supports the growing evidence that use of predictive equations increases the risk of overfeeding.

Ismail, J., A. Bansal, M. Jayashree, K. Nallasamy and S. V. Attri (2019). "Energy Balance in Critically Ill Children With Severe Sepsis Using Indirect Calorimetry: A Prospective Cohort Study." *Journal of pediatric gastroenterology and nutrition* **68**(6): 868-873.

Summary: This study evaluated the daily energy balance in children with severe sepsis. IC was measured with the Quark RMR (Cosmed) metabolic cart. 40 patients were evaluated and the study demonstrated a persistent negative energy balance from days 1 to 7. Furthermore, a persistent negative nitrogen balance was observed from day 1 to 5. There also was poor agreement between predicted and measured REE. The authors concluded: "Predictive equations are inaccurate in estimating the REE in critically ill children with severe sepsis. IC remains the criterion standard for accurate assessment of energy intake, and it should be considered in all patients with metabolic disturbances."

Jakobsson, J., S. Vadman, E. Hagel, S. Kalman and E. Bartha (2019). "The effects of general anaesthesia on oxygen consumption: A meta-analysis guiding future studies on perioperative oxygen transport." *Acta Anaesthesiologica Scandinavica* **63**(2): 144-153.

Summary: Oxygen consumption (VO_2) can change in several ways in the perioperative period, but is seldom monitored directly in routine care. This study investigates the effects of general anesthesia on VO_2 .

- Twenty-four studies including 453 patients were analyzed for VO_2 changes induced by anesthesia. Studies were published during 1969-2000 and the mean age of patients ranged from 28 70 years. VO_2 decreased after anesthesia induction by -65 (-75 ; -55 , 95% CI) mL min $^{-1}$.
- This meta-analysis demonstrates that general anesthesia reduces the global oxygen consumption, but the exact size estimate and its distribution are uncertain.
- In all included studies, oxygen consumption was assessed either by breathing gas analysis, such as indirect calorimetry, or calculated by the reverse Fick method using thermodilution cardiac output by a pulmonary artery or right ventricle catheter.

The authors suggest that oxygen consumption be included in both observational studies and trials on hemodynamic optimization strategies in high-risk surgical patients and related outcomes. Preferably, oxygen consumption changes should be monitored continuously throughout the perioperative period. This requires monitoring methods with high time resolution feasible for pre-, intra- and post-operative settings, or reliable estimation methods.

Jeon, J., D. Kym, Y. S. Cho, Y. Kim, J. Yoon, H. Yim, J. Hur and W. Chun (2019). "Reliability of resting energy expenditure in major burns: Comparison between measured and predictive equations." *Clinical Nutrition* **38**(6): 2763-2769.

Summary: IC: Vmax 29 (Sensor-Medics): This study evaluated 215 patients with burns involving > 20% body surface area and involved a total of 418 IC measurements. The purpose of this study was to evaluate IC versus predictive equations for REE and to derive a new predictive equation (Hangang equation). The novel equation showed the highest level of correlation with calorimetry compared to the other predictive equations used. The Hangang equation is unique in that it considers time (post-burn days) and the ventilator status of the patient, while other predictive equations do not.

Kamel, A., L. Robayo, D. Liang, M. Rosenthal, S. Voils and P. Efron (2019). "Estimated versus measured energy expenditure in ventilated surgical trauma critically ill patients." *Critical Care Medicine* **47**(1).

Summary: This study evaluated the REE via predictive equations compared to indirect calorimetry in surgical trauma patients. A total of 10 predictive equations were used. 104 patients were analyzed. and the closest estimate to IC-REE was the modified Harris-Benedict equation ($r=0.6515$). The authors concluded that predictive equations offer limited effectiveness for estimating REE in this patient population.

Ławiński, M., M. K. Skroński, A. Ukleja, M. Andrzejewska, P. Nyckowski, M. Słodkowski, M. Theilla and P. Singer (2019). "MON-PO600: Indirect Calorimetry in Oncological Surgery Liver Patients – Comparison of Resting Energy Expenditure with Prediction Equations." *Clinical Nutrition* **38**: S281-S282.

Summary: This study evaluated the utility of predictive equations compared to calorimetry in patients undergoing liver resection surgery. In total, 100 patients were enrolled. There was no appreciable difference in the resting metabolic rate between Day 0 and Day 7 following surgery. If IC not available, the Mifflin formula offered the best correlation with IC during pre-surgery evaluation ($R=0.85$). However, there is no optimal predictive formula for REE evaluation for this surgical patient group.

Menegueti, M. G., T. R. de Araújo, A. M. Laus, O. A. Martins-Filho, A. Basile-Filho and M. Auxiliadora-Martins (2019). "Resting Energy Expenditure and Oxygen Consumption in Critically Ill Patients With vs Without Sepsis." *American Journal of Critical Care* **28**(2): 136-141.

Summary: This study evaluated whether REE, RQ and oxygen consumption and carbon dioxide production (measured by indirect calorimetry) differed between critically ill patients with and without sepsis. In total, 205 patients were evaluated with 91 (44%) having sepsis. Analysis of receiver operating characteristic curves showed no significant differences between patients with and without sepsis for any of the indirect calorimetry variables.

Mtaweh, H., M. J. Soto Agüero, M. Campbell, J. P. Allard, P. Pencharz, E. Pullenayegum and C. S. Parshuram (2019). "Systematic review of factors associated with energy expenditure in the critically ill." *Clinical nutrition ESPEN* **33**: 111-124.

Summary: This systematic literature review identified 103 articles included in analysis. In this analysis, 95 clinical factors were evaluated for association with EE in critically ill patients. Of note, groups of factors were significant in different patient populations. The data presented is expansive and beyond the scope of this summary.

Plauth, M., W. Bernal, S. Dasarathy, M. Merli, L. D. Plank, T. Schütz and S. C. Bischoff (2019). "ESPEN guideline on clinical nutrition in liver disease." *Clinical Nutrition* **38**(2): 485-521.

Summary: This item presents the ESPEN guidelines on clinical nutrition in liver disease. It spans acute liver failure, non-alcoholic fatty liver disease, liver cirrhosis, and liver surgery, plus transplantation.

Poulsen, M. K., L. P. Thomsen, S. Kjærgaard, S. E. Rees and D. S. Karbing (2019). "Reliability of, and Agreement Between, two Breath-by-Breath Indirect Calorimeters at Varying Levels of Inspiratory Oxygen." *Nutrition in Clinical Practice* **34**(5): 767-774.

Summary: IC: Beacon 3 (Mermaid Care, device 2) and ECOVX (GE Healthcare, device 1), reference method): This study investigated whether measurements of EE, VO_2 , and VCO_2 by breath-by-breath IC devices 1 and 2 were within-day reliable under conditions of varying FiO_2 , and whether the two systems measured in agreement. (Device 2 does not use the Haldane transformation). The study was conducted in 20 healthy male subjects and IC was measured while breathing through a ventilator facemask, conscious and sitting. Both systems measured EE, VO_2 , and VCO_2 at 21%–85% FiO_2 reliably, but with bias at 85% FiO_2 . The devices were in agreement at 21% and 50% FiO_2 , but further studies need to confirm accuracy at high FiO_2 .

Rattanachaiwong, S. and P. Singer (2019). "Indirect calorimetry as point of care testing." *Clinical Nutrition* **38**(6): 2531-2544.

Summary: This review article addresses the background and utility of indirect calorimetry with a special emphasis on point-of-care (POC) testing. Of note, POC does not refer to novel technologies that are portable (i.e. hand-held) but rather conventional technology that provides information to the clinician at the bedside.

Reneau, J., B. Obi, A. Moosreiner and S. Kidambi (2019). "Do we need race-specific resting metabolic rate prediction equations?" *Nutrition & Diabetes* **9**(1).

Summary: IC: Parvo TrueOne2400: This study aimed to evaluate racial impacts on REE between predictive and calorimetry-based measurements. A total of 114 healthy subjects were enrolled. The authors determined that the formula using height, weight, gender and age systematically overestimated REE and hence predicted higher caloric needs among African-American patients.

Ringel, J. B., D. Jannat-Khah, R. Chambers, E. Russo, L. Merriman and R. Gupta (2019). "Impact of gaps in care for malnourished patients on length of stay and hospital readmission." *BMC Health Serv Res* **19**(1): 87.

Summary: This study evaluated the presence of gaps in care that follow malnutrition diagnosis and their effects on length of stay and 90-day readmission. The hypothesis is that these gaps are associated with increased length of stay and increased readmission. A retrospective chart review was conducted by two registered dietitians, evaluating 22 malnourished patients. Gaps in care were categorized as related to communication, testing/procedure, and discharge. The average participant with any gap in care had a 2.5-day longer LOS compared to those without any gap. Of note, those with a testing/procedure gap had a 6-day increase in LOS.

Singer, P. (2019). "Preserving the quality of life: nutrition in the ICU." *Crit Care* **23**(Suppl 1): 139.

Summary: This review article focuses on nutrition therapy in the ICU, including the catabolic response to stress, energy requirements and prescription, and nutrition in recovery from critical illness.

Sungurtekin, H., S. Karakuzu and S. Serin (2019). "Energy Expenditure in Mechanically Ventilated Patients: Indirect Calorimetry vs Predictive Equations." *Dahili ve Cerrahi Bilimler Yoğun Bakım Dergisi* **10**(1): 7-12.

Summary: IC: M-CAiOVX (GE Healthcare): This prospective study evaluated multiple predictive equations compared to indirect calorimetry measurements in mechanically ventilated critically ill patients. In total, 114 patients were evaluated. All of the predictive equations showed moderate correlation among themselves ($P < 0.05$). The Harris-Benedict and Penn State equations showed the better agreement with IC, compared to other equations. The authors concluded: "Predictive equations are not reliable in determining EE; the confidence intervals are very high and can lead to inadequate feeding or overfeeding."

Tah, P. C., V. R. Hakumat-Rai, B. K. Poh, M. B. Mat Nor, H. Abdul Majid, C. C. Kee, M. K. Zaman, Z. Y. Lee and M. S. Hasan (2019). "MON-PO621: Validity of Predictive Equations for Estimation of Resting Energy Expenditure Among Mechanically Ventilated Critically Ill Patients at Different Phases of Critical Illness." *Clinical Nutrition* **38**: S289-S290.

Summary: This study evaluated predictive equations compared to indirect calorimetry in critically ill patients amongst Southeast Asian populations. Comparison methodology was applied during the acute, late and chronic phases of the ICU stay. In the acute phase, the Penn State equation showed the highest level of agreement. During the late phase, the Brandi equation was the best, and during the chronic phase, the Faisy equation had the highest agreement. Based on the Bland-Altman test, good agreement was also observed between REE-PE and REE-IC, which was characterized by a narrow interval.

Tamura, T., T. Yatabe and M. Yokoyama (2019). "Energy expenditure measured using indirect calorimetry after elective cardiac surgery in ventilated postoperative patients: A prospective observational study." *Clinical Nutrition Experimental* **24**: 15-23.

Summary: IC: CARESTATION Engstrom ventilator (GE Healthcare): This study evaluated REE in patients undergoing cardiac surgery during the post-operative period. This prospective observational study enrolled 47 patients. Bland-Altman analysis was conducted. The mean difference was 116.6 kcal/day between REE measured and REE estimated by Harris-Benedict. Secondary analysis determined no significant difference in REE between on-pump and off-pump groups.

van Zanten, A. R. H., E. De Waele and P. E. Wischmeyer (2019). "Nutrition therapy and critical illness: practical guidance for the ICU, post-ICU, and long-term convalescence phases." *Crit Care* **23**(1): 368.

Summary: This review article summarizes the latest scientific insights and guidelines on ICU nutrition delivery. Specifically, the article provides practical guidance on the delivery of optimal nutrition during the three phases of the patient journey.

Vasileiou, G., S. Qian, R. Iyengar, M. B. Mulder, L. M. Gass, J. Parks, G. D. Pust, R. Rattan, E. Lineen, P. Byers and D. D. Yeh (2019). "Use of Predictive Equations for Energy Prescription Results in Inaccurate Estimation in Trauma Patients." *Nutrition in Clinical Practice* **35**(5): 927-932.

Summary: CARESCAPE R860 with integrated IC: This study of 55 mechanically ventilated trauma ICU patients showed that predictive equations (e.g. Harris-Benedict) overestimated REE compared to IC. On the first day of REE measurement, overestimation was 26%; over seven days, the overestimation was 13%, and at 14 days, the overestimation remained greater than IC at 7%. The study concluded that "The use of weight-based equations and formulas fails to account for the continuous metabolic changes that occur in this population during the first days after injury."

Vest, M. T., E. Newell, M. Shapero, P. McGraw, C. Jurkovitz, S. L. Lennon and J. Trabulsi (2019). "Energy balance in obese, mechanically ventilated intensive care unit patients." *Nutrition* **66**: 48-53.

Summary: IC: CCM Express (MedGraphics): This prospective cohort-controlled study evaluated predictive versus indirect calorimetry-measured energy requirements in obese, critically ill patients. In total, 25 patients had REE measurements obtained, spanning a BMI range of 30-50 kg/m². The mean predicted energy requirement was 1,227 kcal/day, compared with a mean measured target energy requirement of 1,691 kcal/day. The results showed that predictive equations consistently underestimated REE in this obese patient population.

Yatabe, T. (2019). "Strategies for optimal calorie administration in critically ill patients." *Journal of Intensive Care* **7**(1).

Summary: This review article outlines the use of indirect calorimetry in critically ill patients and the strategies required for optimal calorie administration.

Wise, A. K., K. A. Hromatka and K. R. Miller (2019). "Energy Expenditure and Protein Requirements Following Burn Injury." *Nutrition in Clinical Practice* **34**(5): 673-680.

Summary: This review article focuses on the energy expenditure associated with burn patients. The authors state, "Following transition from the resuscitative phase, IC remains the standard with regard to determination of caloric requirements."

Zhang, J., Y. Q. Cui, Z. M. Ma Md, Y. Luo, X. X. Chen and J. Li (2019). "Energy and Protein Requirements in Children Undergoing Cardiopulmonary Bypass Surgery: Current Problems and Future Direction." *Journal of Parenteral and Enteral Nutrition* **43**(1): 54-62.

Summary: This review article addresses energy and protein requirements in children undergoing cardiopulmonary bypass surgery. Topics addressed include poor preoperative nutritional status, difficulty in assessing nutrition, lack of studies measuring REE following cardiopulmonary bypass, and protein requirements in these patients.

Bae, E., *et al.* (2018). "Increased energy expenditure using indirect calorimetry among acute phase patients in neurosurgical intensive care unit." **37**: S52.

Summary: This study evaluated IC measured using the CARESCAPE B650 compared to predictive equations in neurosurgical critically ill patients. Predictive equations were found to underestimate EE in both acute (<14 day LOS) neurosurgical patients, and to a lesser extent, in chronically ill (>14 day LOS) patients. IC should be used to assess EE in neurosurgical patients, notably during the acute phase of disease.

Berg, K. M., *et al.* (2018). "Looking for CO(2): Exploring the Novel Finding of Low Respiratory Quotient After Cardiac Arrest." *J Am Heart Assoc* **7**(13).

Summary: In this editorial in response to a rat-model published in the same journal, the author made extrapolations to human care in cardiac arrest. If accurate measurements can be obtained, however, bedside monitoring of VO₂, VCO₂, and RQ in post-arrest patients can reflect the state of aerobic cellular metabolism and mitochondrial function in real time. These parameters are both potential prognostic indicators and targets of treatment. Subsequent experiments can address whether the altered VO₂, VCO₂, and RQ relate to human recovery from cardiac arrest and explore the mechanisms behind the phenomena.

Chen, Y. H., *et al.* Comparison of the Metabolic Load in Patient Ventilated with Pressure Support Ventilation and Adaptive Support Ventilation Mode with the Same Minute Ventilation. A104. CRITICAL CARE: INVASIVE, NON-INVASIVE, CONVENTIONAL, AND NON-CONVENTIONAL VENTILATION IN ACUTE RESPIRATORY FAILURE: A2550-A2550.

Summary: The Engström CareStation was used to evaluate VO₂ and VCO₂ during pressure-support ventilation (PSV) and adaptive support ventilation (ASV). Metabolic load was significantly lower during ASV versus PSV, as were VO₂ and VCO₂. It is suggested that this lower metabolic load is the result of reduced work of breathing.

De Waele, E., *et al.* (2018). "Does the use of indirect calorimetry change outcome in the ICU? Yes it does." *Curr Opin Clin Nutr Metab Care* **21**(2): 126-129.

SUMMARY: Metabolic monitoring by indirect calorimetry is achieving a level in which it can be implemented in critical care practice. Evidence is available to prove that by guiding your nutritional therapy by measured values, it will change outcome of critically ill patients.

Summary: The highlights of this review article include:

- 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 devices. Agreement could exist on the fact that indirect calorimetry is needed to optimize nutritional therapy, which can improve patients' outcome.
- It is about time to consider nutritional therapy in the critically ill as a sort of 'medication' helping the healing process. As such, it might be beneficial to consider the four Ds of nutritional therapy in an analogy of how to deal with antibiotics and fluids: drug (type of feeding), dose (caloric and protein load), duration (when and how long) and de-escalation (stop enteral nutrition and/or parenteral nutrition when oral intake improves).
- In analogy to 'antibiotic stewardship,' the authors suggest coining the term 'nutrition stewardship.'

De Waele, E., *et al.* (2018). "The CoCoS trial: Caloric Control in Cardiac Surgery patients promotes survival, an interventional trial with retrospective control." *Clinical Nutrition* **37**(3): 864-869.

Summary: Malnutrition is an often overlooked comorbid condition in patients scheduled for cardiac surgery and affects 10-25% of patients. The patients are often considered to have higher in-hospital mortality, have increased length of intensive care and hospital stay, need longer antibiotic and vasopressor treatment and more frequently have positive blood cultures. IC was measured using Vmax™ Encore 29n. Targeted nutrition therapy conferred a survival benefit in female patients, but not in male patients. In addition, there were significantly fewer cardiac arrhythmias in males following surgery that were in the nutrition therapy group. The authors conclude that nutrition therapy can largely benefit elective cardiac surgery patients and deserves to be implemented as a standard-of-care supportive therapy in this setting.

Ebihara, T., *et al.* (2018). "Low energy expenditure among elderly patients in acute, sepsis." *Clinical Nutrition* **37**: S174.

Summary: REE is typically increased in septic patients, but it is unknown if that applies to the elderly (>65 yoa). Comparisons were made in REE (measured) and BEE (estimated) in the elderly and in control (<65 yoa) population. A BEE/REE < 80% was only observed in the elderly population. A BEE/REE > 120% was associated with a high likelihood of death (66.7% in elderly, 0% in controls). In summary, low energy expenditure was only observed in the elderly population and conferred a survival benefit.

Fetterplace, K., *et al.* (2018). "Targeted Full Energy and Protein Delivery in Critically Ill Patients: A Pilot Randomized Controlled Trial (FEED Trial)." *JPEN J Parenter Enteral Nutr.*

Summary: This pilot study looked at protocol-based care (volume target enteral feeding) versus the standard of care. No IC measurement was mentioned to support the protocol treatment arm. The results show that protocol-based feeding resulted in significant improvements in skeletal muscle mass. However, there were no differences in outcomes (mortality and LOS) between the two groups.

Graham, J. (2018). "Oxygen Consumption in Sepsis.", *University of San Diego*

Summary: This study (a dissertation) evaluated metabolics between septic and non-septic patients. There was a difference in oxygen consumption between the two groups of cases [VO_2 (t 3.919, p 0.001), VCO_2 (η = 608, p = 0.003), and lactate (η = 621, p = 0.003)]. The authors stated that future research is needed using larger samples to test predictive models for sepsis so that nurses can intervene to prevent the deterioration of these patients

Guillaume, M., N. Nicolas, E. Sandrine, J. Philippe and E. Guillaume (2018). "CO-68 Indirect calorimetry as a tool to assess the work of breathing in critically ill children." *Annals of Intensive Care* **8**(Proceedings of Réanimation 2018, the French Intensive Care Society International Congress).

Summary: In this study, work of breathing (WOB) was assessed via differing methods, and comparison was made to IC-based utility to assess WOB. Oxygen consumption obtained by IC was higher during the spontaneous breathing test as compared to conventional ventilation (3.8 [3.0–5.2] vs 3.6 [3.1–4.6] ml kg min) but not significantly. Changes in WOB as assessed by VO_2 were poorly correlated with measurements from esophageal pressure and electrical activity of the diaphragm. The authors concluded: "oxygen consumption measured by IC does not seem to be a reliable tool to assess work of breathing in mechanically ventilated children."

Jotterand Chaparro, C., *et al.* (2018). "Estimation of Resting Energy Expenditure Using Predictive Equations in Critically Ill Children: Results of a Systematic Review." *JPEN J Parenter Enteral Nutr* **42**(6): 976-986.

Summary: This meta analysis included 22 studies with 21 equations that estimate REE in children. Only six equations were evaluated by at least three studies in critically ill children; no equation predicted REE within $\pm 10\%$ of MEE in >50% of observations. The Schofield equations and Talbot tables were the least inaccurate of the predictive equations. The author concluded that there is an urgent need for a new validated IC measurement for pediatric ICU patients.

Kagan, I., *et al.* (2018). "Validation of carbon dioxide production (VCO_2) as a tool to calculate resting energy expenditure (REE) in mechanically ventilated critically ill patients: a retrospective observational study." *Crit Care* **22**(1): 186.

Summary: A retrospective observational study involving ventilated patients compared the REE derived from VCO_2 (REE- VCO_2) with the REE derived from IC (REE-IC). REE and RQ were calculated using the Weir equation. 497 measurements were conducted with a median of three measurements per patient. Results showed that there was wide variability without a consistent bias, suggesting that the VCO_2 measurement could widely under- and over-estimate REE. Therefore, REE via IC remains the best tool to estimate caloric needs.

Ladd, A. K., *et al.* (2018). "Preventing Underfeeding and Overfeeding: A Clinician's Guide to the Acquisition and Implementation of Indirect Calorimetry." *Nutr Clin Pract* **33**(2): 198-205.

Summary: In this quality improvement (QI) initiative around IC implementation in a PICU, 69% of measurements resulted in adjustments to energy delivery. 47% of energy prescriptions decreased by a mean of 27%, and 22% increased by a mean of 17%. The authors concluded that their QI initiative demonstrated the implementation and application of IC in the critically ill population and the ability to target energy provision to prevent energy imbalances.

Larsen, B. M. K., *et al.* (2018). "Can energy intake alter clinical and hospital outcomes in PICU?" *Clin Nutr ESPEN* **24**: 41-46.

Summary: This study aimed to determine the incidence of over- and under-feeding and to compare hospital outcomes between these feeding categories in children admitted to the PICU. It found that only 12% of critically ill children were appropriately fed, while 53% were overfed and 35% underfed. Those that were overfed had longer hospital and PICU LOS than those appropriately fed, while those that were underfed had shorter hospital and PICU LOS than those appropriately fed.

Moreira, E., *et al.* (2018). "Update on metabolism and nutrition therapy in critically ill burned patients."

Summary: This review article applicable to burn patients observed that calorie deficit, negative protein balance and antioxidant micronutrient deficiency after thermal injury have been associated with poor clinical outcomes. In this context, personalized nutrition therapy with early enteral feeding from the start of resuscitation is indicated.

Patkova, A., *et al.* (2018). "Prognostic value of respiratory quotients in severe polytrauma patients with nutritional support." *49*: 90-95.

Summary: This study aimed to evaluate the association between energy metabolism and prognosis in polytrauma patients. IC was performed on the fourth ICU day in order to evaluate the impact of EE on outcomes. RQ was significantly lower in fasted polytrauma patients than in those receiving nutritional support (parenteral nutrition). Significant association was demonstrated between ICU LOS and duration of mechanical ventilation for those receiving nutritional support.

Piot, J., *et al.* (2018). "An elevated respiratory quotient predicts complications after cardiac surgery under extracorporeal circulation: an observational pilot study." *J Clin Monit Comput*.

Summary: Following cardiac surgery, hyperlactatemia due to anaerobic metabolism is associated with an increase in both morbidity and mortality. Researchers previously found that an elevated respiratory quotient (RQ) predicted anaerobic metabolism. In the present study, the authors aimed to demonstrate that increased RQ is associated with poor outcomes following cardiac surgery. This was confirmed.

Satoh, D., *et al.* (2018). "Effects of intraoperative nutrients administration on energy expenditure during general anesthesia." *Nutrition* **45**: 37-40.

Summary: This study explored the physiological benefits of the administration of exogenous nutrients during general anesthesia. Recent reports have indicated that intraoperative infusions of glucose and amino acids exert anticatabolic effects. IC was measured with the GE Healthcare E-COVX module. The number of days of intubation and the length of the ICU stay did not differ among the three patient groups studied. The lengths of hospital stay were shorter in the groups receiving intraoperative glucose and amino acids, compared to the control group. Additionally, these results indicate that the infusion of glucose and amino acids during general anesthesia increases REE and exerts a thermogenic effect.

Stapel, S. N., *et al.* (2018). "Indirect calorimetry in critically ill mechanically ventilated patients: Comparison of E-sCOVX with the deltatrac." *Clin Nutr*.

Summary: In this prospective study with Deltatrac and E-sCOVX, measurements of energy expenditure (EE) in critically ill, mechanically ventilated patients were performed simultaneously. Mean EE-E-sCOVX was higher than EE-Deltatrac, with a bias of 235 ± 149 kcal/day, corresponding to a percentage error of 12.1% of the reference method. EE, VCO_2 and VO_2 measured by E-sCOVX and Deltatrac were significantly correlated. RQ was not. The authors concluded –that the E-sCOVX is not accurate and its use is therefore not recommended in critically ill patients. Because maintenance of the Deltatrac is no longer supported, there is a need for a new and reliable device.

Tan, J., *et al.* (2018). "Pilot experience with use of continuous indirect calorimetry in ICU." **37**: S53.

Summary: This pilot study evaluated the GE Healthcare R860 ventilator for determining REE. The technology was easy to use by staff. REE was not affected by time of day and therefore measurement can be obtained daily.

Teigen, L. M., *et al.* (2018). "Use of both quantitative and qualitative methods to improve assessment of resting energy expenditure equation performance in hospitalized adults."

Summary: A large amount of variability was observed with all estimated equations (EE). As the mean calorie level increased, the degree of under-estimation of EE worsened.

Uber, A., *et al.* (2018). "Preliminary observations in systemic oxygen consumption during targeted temperature management after cardiac arrest." **127**: 89-94.

Summary: Cardiac arrest patients receiving targeted temperature management were evaluated. Continuous VO₂ and VCO₂ measurements were obtained with the GE Healthcare CARESCAPE™ B650 monitor and the CARESCAPE E-sCOVX respiratory module. In a post-hoc analysis of the first 12 hours after return of spontaneous circulation, VO₂ was associated with survival (median VO₂ in survivors 3.35 mL/kg/min [2.98, 3.88] vs. non-survivors 2.61 mL/kg/min p=0.039). There was no cut-off value for VO₂ that differentiated survivors and non-survivors. There was no association between VCO₂ and survival. The RQ was higher in survivors -- patients whose first measured RQ was <0.7 had a survival rate of 17%, compared to 64% in patients whose initial RQ was ≥0.7. Venous hyperoxia may offer future prognostic benefit in this population - venous hyperoxia as a state in which central venous oxygen saturation remains elevated despite low-to-normal cardiac output suggests a cellular inability to utilize oxygen and portends a poor prognosis.

Zusman, O., *et al.* (2018). "Predictive equations versus measured energy expenditure by indirect calorimetry: A retrospective validation." *Clin Nutr*.

Summary: A retrospective study in ICU patients evaluating REE estimates compared to IC (Deltatrac) was conducted on 1,565 patients, for a total of 5,847 measurements. This is the largest study evaluating REE versus predictive equations. The results confirm what has been observed in many smaller studies as well as a systematic review, showing a large variability and poor accuracy of predictive equations. The level of accuracy never exceeded 50%.

Acar-Tek, N., *et al.* (2017). "Estimation of Resting Energy Expenditure: Validation of Previous and New Predictive Equations in Obese Children and Adolescents." *J Am Coll Nutr* **36**(6): 470-480.

Summary: Previously developed predictive equations mostly provided inaccurate and biased estimates of REE. However, the new predictive equations allow clinicians to estimate REE in obese children and adolescents with sufficient and acceptable accuracy.

Allingstrup, M. J., *et al.* (2017). "Indirect Calorimetry in Mechanically Ventilated Patients: A Prospective, Randomized, Clinical Validation of 2 Devices Against a Gold Standard." *JPEN J Parenter Enteral Nutr* **41**(8): 1272-1277.

Summary: In this study, the QUARK RMR ICU indirect calorimeter compared better with the gold standard (modified Tissot bell-spirometer method) for values of VO₂ 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.

Berger, M. M., *et al.* (2017). "Impact of the reduction of the recommended energy target in the ICU on protein delivery and clinical outcomes." *Clin Nutr* **36**(1): 281-287.

Summary: Energy targets are a matter of debate for ICU patients. As the guidelines have evolved, energy targets have been reduced, while protein intake objectives have increased. The impact of these changes remains largely unknown. This quality study investigated the clinical impact of these changes in patients with an ICU stay > 3 days. A linear reduction in energy target recommendation without changing the feed composition led to an unplanned and significant reduction in protein delivery, which was associated with a prolonged duration of ventilation and an extended hospital stay.

CARDIA, L., *et al.* (2017). "Resting Metabolic Rate In Patients Submitted To Bariatric Surgery: Comparison of Indirect Calorimetry With Predictive Equations." *Surgery for Obesity and Related Diseases* **13**(10): S141.

Summary: In this study, IC was measured with Ultima CPX (MedGraphics). Gastric bypass patients were evaluated before surgery, peri-operative, and 6 months and 36 months after. The study displayed descriptive statistics only and no conclusions on the application of IC before during or after bariatric surgery were offered.

Carpenter, A., *et al.* (2017). "Predictive Equations Are Inaccurate in the Estimation of the Resting Energy Expenditure of Children With End-Stage Liver Disease." *JPEN J Parenter Enteral Nutr* **41**(3): 507-511.

Summary: This study found that commonly used predictive equations perform poorly in infants and young children with ESLD. Indirect calorimetry should be used when available to guide energy provision, particularly in children who are already malnourished.

Clark, A., *et al.* (2017). "Nutrition and metabolism in burn patients." *Burns Trauma* **5**: 11.

Summary: This review article involving nutritional support for burn patients listed a few highlights. 1) Nutritional support is critical in the treatment of burn patients, in whom the metabolic rate can be greater than twice the normal rate. 2) The primary goal of nutritional support in burn patients is to fulfill the increased caloric requirements caused by the hypermetabolic state while avoiding overfeeding. 3) IC is considered the gold standard with a great concern about overfeeding, which is commonly associated with difficulty in weaning from the mechanical ventilator.

Ferreruela, M., et al. (2017). "Effect of FiO₂ in the measurement of VO₂ and VCO₂ using the E-COXV metabolic monitor." *Med Intensiva* **41**(8): 461-467.

Summary: This study demonstrated good precision for VO₂ and VCO₂ with the GE Healthcare E-COVX module with FiO₂ up to 0.40. There was no clinically significant bias observed with FiO₂ 0.40-0.80. Precision was vulnerable to increased FiO₂, with clinically inadequate VO₂ observed when FiO₂ exceeded 0.6. Measurement of VCO₂ was not affected by changes in FiO₂.

Graf, S., et al. (2017). "Energy expenditure in mechanically ventilated patients: The weight of body weight!" *Clin Nutr* **36**(1): 224-228.

Summary: This study aimed to determine the best prediction strategy when IC is not available. Correlations between estimated EE? and IC were poor regardless of body weight, and agreement was also poor.

Hung, R., et al. (2017). "Comparison of estimates of resting energy expenditure equations in haemodialysis patients." *Int J Artif Organs* **40**(3): 96-101.

Summary: In hemodialysis patients, standard equations underestimated REE.

Jimenez, L., et al. (2017). "Timing of the initiation of parenteral nutrition in critically ill children." *Curr Opin Clin Nutr Metab Care* **20**(3): 227-231.

Summary: This review article is very good for background understanding of parenteral nutrition in critically ill children. The authors summarize guidelines for parenteral nutrition initiation, relying on risk stratification of malnutrition and the ability to accurately assess energy expenditure via indirect calorimetry

Jotterand Chaparro, C., et al. (2017). "Performance of Predictive Equations Specifically Developed to Estimate Resting Energy Expenditure in Ventilated Critically Ill Children." *J Pediatr* **184**: 220-226.e225.

Summary: 15 predictive equations were used to estimate REE. None of the predictive equations tested met the performance criteria for the entire range of REE between 200 and 1,000 kcal/day. Even the equations with the smallest bias may entail a risk of underfeeding or overfeeding, especially in the youngest children. The authors concluded that indirect calorimetry measurement must be preferred in this patient population.

Karlsson, M., et al. (2017). "Ability to predict resting energy expenditure with six equations compared to indirect calorimetry in octogenarian men." **92**: 52-55.

Summary: The accuracy of predictive equations for calculating resting energy expenditure (REE) in elderly people has been questioned. Aging is associated with progressive declines in REE, which is partly explained by loss of fat-free mass (FFM). The Mifflin-St Jeor equation (using FFM) is the most accurate equation for estimating REE in these octogenarian men. The Harris-Benedict or WHO equations are potential alternatives if information on FFM is unavailable, although their accuracy on an individual level is limited. (An unknown IC device used in this study.)

Liu, W., et al. (2017). "Measurements of resting energy expenditure in surgical critically ill patients with mechanical ventilator." **44**(7): 452-455.

Summary: This study compared the differences between measured resting energy expenditure calculated by the indirect calorimetry and the resting energy expenditure calculated by the Harris-Benedict formula. Resting energy expenditure by the Harris-Benedict formula was significantly higher than calculated from indirect calorimetry (P<0.05). Resting energy expenditure by the weight formula was significantly lower than calculated from indirect calorimetry (p<0.05). Although the Harris-Benedict formula and weight formula are convenient in clinical use, the results calculated by them is significantly different from the results calculated by indirect calorimetry. So clinical nutrition support should rely on indirect calorimetry as far as possible. (An unknown IC device used in this study.)

Martinez, E. E., et al. (2017). "Energy and Protein Delivery in Overweight and Obese Children in the Pediatric Intensive Care Unit." *Nutr Clin Pract* **32**(3): 414-419.

Summary: In this investigation involving overweight and obese children, the study cohort had suboptimal nutrition assessments (34%) and macronutrient delivery during their PICU course. Mortality and duration of PICU stay were greater when compared with the general PICU population. PICU duration was 8 days vs 5 days for obese patients compared to the general PICU population. The mortality rate was 7.2% vs 3.3% (P = .045) between obese and general PICU populations. Nutritional assessments were conducted in only 60% of obese patients. There is a need to improve nutritional assessments, utilization of indirect calorimetry-guided energy prescriptions, and optimization of energy and protein delivery in this pediatric population.

Lee, P. S.-P., *et al.* (2017). "Metabolic Requirement of Septic Shock Patients Before and After Liberation From Mechanical Ventilation." **41**(6): 993-999.

Summary: This study identified the difference in energy expenditure and substrate utilization of patients during and upon liberation from mechanical ventilation. The authors concluded that measured energy expenditure was higher during than upon liberation from mechanical ventilation. This could be the increase in work of breathing from the continuous positive pressure support, repeated weaning cycles from mechanical ventilation, and/or the asynchronization between patients' respiration and ventilator support. Future studies should examine whether more appropriately matching energy expenditure with energy intake would promote positive health outcomes. (An unknown IC device used in this study.)

Mouzaki, M., *et al.* (2017). "Can VCO₂-Based Estimates of Resting Energy Expenditure Replace the Need for Indirect Calorimetry in Critically Ill Children?" *JPEN J Parenter Enteral Nutr* **41**(4): 619-624.

Summary: This study found that in pediatric patients undergoing cardiopulmonary bypass, indirect calorimetry was the most accurate method (compared to VCO₂-derived estimates) to determine REE. The authors noted that further evaluation is needed to assess the utility of VCO₂-derived REE estimation.

Oshima, T., *et al.* (2017). "Indirect calorimetry in nutritional therapy. A position paper by the ICALIC study group." *Clin Nutr* **36**(3): 651-662.

Summary: Highlights of this review article include:

- The Deltatrac Metabolic Monitor® produced 35 years ago is often viewed as the reference device.
- Devices with a mixing chamber generate more stable measurements because the gases are physically averaged before being analyzed, allowing the gas analyzers to generate very accurate analysis. The capacity to make reliable measurements in a short duration is also limited, as it takes just as much time for the gas concentrations in the mixing chamber to stabilize.
- Patients in the ICU for > 4 days or those after major surgery are good candidates for IC as they undergo severe stress related to variable metabolic needs. Indeed, these patients are at high nutritional risk, as they are unable to resume sufficient oral intake.
- Obese patients constitute an increasing proportion of the ICU patient population. Their energy requirements are particularly poorly addressed by predictive equations. IC is the only way to determine their metabolic requirements accurately.

Panitchote, A., *et al.* (2017). "Energy expenditure in severe sepsis or septic shock in a Thai Medical Intensive Care Unit." *Asia Pac J Clin Nutr* **26**(5): 794-797.

Summary: This study aimed to measure energy expenditure in severe sepsis/septic shock patients by indirect calorimetry and to assess the correlation of energy expenditures between indirect calorimetry and predictive equations. IC was measured using an Engström Carestation mechanical ventilator. There was poor agreement and correlation between EE using predictive equations versus EE using IC. The Bland-Altman analysis showed a mean difference (limits of agreement) of -757 kcal/day between EE using IC and EE using predictive equations.

Parker, E. A., *et al.* (2017). "Considerations when using predictive equations to estimate energy needs among older, hospitalized patients: a narrative review." **6**(2): 102-110.

Summary: In this review article, the authors observed that as the evidence demonstrating the importance of nutritional supplementation in older, hospitalized adults grows, more accurate energy assessment methods that account for age-related conditions are needed to predict nutritional requirements.

Ramos, F., *et al.* (2017). "Comparison of predictive equations of resting energy expenditure in older adults with chronic obstructive pulmonary disease." **23**(1): 40-42.

Summary: The authors concluded that the majority of equations underestimated the REE and all equations showed low association with IC. Therefore, they suggested that the REE equations used at present study should not be used in older adults with COPD. The main limitation of this study was that the small sample size constituted mainly by male patients does not permit speculation about these results in general COPD population and more studies evaluating higher number of older adults with COPD are needed.

Segadilha, N., et al. (2017). "Energy Expenditure in Critically Ill Elderly Patients: Indirect Calorimetry vs Predictive Equations." *JPEN J Parenter Enteral Nutr* **41**(5): 776-784.

Summary: This study evaluated the degree of agreement between and the accuracy of the REE measured by IC (REE-IC) and REE estimated by predictive equations (REE-PE) in mechanically ventilated elderly patients. The authors concluded that estimated REE showed limited effectiveness in this patient population.

Smallwood, C. D., et al. (2017). "Accuracy of Oxygen Consumption and Carbon Dioxide Elimination Measurements in 2 Breath-by-Breath Devices." *Respir Care* **62**(4): 475-480.

Summary: Of the two breath-by-breath devices tested, only the newest module demonstrated a bias and limits of agreement that were within an a priori determined clinically acceptable range of $\pm 20\%$ for VO_2 and VCO_2 (E-sCAiOVX). The limits of agreement were clinically acceptable from 40 to 100 mL/min. This range corresponds to approximate patient weights of 5 to 16 kg. The older device (E-COVX) did not demonstrate agreement with the simulated values and therefore is not clinically acceptable for use in pediatric patients.

Smallwood, C. D., et al. (2017). "Accuracy of Oxygen Consumption and Carbon Dioxide Elimination Measurements in 2 Breath-by-Breath Devices." *Respir Care* **62**(4): 475-480.

Summary: This study assessed the accuracy and agreement of two devices used to quantify oxygen consumption (VO_2) and carbon dioxide elimination (VCO_2) in children, using a pediatric in vitro model of gas exchange. Of the two devices tested, only the newest module demonstrated a bias and limits of agreement that were within an a priori determined clinically acceptable range of $\pm 20\%$ for VO_2 and VCO_2 (E-sCAiOVX). The limits of agreement were clinically acceptable from 40 to 100 mL/min. This range corresponds to approximate patient weights of 5-16 kg. The older device (E-COVX) did not demonstrate agreement with the simulated values and therefore is not clinically acceptable for use in pediatric patients.

Soussi, S., et al. (2017). "Measurement of Oxygen Consumption Variations in Critically Ill Burns Patients: Are the Fick Method and Indirect Calorimetry Interchangeable?" *Shock* **48**(5): 532-538.

Summary: This study conducted in 23 critically ill burn patients evaluated the interchangeability of oxygen consumption variations measured with the Fick equation versus indirect calorimetry. The results demonstrated poor agreement, and therefore VO_2 measurements by means of IC are not interchangeable with VO_2 obtained by Fick.

Smallwood, C. D. and B. K. Walsh (2017). "Noninvasive Monitoring of Oxygen and Ventilation." *Respir Care* **62**(6): 751-764.

Summary: This comprehensive review article looked at diverse clinical applications for non-invasive monitoring beyond indirect calorimetry (IC). As it pertains to IC, the author highlighted several use cases:

- Nutrition, to detect during mechanical ventilation, spontaneous respirations and non-invasive ventilation. It is recommended to titrate energy prescriptions in critically ill children. Recent evidence suggests VCO_2 can serve as a surrogate for EE
- Potential uses include: titration of end-expiratory pressure during critical illness; titration of minute ventilation during severe obstruction; and assessment of response to pulmonary vasodilatory therapy.
- The optimization of VCO_2 can potentially guide clinicians to the optimal balance between atelectasis and over-distention.

Tignanelli, C. J., A. G. Andrews, K. M. Sietloff, M. R. Pleva, H. A. Reichert, J. A. Wooley, L. M. Napolitano and J. R. Cherry-Bukowiec (2017). "Are Predictive Energy Expenditure Equations in Ventilated Surgery Patients Accurate?" *J Intensive Care Med*: 0885066617702077.

Summary: This study compared the REE measured by IC with REE calculated using specific calorie goals or predictive equations for nutritional support in ventilated adult SICU patients. 419 patients were evaluated in this retrospective study. The HBE, 20, 25, and 30 kcal/kg/d estimates of REE were found to be inaccurate regardless of age, gender, or weight. The HBE and 20 kcal/kg/d underestimated REE, while 25 and 30 kcal/kg/d overestimated REE.

Tignanelli, C. J., et al. (2017). "Are Predictive Energy Expenditure Equations in Ventilated Surgery Patients Accurate?": 0885066617702077.

Summary: Prior studies suggest these equations frequently misjudge actual resting energy expenditure (REE) in medical and mixed intensive care unit (ICU) patients; however, their utility for surgical ICU (SICU) patients has not been fully evaluated. In SICU patients with nutrition requirements essential to recovery, REE was found to be inaccurate and IC measurement should be performed to guide clinicians in determining goal caloric requirements.

Wen-Yi, C., *et al.* (2017). "PT07. 3: The Clinical Outcomes and Medical Costs in Chronic Obstructive Pulmonary Disease Patients on Prolonged Mechanical Ventilation with and without Malnutrition." **36**: S44.

Summary: In patients with chronic obstructive pulmonary disease on prolonged mechanical ventilation, malnutrition was associated with worse clinical outcomes: increased mortality rate and 30-day readmission rates. In addition, hospital charges were 1.7 greater in the malnutrition cohort.

Wen-Yi, C., *et al.* (2017). "PT07.4: The Clinical Outcomes and Medical Costs in Non-Dialysis Chronic Kidney Disease Patients with and without Malnutrition." *Clinical Nutrition* **36**: S44-S45.

Summary: In patients with non-dialysis chronic kidney disease, malnutrition was associated with worse clinical outcomes: increased mortality rate and 30-day readmission rates.

Beggs, M. R., *et al.* (2016). "Do PICU patients meet technical criteria for performing indirect calorimetry?" *Clin Nutr ESPEN* **15**: 80-84.

Summary: Indirect calorimetry is the gold standard for measuring energy expenditure. However, in this current study, technical criteria for IC were met on only one third of total patient days. Moreover, criteria were met on only 29% of days for infants 6 months and younger. Children 24 months of age and older still only met criteria on 40% of patient days. This study highlights a major gap in the feasibility of current recommendations for the care of this population, particularly vulnerable infants. Future studies are needed to develop improved methods to accurately predict and measure energy requirements in critically ill children who do not meet current criteria for indirect calorimetry.

De Waele, E., *et al.* (2016). "VCO₂ calorimetry: stop tossing stones, it's time for building!" *Acta Anaesthesiol Scand.* **20**(1): 399.

Summary: The commenters concurred that VO₂ is the most relevant variable for EE measurement. However, the most accurate and precise estimation of EE in a critically ill population can only be obtained by sampling of inspired and expired oxygen/carbon dioxide concentrations and by measuring expired gas flow. This is the core task of indirect calorimetry.

Moreno, Y. M., *et al.* (2016). "Problems With Optimal Energy and Protein Delivery in the Pediatric Intensive Care Unit." *Nutr Clin Pract* **31**(5): 673-680.

Summary: On average, actual energy intake in critically ill children was 47% of the predicted energy expenditure, and 68% of patients were underfed. Significant gaps in predicted energy requirements combined with prescription and delivery of energy and protein resulted in underfeeding in this PICU population.

Piccolo, M. F., *et al.* (2016). "Harris-Benedict Equation and Resting Energy Expenditure Estimates in Critically Ill Ventilator Patients." *Am J Crit Care* **25**(1): e21-29.

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

Pielmeier, U. and S. J. C. C. Andreassen (2016). "VCO₂ calorimetry is a convenient method for improved assessment of energy expenditure in the intensive care unit." **20**(1): 224.

Summary: This editorial argued that IC remains the gold standard for assessment of EE in ventilated critically ill patients. However, the best validated system, the Deltatrac, is no longer on the market, and new indirect calorimeters have not yet proven to be accurate. More important, predictive equations are inaccurate, and their use should be avoided. VCO₂-based EE provides the best alternative.

Sundström Rehal, M., *et al.* (2016). "Measuring energy expenditure in the intensive care unit: a comparison of indirect calorimetry by E-sCOVX and Quark RMR with Deltatrac II in mechanically ventilated critically ill patients." **20**(1): 54.

Summary: The aim of this study was to determine the level of agreement in gas exchange measurements between the E-sCOVX, Quark RMR and the Deltatrac II in mechanically ventilated ICU patients. There was a significant bias toward higher VO₂ and VCO₂ values with both E-sCOVX and Quark RMR as compared to Deltatrac; that corresponded to 10% overestimation of REE.

Taylor, B. E., et al. (2016). "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.)." *Crit Care Med* **44**(2): 390-438.

Summary: ASPEN Guidelines provide several key recommendations:

- 1) Based on expert consensus, determine nutrition risk on all patients admitted to the ICU for whom volitional intake is anticipated to be insufficient.
- 2) Use indirect calorimetry (IC) to determine energy requirements when available and in the absence of variables that affect the accuracy of measurement.

Use cases highlighted include sepsis, trauma and traumatic brain injury, burns and obesity in critical illness.

Zusman, O., et al. (2016). "Resting energy expenditure, calorie and protein consumption in critically ill patients: a retrospective cohort study." *Crit Care* **20**(1): 367.

Summary: This study, the largest retrospective study (n=6994) completed using indirect calorimetry as opposed to predictive equations to determine energy requirements in mechanically ventilated, critically ill patients, demonstrated a non-linear, significant association between the percent Administered Calories/REE and mortality by 60 days. The findings suggest that both underfeeding and overfeeding appear to be harmful to mechanically ventilated, critically ill patients. Intuitively, achieving a goal of 100 % calories administered would be optimal; in fact, the ideal goal for calories administered with the most favorable survival was achieved at 70%.

De Waele, E., et al. (2015). "Measuring resting energy expenditure during extracorporeal membrane oxygenation: preliminary clinical experience with a proposed theoretical model." *Acta Anaesthesiol Scand* **59**(10): 1296-1302.

Summary: This pilot study evaluated the use of IC in patients with severe respiratory failure undergoing ECMO. [Unknown IC device]

Lago, A. F., E. C. Goncalves, E. C. Silva, M. G. Meneguetti, E. A. Nicolini, M. Auxiliadora-Martins, E. Z. Martinez, A. C. Gastaldi and A. Basile-Filho (2015). "Comparison of Energy Expenditure and Oxygen Consumption of Spontaneous Breathing Trial Conducted With and Without Automatic Tube Compensation." *Journal of Clinical Medicine Research* **7**(9): 700-705.

Summary: IC: Deltatrac II (GE Healthcare): This randomized crossover-design study evaluated spontaneous breathing trials of CPAP with automatic tube compensation (ATC) or CPAP without ATC. The authors concluded that VO_2 and EE obtained during SBT with and without ATC were not different.

Yoshimura, S., et al. (2015). "A short period of fasting before surgery conserves basal metabolism and suppresses catabolism according to indirect calorimetry performed under general anesthesia." *J Anesth* **29**(3): 453-456.

Summary: The authors' findings suggest that a short period of fasting (<8 h) before surgery is more strongly associated with the conservation of basal metabolism.

Smallwood, C. D. and N. M. Mehta (2013). "Gas exchange measurement during pediatric mechanical ventilation--agreement between gas sampling at the airway and the ventilator exhaust." *Clin Nutr* **32**(6): 988-992.

Summary: This investigation compared oxygen consumption (VO_2), carbon dioxide elimination (VCO_2), Resting Energy Expenditure (REE) and respiratory quotient (RQ) in mechanically ventilated children, obtained by two devices using distinct gas sampling methods. Despite strong correlations and small mean biases for VO_2 , VCO_2 and REE obtained by the Viasys Healthcare Vmax[®] and GE Healthcare E-COVX[®], the limits of agreement were beyond the clinically acceptable range. These devices should not be used interchangeably for gas exchange measurements in mechanically ventilated children.

Smallwood, C. D. and N. M. Mehta (2013). "Gas exchange measurement during pediatric mechanical ventilation--agreement between gas sampling at the airway and the ventilator exhaust." *Clin Nutr* **32**(6): 988-992.

Summary: This study found that despite strong correlations and small mean biases for VO_2 , VCO_2 and REE obtained by the Vmax[®] and E-COVX[®], the limits of agreement were beyond the clinically acceptable range. These devices should not be used interchangeably for gas exchange measurements in mechanically ventilated children.

dos Santos, L. J., F. C. Hoff, R. L. Condessa, M. L. Kaufmann and S. R. Vieira (2011). "Energy expenditure during weaning from mechanical ventilation: is there any difference between pressure support and T-tube?" *J Crit Care* **26**(1): 34-41.

Summary: M-COVX model (GE Healthcare): This study compared the EE measured by IC of patients in pressure support (PS) and T-tube (TT) weaning from MV. This was a randomized, cross-over designed study with 40 patients included. The mean EE of patients in TT (1782 ± 375 kcal/d) was 14.4% higher than in PS (1558 ± 304 kcal/d; $P < 0.001$).

Briassoulis, G., et al. (2009). "Influence of different ventilator modes on VO₂ and VCO₂ measurements using a compact metabolic monitor." *Nutrition* **25**(11-12): 1106-1114.

Summary: The influence of different ventilator modes on VO₂ and VCO₂ measurements in adequately sedated critically ill children is not significant. The E-COVX metabolic module is suitable for repeated measurements in well-sedated mechanically ventilated children with stable respiratory patterns.

Briassoulis, G., et al. (2009). "The effects of endotracheal suctioning on the accuracy of oxygen consumption and carbon dioxide production measurements and pulmonary mechanics calculated by a compact metabolic monitor." *Anesth Analg* **109**(3): 873-879.

Summary: E-COVX indirect calorimetry measurements in pediatric sepsis or head injury were not affected by endotracheal suctioning (ETS). Metabolics were reliably measured within 5 minutes following ETS.

El-Khatib, M., P. Bou-Khalil, S. Zeineldine, N. Kanj, G. Abi-Saad and G. Jamaledine (2009). "Metabolic and Respiratory Variables during Pressure Support versus Synchronized Intermittent Mandatory Ventilation." *Respiration* **77**(2): 154-159.

Summary: IC: Deltatrac II: This study evaluated the impact of REE during two differing modes of respiratory support: pressure support ventilation (PSV) or volume-cycled synchronized intermittent mandatory ventilation (SIMV). In total, 14 patients were enrolled. The study found that changes in VO₂, VCO₂ and measured EE were significantly smaller during comparable ventilatory support changes in PSV versus volume-cycled SIMV. The authors concluded, "PSV may be more suitable for progressive respiratory muscle reloading."

Shepherd, Stephen J. and Rupert M. Pearce (2009). "Role of Central and Mixed Venous Oxygen Saturation Measurement in Perioperative Care." *Anesthesiology* **111**(3): 649-656.

Summary: Venous oxygen saturation reflects the balance between global oxygen delivery and oxygen consumption, which may be affected by a wide range of factors during the perioperative period. This article describes the physiology and measurement of mixed and central venous oxygen saturation and explores the findings of clinical investigations of their use in perioperative care. Some highlights pertaining to VO₂:

- Few studies have explored the relationship between VO₂ and venous saturation during the perioperative period. This may reflect poor recognition of the importance of VO₂ as a determinant of venous saturation.
- Increases in VO₂ resulting from pain, anxiety, or shivering may all result in a decrease in venous saturation. General anesthesia results in a decrease in VO₂ as a result of decreased work of breathing, motor activity and body temperature.

Inadomi, C., et al. (2008). "Comparison of oxygen consumption calculated by Fick's principle (using a central venous catheter) and measured by indirect calorimetry." *J Anesth* **22**(2): 163-166.

Summary: This study investigated the clinical usefulness of the Fick method using central venous oxygen saturation (ScvO₂) and cardiac output (CO) measured by Pulse Dye -Densitometry (PDD) for monitoring oxygen consumption (VO₂). This prospective clinical study was performed in 28 mechanically ventilated postoperative patients after major abdominal surgery. VO₂ values determined by the Fick method were significantly lower than those measured by indirect calorimetry.

Haugen, H. A., et al. (2007). "Indirect calorimetry: a practical guide for clinicians." *Nutr Clin Pract* **22**(4): 377-388.

Summary: This review gives clinicians a comprehensive overview of indirect calorimetry. Indirect calorimetry offers a scientifically-based approach to customize a patient's energy needs and nutrient delivery to maximize the benefits of nutrition therapy. With recent advances in technology, indirect calorimeters are easier to operate, more portable, and affordable. Increased utilization of indirect calorimetry would facilitate individualized patient care and should lead to improved treatment outcomes.

Patt, P. L., et al. (2007). "Estimation of resting energy expenditure in children with spinal cord injuries." *J Spinal Cord Med* **30** Suppl 1: S83-87.

Summary: This study found that measured REE was lower than the results of prediction equations in pediatric patients with spinal cord injuries. Further validation studies are needed.

Weintraub, V., F. B. Mimouni and S. Dollberg (2007). "Changes in energy expenditure in preterm infants during weaning: a randomized comparison of two weaning methods from an incubator." *Pediatr Res* **61**(3): 341-344.

Summary: IC: Deltatrac II (GE Healthcare): In this study, 42 preterm infants were assessed in an RCT with one of two weaning methods to assess the impact on REE. REE increased significantly at the time an infant was weaned from the incubator, regardless of weaning method. A comparison of the six infants who failed weaning with the 36 that had a successful weaning from the incubator revealed that mode of weaning was not significantly influential (two failures/19 infants (10.5%) in the warming bassinet group versus 4/23 (17.4%) in the incubator group, p=0.67). Baseline REE was almost significantly lower (p = 0.06) in the failed group (219 ± 11 kJ/kg/d) than in the successful group (236 ± 7 kJ/kg/d).

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Peyton, P. J. and G. J. Robinson (2005). "Measured pulmonary oxygen consumption: difference between systemic oxygen uptake measured by the reverse Fick method and indirect calorimetry in cardiac surgery." *Anaesthesia* **60**(2): 146-150.

Summary: Measurement of oxygen uptake by indirect calorimetry was compared with the reverse Fick method in a series of patients undergoing cardiac surgery. IC was performed with non-GE technology. Indirect calorimetry overestimated the reverse Fick value by 11.3% ($p < 0.001$), a finding consistent with the results of previous studies with similar patient groups.

Donaldson, L., *et al.* (2003). "Clinical evaluation of a continuous oxygen consumption monitor in mechanically ventilated patients." *Anaesthesia* **58**(5): 455-460.

Summary: This study used M-COVX to measure VO_2 and concluded that there were small errors between M-COVX VO_2 and calculated values.

Miwa, K., M. Mitsuoka, S. Takamori, A. Hayashi and K. Shirouzu "Continuous Monitoring of Oxygen Consumption in Patients Undergoing Weaning from Mechanical Ventilation."

Summary: IC: Puritan-Bennett 7250 Metabolic Monitor: Among 20 patients evaluated in this study, a total of 208 weaning trials were performed, including 145 that were successful. A statistical difference in oxygen cost of breathing (OCOB, respiratory frequency/tidal volume), ΔRR , and ΔEE was found between successful and failed weaning trials. OCOB $< 30\%$ showed the greatest accuracy among these three measures. The authors added, "Continuous monitoring of VO_2 is useful to predict success or failure of trials attempting to reduce mechanical ventilatory support."

Kovachev, I., *et al.* (2002). "[Assessment of oxygen delivery (DO_2) and oxygen consumption (VO_2) in severe pre-eclamptic patients]." *Akush Ginekol (Sofia)* **41**(3): 18-23.

Summary: No results can be determined except for demonstration of use of VO_2 in management of preeclampsia.

Epstein, C. D., *et al.* (2000). "Comparison of methods of measurements of oxygen consumption in mechanically ventilated patients with multiple trauma: the Fick method versus indirect calorimetry." *Crit Care Med* **28**(5): 1363-1369.

Summary: This study concluded that IC was superior to the Fick method of calorimetry in multiple trauma patients.

Peerless, J. R., *et al.* (2000). "Oxygen consumption in the early postinjury period: use of continuous, on-line indirect calorimetry." *Crit Care Med* **28**(2): 395-401.

Summary: This study aimed to determine patterns of oxygen consumption (VO_2) using indirect calorimetry (IC) for the first 24 hours after serious blunt traumatic injury. The authors found that seriously injured patients are hypermetabolic in the early post-injury period. The level of VO_2 was unrelated to injury severity and did not predict the onset of multiorgan dysfunction.



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