COMPARISON OF CALCULATED ENERGY EXPENDITURE TO MEASURED ENERGY EXPENDITURE IN OVERWEIGHT AND OBESE BURN PATIENTS IN AN ICU SETTING: A RETROSPECTIVE STUDY

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Recommended Citation

Skinner, Elle Maree; Deborah A. Cohen; Orrin B. Myers; and Diana Gonzales-Pacheco. "COMPARISON OF CALCULATED ENERGY EXPENDITURE TO MEASURED ENERGY EXPENDITURE IN OVERWEIGHT AND OBESE BURN PATIENTS IN AN ICU SETTING: A RETROSPECTIVE STUDY." (2018). [https://digitalrepository.unm.edu/educ_ifce_etds/73](https://digitalrepository.unm.edu/educ_ifce_etds/73)

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by

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BS NUTRITION AND DIETETICS

THESIS

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

NUTRITION

The University of New Mexico
Albuquerque, New Mexico

December, 2018
ACKNOWLEDGEMENTS

I hereby acknowledge Dr. Deborah Cohen, my advisor and committee chair for her constant encouragement and guidance, for continually investing in my academic and professional development, as well as keeping me on track throughout the research journey.

I would also like to thank my committee members. Dr. Orrin Myers, thank you for your continual encouragement and advice. I appreciate the time and effort that went in to teach me statistics and to mentor me through the data analysis. Dr. Diana Gonzales-Pacheco thank you for your valuable input, guidance and ongoing encouragement throughout the research process.

To all the friends and family I have made in the United States, thank you for your encouragement and social support throughout this journey.

To my family in Australia, thank you for always encouraging me to achieve my dreams and strive for success. Thank you to my sister and her family here in the United States, you have been that piece of home I have missed.

Last but not least to my husband, Aaron, your grace, loyalty and kindness continually amazes me. You’re my biggest encourager and I couldn’t have gotten through this without you.
COMPARISON OF CALCULATED ENERGY EXPENDITURE TO MEASURED ENERGY EXPENDITURE IN OVERWEIGHT AND OBESE BURN PATIENTS IN AN ICU SETTING: A RETROSPECTIVE STUDY

BY

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ABSTRACT

Burns cause massive dermal wounds. Wound healing elicits a significant catabolic response and increase in energy expenditure, and thus, calorie needs. Overfeeding and/or underfeeding the overweight and obese critically ill patient can increase complications. Indirect Calorimetry (IC) is considered the ‘gold standard’ for the measurement of Energy Expenditure (EE). Predictive equations are calculated to estimate EE instead. This study is a retrospective chart review. The difference between predictive energy expenditure (via Curreri formula) and measured IC were analyzed via non-parametric Wilcoxon signed rank match paired tests. Curreri equation prediction was analyzed on the ability to match IC (0% over or under prediction). A total of 13 participants met inclusion criteria. The Curreri equation showed a mean overprediction of 29% using actual body weight, 10% for ideal body weight and 2% for adjusted ideal body weight (obese only). More research with larger sample sizes is needed to further determine if the use of ideal body weight in the Curreri predictive equation will reduce significant over prediction and therefore overfeeding of energy.
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Chapter 1.

Background and Introduction

I – Defining Overweight and Obesity.

Two in three adults are classified as overweight and one in three adults as obese in the United States. The cause of overweight and obesity is multifactorial and includes diet/nutrition, physical activity, environment and genetics. Nutrition plays an important role in the development of overweight and obesity; not only the type of food and calories consumed but also the quantity. When an individual consumes more calories or energy in the form of carbohydrate, fat or protein than what is needed for basal metabolic requirements and physical activity the excess is converted to triglyceride and stored in adipose tissue.

To classify an individual’s weight related health risk clinicians rely on anthropometric data, such as weight and height to make objective assessments. The most frequently used measure for overweight or obesity classification is body mass index (BMI). The BMI is an easy, quick, low skill and cost-effective method for classifying weight and assessing risk of developing chronic diseases as a result of excess weight. BMI is also used as a surrogate to evaluate body fat in the absence of more sophisticated expensive methods such as underwater weighing.

BMI classifications for weight are as follows: underweight BMI ≤ 18.49kg/m², normal weight BMI ≥ 18.5 to 24.9kg/m², overweight BMI ≥ 25.0 to 29.9kg/m², obesity class I BMI ≥ 30.0 to 34.9kg/m², obesity class II BMI ≥ 35.0 to 39.9kg/m² and obesity class III BMI ≥ 40.0. A BMI >30 indicates an increased risk of developing chronic
diseases including hypertension, type 2 diabetes mellitus, stroke, cardiovascular disease and these individuals also have a higher rate of all-cause mortality.  

II - Healthcare Expenditures Associated with Overweight and Obesity in the United States.

Compared to normal weight individuals, overweight and obese individuals have increased healthcare costs. Kent et al reported that in 2016 overweight and obesity were associated with approximately 15% of U.S healthcare costs. Another study by Kim et al. further demonstrated when compared to their non-obese counterparts, an additional $1901 per person per year was spent on total medical costs related to obesity.

Increased healthcare costs associated with overweight and obesity are influenced by the number of co-morbidities and age of an individual. As an obese person ages, there is a linear increase in healthcare dollars associated with inpatient and outpatient medical care. In an intensive care unit (ICU) setting, costs can be influenced by the numerous and complicated treatments required to sustain life, including mechanical ventilation. Obese critically ill patients typically require more days on mechanical ventilation compared to non-obese patients. An obese critically ill patient may require prolonged mechanical ventilation due to a number of different factors including hyperglycemia and increased risk for respiratory infections. A delay in ventilator weaning, regardless of the reason, results in a longer ICU length of stay (LOS), and thus, increases healthcare costs.
III- Overweight and Obesity in the Intensive Care Unit (ICU).

The ICU setting is specifically designed for those patients who experience life-threatening illness, trauma, and injuries, including burns, multi-system organ failure and sepsis. As the prevalence of overweight and obesity in the US continues to increase, the number of overweight and obese patients admitted to an ICU is also projected to grow.

The obese individual who becomes critically ill presents a unique set of challenges for clinicians because excess body weight provides additional challenges to the physiological response to injury and healing. Overweight and obese patients have a greater risk of experiencing more complications (such as hyperglycemia) secondary to their primary injury/illness compared with patients who have a normal BMI. For the critically ill patient, regardless of BMI, achieving a normal blood glucose range is one of the primary goals because hyperglycemia increases the risk of impaired leukocyte production which in turn increases risk for infectious complications, reducing wound healing and increasing the need for antibiotics. Blood glucose control becomes a more significant challenge in overweight and obese critically ill patients. Obese individuals are more likely also to have the comorbidity of diabetes, this can compound the risk for insulin resistance and occurrence of hyperglycemic events in comparison to non-obese individuals. Scientific literature describes an associated decrease in wound healing capabilities in obese individuals which is related to decreased vascularity linked with increased adipose tissue. As a result, some obese individuals are at greater risk for poor wound healing because of the suppression of insulin production, poor vascularity and consequent anti-inflammatory mediators all of which increase hospital LOS and thus, healthcare costs.
It is because of these potential complications clinicians should aim to meet energy expenditures with precision to ameliorate possible exacerbation of risk factors.

**IV – Use of predictive equations to assess energy expenditure in the overweight and obese critically ill patient.**

Energy expenditure (EE) is variable and based on preexisting lean muscle, adipose tissue mass, metabolic stress, illness or injury and, therefore it is difficult to employ a “one size fits all” approach. Energy expenditure in humans reflects the required amount of calories an individual needs for the body to perform basic physiological functions. Energy is derived from carbohydrate, fat and protein. These fuels are oxidized and metabolized to generate cellular energy forms, which are known as adenosine triphosphate (ATP). The body then uses ATP to perform physiologic functions such as maintaining neurologic and respiratory function, as well as provide energy for growth, repair and muscle movement. One method to calculate or estimate EE is by the use of predictive equations. Predictive equations typically utilize height, weight, a stress factor (a number which accounts for an increase in metabolic demand due to the type of injury), age, gender, respiratory rate and at times maximum body temperature over a 24 hour period. Predictive equations are a cost-effective and time-efficient method, especially when compared to measuring energy expenditure, by indirect calorimetry (IC).

Some commonly used predictive equations that have been validated in critically ill overweight and obese individuals include: Harris Benedict Equation (HBE), Mifflin-St Jeor (MSJ) and Ireton Jones (IJ), refer to appendix one. The HBE is one of the most commonly utilized equations by Registered Dietitian Nutritionists (RDN) in clinical practice and was initially developed using non-obese, healthy individuals (primarily...
males) in the early 1900's. Like most predictive equations, the HBE incorporates height, weight, age, and gender to predict EE. The IJ equation is indicated for use in both spontaneous breathing and ventilator dependent patients specifically in the inpatient, hospital setting. The Academy of Nutrition and Dietetics (AND) conducted a systematic review which concluded MSJ to be the most appropriate predictive equation for non-critically ill non-obese and obese individuals.

Frankenfeild et al reported that using the HB equation in obese critically ill patients with a BMI >45 kg/m² on average, successfully predicted, within ±10% margin of error, on measured EE through IC, 60% of the time; whereas MSJ and IJ predicted EE within the set ±10% margin of error 55% and 29% of the time, respectively.

There is controversy regarding which body weight (BW) to use when calculating EE via predictive equations. The appropriate use of actual BW, ideal BW or adjusted ideal BW has not been adequately studied or evaluated. Ideal BW is calculated using the Hamwi method (males: 48.1 kg for the first 152.4 cm + 1.1 kg for each additional cm and females: 45.5 kg for the first 152.4 cm + 0.9 kg for each additional cm) or the use of adjusted ideal body weight (actual BW - ideal BW x 0.25 + ideal BW). Utilizing an ideal or adjusted ideal BW in a predictive equation stems from assumption within clinical practice that particular conditions such as obesity warrants a modified weight to avoid overfeeding. Indices which delineate when to use ideal or adjusted ideal BW have been established and includes the following equation: dividing the actual BW by the ideal BW. This generates a percentage where then the clinician can determine the excess over ideal BW. If an individual’s actual BW is calculated as 100-109% of ideal BW, then
the actual BW is used in the predictive equation, if 110-124% of ideal BW use ideal BW and if >125% use adjusted ideal BW\textsuperscript{31}.

The use of an alternate BW instead of the individuals’ actual BW when trying to determine EE, may increase the risk for over or underfeeding as the formulas to calculate BW have not been adequately validated in obese patients\textsuperscript{33}. One group of investigators concluded that predictive equations, including HBE, Cunningham, IJ and Curreri, significantly overpredicted calorie needs when using actual BW, refer to appendix one for equations\textsuperscript{34}. This may be attributed to skeletal muscle mass as opposed to fat mass, being the site of metabolic demand, not necessarily the entire individual’s body weight\textsuperscript{26}. However, it is difficult to measure acutely ill hospitalized patients muscle mass and fat free mass at bedside due to edema and immobility and therefore difficult to assess why actual BW can lead to over predicted EE\textsuperscript{33}. The position of the AND is that the use of adjusted BW when calculating EE using predictive equations does not improve the accuracy of predictive equations and that there is minimal evidence to support using adjusted BW in practice\textsuperscript{32}. However, a survey of practices by nutrition professionals in the US who care for obese burn patients reported, on average, 58% of RDN’s utilize the ideal BW or adjusted ideal BW over the patients’ actual or admit BW in predictive calculations\textsuperscript{21} and that this practice was employed in an attempt to avoid calorie overestimation\textsuperscript{21}. However, by using ideal BW or adjusted IBW not previously validated in a predictive equation or endorsed by industry leaders could potentially result in clinical practice that does not truly meet the individuals’ specific nutrition care needs.

Neither American Society for Parenteral and Enteral Nutrition (ASPEN) or Society of Critical Care Medicine (SCCM) hold a specific position regarding which BW
is best to use when calculating EE using predictive equations. The 2016 joint ASPEN and SCCM guidelines recommend the use of 11-14kcal/kg of actual BW for patients with a BMI of 30-50 and 22-25kcal/kg of ideal BW for those with a BMI > 50 when IC is not available. However, it is important to note this specific recommendation is “based on expertise” level of evidence, indicating the lack of research to support a conclusive position on the use of ideal or adjusted ideal BW\(^{35}\).

Both the AND and ASPEN/SCCM Guidelines for provision and assessment of nutrition support therapy in adult critically ill patient advocate the use of IC as first method to accurately determine EE\(^{35,36}\). It is because of the lack of evidence surrounding which predictive equation and what body weight to use in obese patients, as well as the day to day variability in medical needs of these patients, that IC is the best method for determining energy expenditure in critically ill patients. In absence of IC, the guidelines encourage the use of validated predictive equations to estimate EE. Without validated predictive equations, obese patients may be at risk for over or underfeeding when energy expenditure is calculated using predictive equations not designed for the obese population.

**VI – Measuring energy expenditure in overweight and obese critically ill patients.**

Indirect calorimetry is considered the “gold standard” for measuring EE in the clinical setting. This method utilizes gas volume measurements of oxygen consumption and CO\(_2\) production, gas concentrations released at a specific time points\(^{37,38}\). EE is measured from gas concentrations as O\(_2\) and CO\(_2\) indirectly represent heat loss\(^{39}\). Furthermore, IC can indicate type of macronutrient substrate (carbohydrate, fat or protein) predominantly utilized for energy production via the calculated respiratory
quotient (RQ) measure. The RQ scale ranges from 0.6 to 1.2 dependent on amount of carbon present in exhalation. For example, the lower containing carbon macronutrients protein and fat exhibit RQ’s of approximately 0.6 and 0.7 respectively when being used as the primary fuel source. Limitations of IC include inaccurate measurements related to poor lung function (i.e. when fraction of inspired oxygen is over 50%), requires an individual to not have chest tubes and that they are in a stable resting state for up to 30 minutes prior to testing, which can be difficult to achieve in a non-mechanically ventilated critically ill patient and may not be appropriate for patients on dialysis.

VII- Nutritional needs of the adult overweight and obese burn patient.

One of the most metabolic demanding injuries in the critical care setting is thermal or burn injury. Burn related injury elicits a significant catabolic response and consequent increase in the individual's macronutrient and micronutrient needs. It becomes increasingly hard to meet macronutrient needs including protein in a burn patient due to large protein loses via wound exudate and proteinuria experienced during the first five to ten days of a burn injury. In addition, patients, in the time period shortly following a burn injury, are often not able to take nutrition by mouth due to possible intubation, various surgeries and fluid resuscitation procedures which prevent the use of the GI tract for feeding. The physiological response to burn injury follows a stress-induced pathway, resulting in hypermetabolism and hypercatabolism, characterized by simultaneous increases in body temperature, glycogenesis, proteolysis and lipolysis. The inflammatory response that follows results in loss of lean body mass, muscle weakness, and poor wound healing. Thermal or burn injuries cause increased metabolic demands based on total amount of body surface area (TBSA) subjected to heat injury,
resulting in differing EE directly related to variations of TBSA injured. For example, an individual with a 10% TBSA burn injury has lower energy needs compared to an individual with a 30% TBSA burn injury. Utilizing IC in these patients may significantly reduce error with respect to macronutrient provision and allow clinicians to assess EE that more closely resembles actual needs.

It is important that precise EE calculations are conducted as part of clinical care for all patients, however, especially those who are susceptible to over and underfeeding. As overweight and obese patients are at higher risk for poor outcomes including prolonged LOS and mechanical ventilation days it is imperative predictive equations used in this population have been validated and deemed accurate for use. There is a gap in the literature regarding EE of non-critically ill vs. critically ill overweight and obese burn patients. Furthermore, only a small body of literature currently exists regarding the accuracy of predictive equations to estimate EE in these patients. The objective of the current study is to evaluate how energy needs estimated by predictive equation (Curreri) compare to energy needs measured by IC in overweight and obese adult burn patients (>20% TBSA).
Studies assessing the energy expenditure of a critically ill obese patients

Nutrition research on critically ill patients who require enteral and parenteral nutrition support has historically focused on the importance of meeting energy needs and defining what constitutes adequate provision of energy. The purpose of this literature review is to evaluate the literature published between July 2008 and September 2017 regarding research related to the measured versus estimated energy expenditure of critically ill burn patients and to identify gaps in the literature related to the energy expenditure of critically ill overweight and obese burn patients.

Two studies evaluated EE of critically ill patients where measured EE was compared to estimated or calculated EE using predictive equations\textsuperscript{22, 48}. Anderegg et al.\textsuperscript{22} conducted a single center observational study to determine which predictive equation accurately predicted estimated resting energy expenditure (REE) within 10\% of measured REE in 36 obese patients (15 males, 21 females, mean combined age of 49.6 years, mean combined BMI of 38.2) The sample included several different medical sub-groups (n=17 critical care/trauma, n=4 general surgery, n=3 transplant surgery, n=3 GI surgery, n=3 neurosurgery, n=2 surgical oncology, n=2 cardiothoracic surgery and n=1 ENT). Investigators utilized two different indirect calorimeters: a metabolic cart used on mechanically ventilated patients (n= 27) and a portable handheld device (Medgem\textsuperscript{TM}), which was used on spontaneously breathing subjects (n= 9). Seven predictive equations were evaluated including HBE with and without stress factors (stress factor 1.2 for acute non-critically ill patients n= 19, and 1.5 for critically ill n= 17), MSJ, IJ for ventilated...
patients, IJ for spontaneously breathing, and IJ for obese patients. In addition, fixed 21kcal/kg of actual BW, fixed 25kcal/kg of adjusted body weight and fixed 25kcal/kg of actual body weight based equations were also evaluated. Predictive equations used the adjusted ideal BW defined as the sum of ideal BW plus 25% of the difference between ideal weight and actual weight. The authors used limits-of-agreements parameters and standard deviations to compare each predictive equation with the measured IC. Overall, the investigators found that the predictive equation that most frequently predicted REE within measured REE of 10% was the HBE using adjusted ideal BW, with a stress factor of 1.5 for critical illness and a stress factor of 1.2 for acute non-critical injury. The authors stated that when the HBE and actual BW with no stress factor was evaluated using the Bland and Altman analysis, the equation had the greatest stability regarding limits of agreement (mean overprediction was the lowest absolute error at 110kcal). However, this calculation lacked precision predicting within 10% error for 38.9% of study participants. The least accurate equation was the IJ for obese and spontaneous breathing patients as they both only predicted within 10% margin of error for 5.6% of participants respectively. A limitation of this study was its small sample size. The study included no participants with a BMI over 40kg/m² making their results less generalizable to severely obese individuals. In addition, the inclusion of both critically ill and acute non-critically ill patients in the same study may have increased the occurrence for outliers and statistical bias due to additional confounding variables such as physiologic stresses increasing EE.

A study by Alves et al compared the performance of predictive equations to measured resting EE, using IC, in overweight and obese critically ill patients. The authors
conducted a prospective study that compared measured EE in fasting and fed state obese (defined as BMI \( \geq 30 \)) patients and compared the measured EE to predictive equations (HBE and IJ) calculated using actual BW, adjusted ideal BW \([(\text{actual BW} - \text{ideal BW}) \times 0.25] + \text{ideal BW}\). Ideal BW was defined based on the body frame applied to Metropolitan Insurance Company table, average BW \([(\text{actual BW} + \text{ideal BW})/2]\) and lastly a comparison of fixed BW equation; 21 calories/kg of actual body weight\(^{48}\) to measured EE. The investigators collected 71 IC measurements on \(N = 44\) patients (26 males, 18 females, average age of 59, average BMI 36.4, \(n=8\) bariatric surgical/fistulae, \(n=6\) septic/ARDS, \(n=5\) stroke, \(n=5\) COPD + acute respiratory failure, \(n=5\) coronary disease, \(n=4\) cancer, \(n=3\) aortic aneurysm, \(n=3\) abdominal surgery, \(n=2\) polytrauma, \(n=1\) neuro, \(n=1\) biliary pancreatitis and \(n=1\) hepatic encephalopathy). An indirect calorimeter (DEKTATRIC II\textsuperscript{®}) was used to measure EE for each mechanically ventilated patient, while those who were not mechanically ventilated had EE measured using a canopy attachment to the IC machine. Each patient was evaluated twice; the first IC measurement was obtained during a fasting state and the second IC was obtained 24 hours after reaching goal calories provided by either enteral or parenteral nutrition support. Results demonstrated that the HB equation using actual body weight was the closest to measured resting EE in both fed (\(n = 29, p < 0.004\)) and fasting states (\(n = 42, p < 0.0001\)). In addition, the IJ equation using adjusted IBW was shown to predict measured EE within 8% error \((p = 0.19)\). The 21 calorie per kg of actual body weight and IJ using actual body weight was found to be the least accurate. With the 21 calorie per kg overpredicted EE by 22% in the fasting state and 13% in the fed state, IJ overpredicting by 35% in the fasting state and 25% in the fed state. The limitations of this study included the heterogenous
diagnoses, which could have accounted for the large differences in REE reported. The authors concluded that, overall, there were large ranges of variability with the limits of agreement when REE predictive equations were compared to measured REE.

Mogensen et al 40 conducted a retrospective study of metabolic carts performed at their institution between 2004 and 2010 for the purpose of validating body weight predictive equations recommended in the 2013 ASPEN Guidelines for hospitalized critically ill and non-critically ill obese patients. The investigators also compared the 2013 ASPEN recommendations against widely used predictive equations, including HBE and IJ for obesity and evaluated predictive equation accuracy across differing classifications of obesity (obese, defined as BMI 30 - 50kg/m² and super obese, defined as BMI >50kg/m²). The following predictive equations and calories per kilogram ranges were evaluated: ASPEN Actual BW x (12.5 calories/kg), ASPEN. Ideal BW x (23.5 calories/kg), HB calculated using adjusted ideal BW [(actual weight – IBW) x 0.25] + Ideal BW, and IJ-Obesity equation calculated using actual body weight. The HAMWI method was utilized to calculate IBW for the ASPEN IBW equation. The authors also assessed the 2009 SCCM/ASPEN joint guidelines hypocaloric recommendations by comparing calculated predictive resting EE compared to 65% of measure resting EE via IC. A retrospective electronic medical chart review was conducted over the six-year time period on 257 patients who met the criteria of having a metabolic cart study requested 66 studies were for obese patients. Of the obese patients, 23 metabolic study requests were reported to be canceled prior to collection and 12 IC studies deemed inaccurate and therefore excluded. A total of 31 obese patients were included in the study (n=13 medical, n=4 trauma, n=2 burn [n=1 at 30% TBSA, n=1 at 40% TBSA], n=5 acute
respiratory distress syndrome, n=4 cardiac surgery, n=1 fasciitis, n=1 skin graft-versus-host disease requiring surgical intervention). A predicted resting EE was reported to be precise when the upper bound of 95% confidence interval (CI) was \( \leq 15\% \), with bias intervals calculated by the difference of measured resting EE and predicted resting EE using 95% CI values. As defined by the authors, unbiased CI were values which overlapped zero, which indicated the predictive equation did not over or underestimate calorie needs when compared to 65% of measured resting EE. Authors defined accuracy when predictive equation resting EE fell within 55-75% of the measured resting EE (± 10%). A predictive equation was defined as accurate if at least 70% of the patients predicted calorie needs were plotted within this range. The HBE using a stress factor of 0.65 and ASPEN Ideal BW x 23.5 kcal had the highest correlation to 65% measured resting EE for the total cohort. All of the predictive equations were found to be imprecise and predicted < 65% measured REE. Fewer than 70% (n = 21) of the participants had predicted EE within the defined ± 10% of 65% measured resting EE. The predictive equations performed better when analyzed as part of the obesity defined subgroups. For the obese subgroup, all four predictive equations were deemed unbiased. Furthermore, the ASPEN IBW formula (23.5 kcal/kg) was found to be unbiased with relatively good predictive accuracy for the super obese subgroup. There was wide variation in the average predictive resting EE to measured resting EE. In the total cohort there was a 710kcal difference between average measured resting EE and EE predicted by the HBE, with the greatest average difference for the total cohort being between the measured resting EE and ASPEN Ideal BW equation (difference of 797kcal). The limitations of this study included small sample size, retrospective data collection of variables such as
height, weight and BMI as accuracy was not able to be verified. In addition illness severity such as other critical illness related injuries or co-morbidities was not available. The study also did not identify participant race or ethnicity, which may limit generalizability. Authors did not control for possible confounding variables, including use of paralytics nor did they identify the presence or absence of fever, which are known to influence EE.

Stucky et. al\textsuperscript{26} conducted a retrospective study with the primary objective being to evaluate the accuracy of three predictive equations, HBE, Cunningham, and the Diabetic Prediction equation compared to measured resting EE\textsuperscript{26}. The secondary objective was to determine the accuracy and requirement of stress factors used in predictive equations. The investigators tested each equation on its own and then with an added injury factor of 20\% to account for elevated EE due to stress caused by trauma and critical illness. The investigators used actual BW for the HB and Diabetic Prediction equations and fat-free mass for the Cunningham equation. Fat-free mass was calculated by the sum of the participants’ ideal weight, as defined as BMI 25 with the addition of actual weight minus ideal weight multiplied by 0.25 (or 25\%). The authors did not report how ideal body weight was calculated. Data was analyzed using the Bland and Altman analysis. A total of 28 obese participants (n=19 trauma and n=9 burn ages, genders not identified) were included (BMI range 30-40kg/m\textsuperscript{2}, burn patient TBSA range 20-67\%). Only one IC measurement was obtained on each participant during the post-acute period of injury (initial 3-5 days). The authors reported that the HB equation underpredicted resting EE the least, by 14\% as a standalone equation. The Cunningham equation had the most significant bias of underprediction, on average underpredicting by 31\% of measured
EE. The authors reported the Cunningham equation with the injury factor was the least likely to underpredict bias for both the trauma and burn populations, with an underprediction of 9%. Both the HB and the Diabetic Prediction equations overestimated resting EE when the injury factor was utilized. Authors reported the average measured REE for both groups was 21kcal/kg/d. Limitations of this study included small sample size, participants with BMI > 45kg/m² were not included, limiting the generalizability of results to all classes of obesity. Variations in TBSA (20-67%) may have caused a wide variation in EE. Authors did not account for possible analysis of energy differences or bias of equations amongst potential sub-groups of TBSA percentage.

II – Summary of previous studies and rationale.

Predictive equations have been compared to measured resting EE in critically ill overweight and obese patients. The most studied predictive equations during the time period of the current literature review were the HBE and IJ equations. Investigators studied factors that influenced estimated energy needs from predictive equations including the use of different body weights (actual BW, ideal BW and adjusted ideal BW) in conjunction with calorie per kilogram formulas. All of the studies reviewed demonstrated that HB equation without an injury factor best predicted measured resting EE in obese hospitalized critically ill patients. Although all the studies assessed the needs of critically ill overweight or obese patients, it is important to note that amongst these studies only the study by Stucky et al and Mogensen et al included patients that had a burn injury; nine and two participants respectively. Of concern was the analysis of the sample as one group, this may not show accurate validation of the predictive equation as the sample size likely had varying types of
injuries which cause variations to EE. Only one study assessed the data in subgroups of BMI categories, reporting how predictive equations demonstrate bias and that a one-size fits all approach for predictive equation use may not be appropriate. No studies reported ethnicity or race or other influencing factors, including fever which can significantly affect EE during IC measurements. However, the study by Alves et al did conduct IC measurements in both the fasting and fed states, accounting for the thermogenic effect of food, which has a small effect on EE. There is a gap in the literature which addresses the use of predictive equations specifically in overweight and obese critically ill burn patients. Furthermore, there is a gap in the literature that demonstrates how varying total burn surface areas amongst different BMI obese subgroups (obese class I, class II and class III) influences the validity of predictive equation use. This study aims to address how energy needs estimated by predictive equations (Curreri) compare to energy needs as measured by IC in overweight and obese adult burn patients with >20% TBSA.
Chapter 3
Methodology

I. IRB Approval

The original Institutional Review Board Protocol application was submitted to the University Of New Mexico Human Research Protections Office Institutional Review Board in April 2016 and IRB approval was granted June 2016. Protocol continuing review application and protocol deviations report for change in methodology to retrospective data collection was submitted February 2017 and IRB approval was granted May 2017. After approval, screening and recruitment was initiated May 2017.

II. Research Design

This study was a quasi-experimental retrospective design. The independent variables included the predictive equations. The dependent variables included measured EE and ICU LOS. The categorical variable was BMI and the continuous variables were height, weight and body temperature. Usual care for all University of New Mexico Hospital (UNMH) patients includes measuring height and weight in the UNMH emergency room prior to the initiation of fluid resuscitation. For the purpose of this study weight and height data was only collected once to determine BMI. This was the weight documented in the Electronic Medical Record (EMR) with a date and time stamp ± 30mins of the admission date and time. Only the weight measurement captured during the admission period was used to avoid weight data which may have been falsely increased post onset of fluid resuscitation. The data accessed from the EMR including actual BW, height, BMI, ideal BW, adjusted ideal BW, goal rate of feeding and IC measurements are all components of a standard nutrition assessment. Calculations by the RDN of energy needs using predictive equations is considered standard care for UNMH ICU patients and
usually occurred within the first 1-3 days of admission.

Inclusion criteria included males and females between 18 and 65 years of age, TBSA >20%, BMI > 25kg/m2, had one or more IC measurements obtained within week 1 – 4 of initial injury, and an admission BMI which categorized them as overweight or obese, and admitted to the UNMH Trauma, Burn and Surgical (TBSI) ICU. The exclusion criteria of this study included individuals who were pregnant, under the age of 18 years or over the age of 65 years at the time of UNMH TBSI ICU admit and had a TBSA <20%.

**Sampling and recruitment**

Nonprobability, convenience sample was obtained from the accessible population of UNMH TBSI ICU due to the Student Investigator being an employee of the hospital and having access to the identified patient population.

**III. Data Collection**

*Screening*

Screening was conducted by auditing the UNMH TBSI ICU patient log book. The purpose of screening was to obtain potential participants medical record numbers (MRN), age and admission diagnosis (N = 368). The UNMH TBSI ICU log books were utilized to screen for potential participants from January 2011 to December 2016. The ICU log books (ledgers) are written records tracking patients physical location, admit date/discharge, admission diagnosis and MRN. Potential participants (n = 32) were screened for admit diagnosis "Burn", TBSA ≥ 20%, BMI ≥ 25kg/m², aged between 18-65 years and a negative pregnancy test. If a potential participant met this criteria the MRN was documented on a screening form (see Appendix 1). Once potential participants were
identified the MRN was used to access the medical health record via “Powerchart”, which is the UNMH designated, password protected, EMR system which houses all patient records. Power chart access is granted to clinical personnel by UNMH health care providers once completion of HIPAA training and background check (upon employment) is completed.

Data that was abstracted from the EMR included; demographic information (gender and ethnicity), medical (primary diagnosis, ICU admit/discharge date, date fluid resuscitation was completed and comorbidities on admit) and date/time of IC, IC data (respiratory quotient, EE, feeding method), anthropometric data (height and weight), EE as calculated by the Curreri equation, FIO₂, maximum temperature within 24hours prior to IC, surgery 24hours prior to IC, and use of oxandralone 24 hours prior to IC (see Appendix Two for Data Tool and Appendix Three for equation). Only data from the ICU admission for burn injury was included in the data analysis, even if an individual had previous hospital admissions.

It was anticipated that participants would be participating in the study from admission until discharge or transfer out of the ICU. Once a participant had left the ICU their inclusion in the study concluded.

**IC Measurement Protocol** (see Appendix Three): This study followed the UNMH standard of care for IC measurement, every patient admitted to the ICU with >20% TBSA. For full timeline of how the IC was measured and IC operational definitions (see Appendix Three UNMH Pulmonary Diagnostics procedure for IC measurements). Per UNMH policy and for the purposes of this study, IC measurements were assumed to have been collected in a unified manner in accordance to the steps specified in the policy (Appendix Three).
*Nutrition Assessment* (see Appendix Four): Once participants were deemed eligible for inclusion in the study, anthropometric data collected from the medical record was used to calculate BMI, ideal BW, and adjusted ideal BW. In combination with the reported TBSA percentage from the medical record, the predicted EE using the Curreri equation was also calculated, (see Appendix Four).

**Data Storage**

Each participant was assigned a unique study identification number that linked the study data to Private Health Information for the protection of confidentiality during data collection and data analysis. A password protected REDCap account was used to house all electronic study data, and only the investigator had access to this database.

**IV. Data Analysis**

For statistical analysis of the data, STATA Data Analysis and Statistical Software, version 15, released 2017 (StataCorp LLC, 4905 Lakeway Drive College Station, Texas 77845-4512 USA) was used.

Demographic and anthropometric data, including; Age, height, gender, ethnicity, BMI, actual BW, ideal BW and adjusted ideal BW were reported using descriptive statistics, measures of central tendency (means and percentiles) and dispersion (standard deviations). In addition TBSA %, ICU LOS, days until first IC measure, intubation at time of first IC measure, having two or more IC measures during the first 4 weeks of admit and average days ventilated during the first 4 weeks were analyzed using descriptive statistics, measures of central tendency (means and percentiles) and dispersion (standard deviations).
Comparison of measured EE to predictive EE Analysis

After demographic and medical data was analyzed, descriptive statistics (means and standard deviations) of the predicted energy expenditure and measured energy expenditure (delineated as calories) were computed. The count of participants whom energy expenditure calculated by predictive equation using actual BW or ideal BW came within ±10% error of their corresponding measured (n = 13) and the count of participants whom energy expenditure calculated by predictive equation using adjusted ideal BW came within ±10% error of their corresponding measured (n = 7) were reported to determine the average occurrence which the equation performed within the acceptable error margin. For the purposes of absolute error, an over or under prediction of 200 calories was considered significant and therefore was also analyzed.

Non-parametric, Wilcoxin sign rank test analysis was conducted to test the strength of the difference between mean predictive energy expenditure (via Curreri formula) and measured IC, interchanging the independent variables of actual, ideal or adjusted ideal BW within the equation. Statistical significance was set at p <0.05. Absolute error (Kcals) and relative calculation error (percentage of bias) was assessed. In addition, an acceptable margin of error was set at ±200kcals and ±10%.

A post hoc sensitivity analysis was undertaken to further analyze results with the removal of outliers.
I. Participants

A total of 368 patients were identified who had an ICU LOS greater than three days and with an admitting diagnosis of ‘burn injury’ during the time period of January 1, 2011 and December 31, 2016. Of these, $n=277$ (75.3%) patients were deemed ineligible due to TBSA% < 20%; $n=32$ (8.6%) were either under the age of 18 years or over the age of 65 years and 27 (7.3%) had a BMI <25kg/m$^2$. Of the remaining 32 patients, 19 (59.4%) did not receive IC within the first four weeks of admission to the ICU. A total of $n=13$ (3.5%) of the total screened patients ($N = 368$) met the inclusion criteria (see Figure 1).
II. Chart Review Data

Patient Characteristics: Total Sample

A total of 13 patients met all of the inclusion criteria. Of the 13 participants, 12 participants (92%) were male and one (8%) was female. Age ranged from 25 years to 62 years (mean 44 years; SD ± 12.5). Hispanic/Latino was the most common ethnicity (n= six, 46.2%); White/Caucasian (n= two; 15.4%), American Indian/Alaska Native (n=2; 15.4%), four participants (23%) did not state their ethnicity. In males, the mean BMI was 32.6 (SD ± 9.6; range 25.4 to 59.1) and the BMI of the female was 26.5. Seven study participants were classified as overweight and six were classified as obese.

Patient Characteristics: Overweight (BMI 25-29.99)

Fifty-four percent of study participants were classified as overweight by BMI. Of these overweight participants, six (86%) were male (n= six), one (14%) was female. The overweight participants had an age range of 26-62 years (mean 40 years; SD ± 12.2). A
total of five (71.4%) participants in the overweight group identified as Hispanic/Latino. One (14.3%) participant and one (14.3%) did not identify their ethnicity. There were no participants who identified as White/Caucasian in the overweight group.

*Patient Characteristics: Obese (BMI > 30)*

Six (46%) were classified as obese by BMI. Of these, 100% were male and the age range was 25-60 years (mean years 49, SD ± 12.1). One (16.7%) participant in the obese group identified as Hispanic/Latino, two (33.3%) participants identified as White/Caucasian, one (16.7%) identified as American Indian/Alaska Native and two (33.3%) did not identify their ethnicity. The mean BMI was 38.6 (SD ± 10.8; range of 30.01 to 59.1). Within the obese group, three (50%) were classified as class I obesity, two (33.3%) were class II obesity and one (16.7%) was class III obesity. Mean admit BW in the obese participants was 112.3kg (SD ± 30.6; range of 79.9 to 161kg). The mean ideal BW was 68.2kg (SD ± 12.5) and adjusted ideal BW was 79.2kg (SD ± 13.9). The mean height was 170.7cm (SD ± 10.1; range of 163 cm to 193cm) for the obese participants.

Compared to the overweight participants, the obese participants, on average, were 7.4cm shorter and weighed 27kg more, the average obese BMI was 38.6 compared to the average overweight participants BMI was 26.7. Table 1 summarizes the patient characteristics for total cohort, and the overweight and obese groups.
### Table 1. Patient Characteristics (N =13)

<table>
<thead>
<tr>
<th></th>
<th>Total Cohort (N = 13)</th>
<th>Overweight, BMI 25-29.99kg/m² (n = 7)</th>
<th>Obese, BMI ≥ 30 kg/m² (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) mean±SD</td>
<td>44±12.5</td>
<td>40±12.3</td>
<td>49±12.1</td>
</tr>
<tr>
<td>Height (cm) mean±SD</td>
<td>174.7±10.8</td>
<td>178.1±9.8</td>
<td>170.7±10.1</td>
</tr>
<tr>
<td>Gender mean and (male %)</td>
<td>12 (92%)</td>
<td>6 (86%)</td>
<td>6 (100%)</td>
</tr>
<tr>
<td>Ethnicity mean and (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White/Caucasian</td>
<td>2 (15.4%)</td>
<td>0 (0%)</td>
<td>2 (33.3%)</td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>6 (46.2%)</td>
<td>5 (71.4%)</td>
<td>1 (16.7%)</td>
</tr>
<tr>
<td>American Indian/Alaska Native</td>
<td>2 (15.4%)</td>
<td>1 (14.3%)</td>
<td>1 (16.7%)</td>
</tr>
<tr>
<td>Not Stated</td>
<td>4 (23.0%)</td>
<td>1 (14.3%)</td>
<td>2 (33.3%)</td>
</tr>
<tr>
<td>BMI (kg/m²) mean±SD</td>
<td>32.2±9.4</td>
<td>26.7±1.3</td>
<td>38.6±10.7</td>
</tr>
<tr>
<td>Admit BW (kg) mean±SD</td>
<td>97.6±25.5</td>
<td>85±10.7</td>
<td>112±30.6</td>
</tr>
<tr>
<td>IBW (kg) mean±SD</td>
<td>72.2±12.4</td>
<td>75.7±12.1</td>
<td>68.2±12.5</td>
</tr>
<tr>
<td>Adjusted IBW for Obese patients only (kg)</td>
<td></td>
<td></td>
<td>79.2±13.9</td>
</tr>
</tbody>
</table>

BMI, body mass index; Admit BW, admit body weight; IBW, ideal body weight; Adjusted IBW, adjusted ideal body weight.

### Table 2. Medical Characteristics for Total Sample (N =13)

<table>
<thead>
<tr>
<th></th>
<th>Total Cohort (N = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total body surface area % burned (range)</td>
<td>23 to 86%</td>
</tr>
<tr>
<td>ICU LOS (days) mean±SD</td>
<td>73±55</td>
</tr>
<tr>
<td>Days until first IC measure mean±SD</td>
<td>10.4±7.9</td>
</tr>
<tr>
<td>Intubated at time of first IC mean and (%)</td>
<td>11 (85%)</td>
</tr>
<tr>
<td>Obtained two IC measures during week 1-4 of admit mean and (%)</td>
<td>6 (46%)</td>
</tr>
<tr>
<td>Average number of days ventilated during first 4 weeks (days) mean ±SD</td>
<td>17.9±11.5</td>
</tr>
</tbody>
</table>

ICU, intensive care unit, LOS, length of stay, IC, indirect calorimetry.
Medical Characteristics, Total Sample

Of the 13 eligible participants, three (23%) participants had hypertension, two (15.3%) with chronic asthma and one (7.6%) had prediabetes. Other comorbidities of participants included: obstructive sleep apnea (n=1, 7.6%), alcohol misuse syndrome (n=1, 7.6%), epilepsy (n=1, 7.6%), chronic pain and anxiety (n=1, 7.6%), and intravenous drug misuse (n=1, 7.6%). The TBSA% range for the total sample was 23% to 86%. Two participants (15.3%) had a documented inhalation injury.

The mean LOS in the ICU was 73 days (SD ± 16; range of 21 to 177 days). Eleven (84.6%) participants required mechanical ventilation. The average number of days those participants requiring mechanical ventilation within the first four weeks of admission to the ICU was 16.15 (SD ± 12.2; range 1 to 31). Two (18%) participants requiring mechanical ventilation were ventilated beyond the first month of ICU stay. Eleven (85%) of the participants were intubated at the time of the first IC measure and only two (14%) participants were not intubated at the time of the first IC. All participants had an FIO2, ≤50% and were deemed to have achieved steady state during the IC collection period. Of the total sample only six (46%) participants had a second IC measurement collected within the four week study. The mean number of days until the first IC measure was 10.4 days (SD ± 7.9).

Six participants had two IC measures during the four week study period and the mean number of days after ICU admission and at first IC was 9.6 (SD ± 7.7), compared to 11.3 days (SD ± 8.5) for participants who had only one IC measure. No significant difference (p = 0.676) was found between the participants who had a second IC compared to those who only had one IC measure. Table 2 summarizes the clinical characteristics.
Table 3. Medical Characteristics of participants by BMI group (overweight or obese).

<table>
<thead>
<tr>
<th></th>
<th>Overweight, BMI 25-29.99kg/m² (n = 7)</th>
<th>Obese, BMI ≥ 30 kg/m² (n = 6)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total body surface area % burned, range</td>
<td>23 to 86%</td>
<td>25 to 46%</td>
<td>0.596</td>
</tr>
<tr>
<td>ICU LOS (days) mean±SD</td>
<td>76.9±65</td>
<td>68.5±46.2</td>
<td>0.799</td>
</tr>
<tr>
<td>Days until first IC measure mean±SD</td>
<td>10.9±8</td>
<td>9.8±8.4</td>
<td>0.827</td>
</tr>
<tr>
<td>Intubated at time of first IC mean and (%)</td>
<td>5 (71%)</td>
<td>10 (100%)</td>
<td></td>
</tr>
<tr>
<td>Obtained two IC measures during week 1-4 of admit mean and (%)</td>
<td>3 (43%)</td>
<td>3 (50%)</td>
<td></td>
</tr>
<tr>
<td>Average number of days ventilated during first 4 weeks (days) mean ±SD</td>
<td>13±11.9</td>
<td>23.7±8.5</td>
<td></td>
</tr>
</tbody>
</table>

ICU: intensive care unit, LOS: length of stay, IC: indirect calorimetry

Medical Characteristics: Overweight (BMI 25-29.99) and Obese (BMI > 30)

The TBSA% range for the overweight group was 23% to 86% while the TBSA% range for the obese group was 25% to 46%. The average ICU LOS for the overweight group was 76.9 days (SD ± 65; range 22 to 177 days) and for the obese group 68.5 days (SD ± 46.2; range 21 to 154 days). The mean ICU LOS of the overweight participants was 8.4 days longer (p = 0.799) compared to the obese participants, however this may be attributed to a higher mean TBSA% of the overweight participants. The mean number of days (within the first four weeks of ICU admission) of mechanical ventilation for the overweight participants was nine days (SD ± 11.5) and for the obese participants this was 24.5 days (SD ± 6.7). A difference of 15.5 days between the mechanical ventilation days of the two groups was found. However, no significance could be determined due to small sample size. Five (71%) overweight participants were intubated at the time of the first IC measurement and two participants were not. All of the obese participants were ventilated at the time of the first IC measurement. Of the overweight group only three (42.8%) had a second IC measurement within the first 4 weeks while three (50%) of the obese group
had a second IC measurement obtained within four weeks. In the overweight group, the average number of days until the first IC measure was 10.8 days (SD ± 8; range 3 to 23 days). In the obese group the mean number of days was 8.4 (SD ± 8.4; range 4 to 23 days) from admission to the ICU to first IC and this difference was not statistically significant (p = 0.827). Table 3 presents the clinical characteristics for each overweight or obese group.

III. Measured EE by IC and Estimated EE using the Curreri equation

Comparison of calculated EE by different BW to measured EE for first IC

The mean EE obtained at the first IC measurement was 3289kcals (SD ± 970; range 2164 to 5910 kcals). This equates to a mean of 34.7 kcals/kg when using admit BW and 47.7 kcals/kg based on ideal BW. For the six participants who met the criteria to use adjusted ideal BW, the average measured kcals/kg was 34.3. The mean measured EE in the overweight group was 2930 kcals (SD ± 567; range 2164 to 3806 kcals) and in the obese group the mean measured EE was 3705 kcals (SD ± 1220; range 2445 to 5910 kcals).

The mean estimated EE using admit BW in the Curreri equation for the total sample was 4086 kcals (SD ± 824; range of 2670 to 5668 kcals) and 3896 kcals (SD ± 912; range of 2670 to 5668kcals) for the overweight group. For the obese group, mean estimated EE calculated with the Curreri equation using admit BW was 4309 kcals (SD ± 721; range of 3718 to 5400kcals).

The mean calculated EE using ideal BW for the total sample was 3400 kcals (SD ± 662; range 2497 to 4805kcals) and for the obese group was 3173 kcals (SD ± 585;
range 2549 to 4127 kcals). Using the Curreri equation, the overweight group had a calculated mean EE of 3595 kcals (SD ± 702; range 2497 to 4805 kcals).

In the obese participants (n=6) for whom the Curreri equation was calculated using adjusted ideal BW the mean measured EE was 3705 kcals (SD ± 1220; range 2164 to 5910 kcals) compared to calculated EE of 3480 kcals (SD ± 586; range 2997 to 4589 kcals). Table 4 summarizes EE calculated by Curreri, using admit BW, ideal BW and adjusted ideal BW to measured EE for the first IC.
Table 4. Descriptive results of Curreri equation and first IC for total sample (n = 13) and by different body weight used in equation (actual BW, ideal BW or adjusted ideal BW) and BMI classifications (Overweight n = 7 and Obese n = 6).

<table>
<thead>
<tr>
<th></th>
<th>First IC measure (mean±SD) (kcals)</th>
<th>First IC measure (median Kcals)</th>
<th>Curreri EE (mean±SD) (kcals)</th>
<th>Curreri EE (median Kcals)</th>
<th>Curreri EE (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual BW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 13)</td>
<td>3288±970</td>
<td>3151</td>
<td>4086±824</td>
<td>3905</td>
<td>2670-5668kcals</td>
</tr>
<tr>
<td>Overweight (n =7)</td>
<td>2930±567</td>
<td>3018</td>
<td>3896±912</td>
<td>3798</td>
<td>2670-5668kcals</td>
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<td>Obese (n =6)</td>
<td>3705±1220</td>
<td>3365</td>
<td>4309±721</td>
<td>3985</td>
<td>3718-5400kcals</td>
</tr>
<tr>
<td>Ideal BW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 13)</td>
<td>3288±970</td>
<td>3151</td>
<td>3400±662</td>
<td>3417</td>
<td>2497-4805kcals</td>
</tr>
<tr>
<td>Overweight (n =7)</td>
<td>2930±567</td>
<td>3018</td>
<td>3595±702</td>
<td>3527</td>
<td>2497-4805kcals</td>
</tr>
<tr>
<td>Obese (n =6)</td>
<td>3705±1220</td>
<td>3365</td>
<td>3172±586</td>
<td>3071</td>
<td>2549-4127kcals</td>
</tr>
<tr>
<td>Adjusted Ideal BW</td>
<td>Obese (n =6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 6)</td>
<td>2996±642</td>
<td>3260</td>
<td>4014±824</td>
<td>4022</td>
<td>2670-5400kcals</td>
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<tr>
<td>Overweight (n =3)</td>
<td>2616±760</td>
<td>2744</td>
<td>3571±781</td>
<td>3988</td>
<td>2670-4055kcals</td>
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<td>Obese (n =3)</td>
<td>3376±146</td>
<td>3412</td>
<td>4457±821</td>
<td>4065</td>
<td>3905-5400kcals</td>
</tr>
</tbody>
</table>
| Kcals, calories; BMI, body mass index; IC, Indirect Calorimetry; BW, Body Weight

Table 5. Descriptive results of Curreri equation and second IC for (n = 6) and by different body weight used in equation (actual BW, ideal BW or adjusted ideal BW) and BMI classifications (Overweight n = 3 and Obese n = 3).

<table>
<thead>
<tr>
<th></th>
<th>Second IC measure (mean±SD) (kcals)</th>
<th>Second IC measure (median Kcals)</th>
<th>Curreri EE (mean±SD) (kcals)</th>
<th>Curreri EE (median Kcals)</th>
<th>Curreri EE (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual BW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 6)</td>
<td>2996±642</td>
<td>3260</td>
<td>4014±824</td>
<td>4022</td>
<td>2670-5400kcals</td>
</tr>
<tr>
<td>Overweight (n =3)</td>
<td>2616±760</td>
<td>2744</td>
<td>3571±781</td>
<td>3988</td>
<td>2670-4055kcals</td>
</tr>
<tr>
<td>Obese (n =3)</td>
<td>3376±146</td>
<td>3412</td>
<td>4457±821</td>
<td>4065</td>
<td>3905-5400kcals</td>
</tr>
<tr>
<td>Ideal BW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 6)</td>
<td>2996±642</td>
<td>3260</td>
<td>3420±671</td>
<td>3645</td>
<td>2497-4127kcals</td>
</tr>
<tr>
<td>Overweight (n =3)</td>
<td>2616±760</td>
<td>2744</td>
<td>3391±778</td>
<td>3762</td>
<td>2497-3913kcals</td>
</tr>
<tr>
<td>Obese (n =3)</td>
<td>3376±146</td>
<td>3412</td>
<td>3449±719</td>
<td>3527</td>
<td>2694-4127kcals</td>
</tr>
<tr>
<td>Adjusted Ideal BW</td>
<td>Obese (n =3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 3)</td>
<td>3376±146</td>
<td>3412</td>
<td>3749±800</td>
<td>3365</td>
<td>2997-4589kcals</td>
</tr>
</tbody>
</table>
| Kcals, calories; BMI, body mass index; IC, Indirect Calorimetry; BW, Body Weight

31
Comparison of calculated EE by different BW to second IC measurement of EE

Six (46.1%) participants had a second IC measurement obtained within the first four weeks of ICU admission. The mean measured EE was 2996 kcals (SD ± 642; range 1801 to 350 kcals) which equates to an average of 31.2 kcals/kg when using admit BW and 40.7 kcals/kg when using ideal BW. For the three participants who met criteria to use adjusted ideal BW the average measured EE was 41.9 kcals/kg. For the overweight group (n = 3), the measured EE was 2616 kcals (SD ± 760; range 1801 to 3500 kcals) and obese 3376 kcals (SD ± 146; range 2215 to 3500 kcals).

For the sample of participants who had received a second IC, the average estimated EE using admit BW in the Curreri equation was 4014 kcals (SD ± 824; range 2670 to 5400 kcals). The mean calculated EE for the overweight group was 3571 kcals (SD ± 781; range 2670 to 4055 kcals) and was 4457 kcals (SD ± 821; range 3905 to 5400 kcals) for the obese group.

For the sample of participants who had received a second IC, the mean estimated EE using ideal BW in the Curreri equation was 3420 kcals (SD ± 671; range 2497 to 4127 kcals) and for the overweight group was 3391 kcals (SD ± 778; range 2497 to 3923 kcals). The obese group had a mean calculated EE of 3449 kcals (SD ± 719; range 2694 to 4127 kcals).

In the obese participants (n=3) who had the Curreri calculated using adjusted ideal BW the mean measured EE was 3376 kcals (SD ± 146; range 3215 to 3500 kcals) and the calculated EE was 3749 kcals (SD ± 800; range 2997 to 4589 kcals). Table 5 summarizes EE calculated by the Curreri equation, using admit BW, ideal BW and adjusted ideal BW to measured EE for the second IC.
Table 6. Analysis of bias in Curreri predictive equation using actual BW compared to first IC and second IC (Wilcoxon Sign Rank).

<table>
<thead>
<tr>
<th></th>
<th>Curreri absolute error mean±SD (p-value)</th>
<th>Curreri relative error mean±SD (p-value)</th>
<th>Frequency of Curreri calculations which met ±200kcals bias frequency(%)</th>
<th>Frequency of Curreri calculations which met ±10% bias frequency(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First IC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 13)</td>
<td>799±1019 (0.019)</td>
<td>29%±29 (0.011)</td>
<td>0/13(0%)</td>
<td>0/13(0%)</td>
</tr>
<tr>
<td>Overweight (n = 7)</td>
<td>966±567 (0.018)</td>
<td>33%±21 (0.018)</td>
<td>0/7(0%)</td>
<td>0/7(0%)</td>
</tr>
<tr>
<td>Obese (n = 6)</td>
<td>604±1421 (0.249)</td>
<td>25%±36 (0.173)</td>
<td>0/6(0%)</td>
<td>0/6(0%)</td>
</tr>
<tr>
<td><strong>Second IC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 6)</td>
<td>1018±543 (0.028)</td>
<td>35%±18 (0.027)</td>
<td>0/6(0%)</td>
<td>0/6(0%)</td>
</tr>
<tr>
<td>Overweight (n = 3)</td>
<td>955±322 (0.109)</td>
<td>39%±16 (0.103)</td>
<td>0/3(0%)</td>
<td>0/3(0%)</td>
</tr>
<tr>
<td>Obese (n = 3)</td>
<td>1081±788 (0.109)</td>
<td>32%±23 (0.109)</td>
<td>0/3(0%)</td>
<td>0/3(0%)</td>
</tr>
</tbody>
</table>

Kcals, calories; BMI, body mass index; IC, Indirect Calorimetry

Table 7. Analysis of bias in Curreri predictive equation using ideal BW compared to first IC and second IC (Wilcoxon Sign Rank).

<table>
<thead>
<tr>
<th></th>
<th>Curreri absolute error, ±200kcals mean±SD</th>
<th>Curreri relative error, ±10% mean±SD</th>
<th>Frequency of Curreri calculations which met ±200kcals bias frequency(%)</th>
<th>Frequency of Curreri calculations which met ±10% bias frequency(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First IC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 13)</td>
<td>+112±1220 (0.173)</td>
<td>+10%±29 (0.133)</td>
<td>2/13(15.4%)</td>
<td>3/13(23%)</td>
</tr>
<tr>
<td>Overweight (n = 7)</td>
<td>+664±371 (0.018)</td>
<td>+23%±17 (0.018)</td>
<td>1/7(14.3%)</td>
<td>1/7(14.3%)</td>
</tr>
<tr>
<td>Obese (n = 6)</td>
<td>-531±1575 (0.753)</td>
<td>-6%±33 (0.753)</td>
<td>1/6(16.7%)</td>
<td>2/6(33.3%)</td>
</tr>
<tr>
<td><strong>Second IC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sample (n = 6)</td>
<td>+424±565 (0.075)</td>
<td>+17%±21 (0.075)</td>
<td>1/6(16.7%)</td>
<td>1/6(16.7%)</td>
</tr>
<tr>
<td>Overweight (n = 3)</td>
<td>+775±215 (0.109)</td>
<td>+31%±12 (0.109)</td>
<td>0/3(0%)</td>
<td>0/3(0%)</td>
</tr>
<tr>
<td>Obese (n = 3)</td>
<td>+74±619 (0.593)</td>
<td>-2%±19 (0.593)</td>
<td>1/3(33.3%)</td>
<td>1/3(33.3%)</td>
</tr>
</tbody>
</table>

Kcals, calories; BMI, body mass index; IC, Indirect Calorimetry

Table 8. Analysis of bias in Curreri predictive equation using adjusted ideal BW compared to first IC and second IC (Wilcoxon Sign Rank).

<table>
<thead>
<tr>
<th></th>
<th>Curreri absolute error, ±200kcals mean±SD</th>
<th>Curreri relative error, ±10% mean±SD</th>
<th>Frequency of Curreri calculations which met ±200kcals bias frequency(%)</th>
<th>Frequency of Curreri calculations which met ±10% bias frequency(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First IC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obese (n = 6)</td>
<td>-224±1535 (0.917)</td>
<td>+2%±34 (0.753)</td>
<td>1/6(16.7%)</td>
<td>1/6(16.7%)</td>
</tr>
<tr>
<td><strong>Second IC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obese (n = 3)</td>
<td>+669±718 (0.180)</td>
<td>+11%±22 (0.593)</td>
<td>1/3(33.3%)</td>
<td>2/3(66.7%)</td>
</tr>
</tbody>
</table>

Kcals, calories; BMI, body mass index; IC, Indirect Calorimetry

33
IV. Participants calculated Curreri energy expenditure bias compared to measured EE by IC.

**Total Sample: Proportion of over and under calculation of EE by Curreri equation to first IC**

For the 13 participants, none met the 200kcals or ±10% calculation error for the Curreri equation using actual BW (refer to Table 6). On average, the use of actual BW resulted in an over calculation of +799 kcals (SD ± 1019; range of -2005 to +2249kcals) when compared to measured EE obtained during the first IC measurement (p=0.019). For relative bias, a mean over calculation of 29% (SD ± 29; range -34% to 75%) occurred (p = 0.011).

For the Curreri equation using ideal BW, two participants (15.4%) met the ±200 kcals acceptable margin of error and three (23%) participants met the ±10% calculation equation error (refer to table 7). No significant difference was detected using ideal BW, showing a mean over calculation of +112kcals (SD ± 1220; range -3215 to +1253kcals; p = 0.279) and for relative error, a mean over calculation of +10% (SD ± 29; range -54 to +58%; p = 0.133). For the total sample, the Curreri equation using ideal BW appeared to have greater accuracy with a demonstrated lower margin of error than admit BW.

**Proportion of over and under calculation of EE by the Curreri equation to second IC measurement in the total sample**

Of the participants (n=6) who had a second IC measurement obtained, the Curreri equation, calculated with admit BW, 100% exceeded the ±10% and 200kcals calculation error (refer to table 6). On average, an absolute error over calculation of +1018kcals (SD ± 543; range +565 to +1988kcals (p = 0.028) and a relative error over calculation of
+35% (SD ± 18; range +16 to +58%; p = 0.027), was reported when compared to measured EE for the second IC.

Using the Curreri equation with ideal BW, one of six participants had a calculated EE within ±200kcal or 10% calculation error (refer to table 7). An average over calculation of +424kcal (SD ± 565; range of -521 to +1018kcal; p = 0.34) and +17% (SD ± 21; range -16% to +39%; p = 0.074) was reported. For the six participants who received a second IC, the Curreri equation using ideal BW appeared to have greater accuracy with a demonstrated lower margin of error than admit BW.

Overweight group: Proportion of over and under calculation of EE by Curreri equation to first and second IC

There was a significant difference (p = 0.018) when comparing measured EE (1st IC measurement) to the Curreri equation using admit BW with a mean over calculation of EE by +966kcal (SD ± 567; range +268 to +1862kcal). This equated to a relative error of +33% (SD ± 21; range +11 to +75%; p = 0.011), refer to table 6. No participant met either the ±200 kcal or 10% calculation error. For the first IC in the overweight group (n=7) using the Curreri equation with ideal BW, only one had a calculated EE within ±200kcal or 10% calculation error. There was a significant difference with a mean of overprediction of 664kcal (SD ± 371; range +95 to +1253kcal; p = 0.018) and relative error over calculation of +23% (SD ± 17; range +4 to +58%; p = 0.018), refer to table 7.

Error in accurately calculating EE for overweight participants with the Curreri equation was shown when the second IC measure was assessed. Only three (42.8%) received a second IC measure. When comparing the Curreri equation using admit BW to measure EE from the second IC there was no difference with a mean over calculation of
+955kcal (SD ± 322; range of +685 to +1311kcal; p = 0.109) and relative error of 
+39% (SD ± 16; range +21 to +48%; p = 0.103) despite no participants meeting the 
±200kcal or 10% margin of calculation error (table 6). In addition, no significant 
difference was shown with the use of ideal BW in the Curreri equation compared to the 
measure EE from the second IC, an average over calculation of +775kcal (SD ± 215; 
range +610 to +1018kcal; p = 0.109) which equated to +31% (SD ± 12; range +18 to 
+39%; p = 0.109), despite no participants meeting ±200kcal or 10% margin of 
calculation error (refer to table 7).

Obese group: Proportion of over and under calculation of EE by Curreri equation to first 
and second IC

When comparing measured EE from the first IC to the Curreri equation using 
adm BW, no participants met the ±200kcal or 10% margin of calculation error. An 
average over calculation of EE by +604kcal (SD ± 1421; range -2913 to +1438kcal; p = 
0.249). This equated to an average overprediction of +25% (SD ± 36, range -34% to 
+71%; p = 0.173), refer to table 6. The use of ideal BW in the Curreri equation compared 
to the measured EE from the first IC showed no significant difference with an average 
under calculation of 531kcal (SD ± 1575; range -527 to +715 kcal; p = 0.600). This 
equated to a relative error of negative six percent (SD ± 33; range -16 to +21%; p = 
0.753), refer to table 7. Of the six (46.1%) participants who qualified for the adjusted 
ideal BW use in the Curreri equation, one met the ± 200kcal and ±10% calculation error. 
This equated to a mean under calculation of -224kcal (SD ± 1535; range of -2913 to 
1438kcal; p = 0.917), refer to table 8. For relative error a mean over calculation of two 
percent (SD ± 34; range -49 to +46% over; p = 0.753) was shown. All participants (n=6)
who had the Curreri equation calculated using adjusted ideal BW, were classified as obese.

Of the obese participants, only three (50%) received a second IC measure. When comparing Curreri equation using admit BW to measure EE from the second IC, no participants met the ±200kcals or 10% margin of calculation error. There was no statistical significance shown, with an average over calculation of +1081kcals (SD ± 788; range +565 to +1988kcals; p = 0.109). This resulted in a relative error of +32% (SD ± 23; range +16 to +58%; p = 0.109), refer to table 6. The use of ideal BW in the Curreri equation compared to the measured EE from the second IC showed one study participant meeting ±200kcals and two (33.3%) meeting the 10% margin of calculation error. No difference was shown with an average under calculation of only -74kcals (SD ± 619; range -3216 to +976kcals; p = 0.593), which equated to +2% (SD ± 19; range -16 to +21%; p = 0.593), refer to table 7.

Of the three participants who qualified for the adjusted ideal BW use in the Curreri equation, one met the ±200kcals calculation error and two met the ±10% calculation error. The mean overcalculation was +669kcals (SD ± 718; range of -218 to +1177kcals; p = 0.180) and relative error over calculation was +11% (SD ± 22; range -seven to +35%; p = 0.593), refer to table 8.

Table 6, 7 and 8 summarize the analysis of bias of EE calculated by Curreri, using admit BW, ideal BW and adjusted ideal BW to measured EE for the first IC and second IC. Appendix 5 provides the range of error for each body weight when compared to first and second IC.
V. Sensitivity Analysis

Comparison of calculated EE by different BW to measured EE for first IC (n = 11).

A sensitivity analysis was undertaken, removing two participants identified as outliers by BMI. Both participants had a BMI > 40 kg/m² and consequently the highest measured EE. The mean BMI of the 11 participants who had a first IC measurement was 28.97 (SD ± 3.73; range of 25.4 to 36.5). Seven (63.6%) of these participants were classified as overweight and four were obese. The mean TBSA was 42.5% (SD ± 16.6; range 23 to 86%).

None of the participants met the ±10% or 200kcal calculation error for the Curreri equation using admit BW. Using admit BW in the Curreri equation demonstrated a mean over calculated EE of +1046kcal (SD ± 625; range +268 to +2249kcal; p = 0.003) and a relative error of +36% (SD ± 22; range +11% to +75%; p = 0.003).

Calculation of the Curreri equation with ideal BW, two (18.8%) met the ±200kcal absolute error and three met the ±10% for the Curreri equation using ideal BW. A significant difference was detected, a mean over calculation of +569 kcal (SD ± 398; range -52 to 1253kcal; p = 0.004) and relative error of +20% (SD ± 15; range -1 to 58%; p = 0.004).

There was a significant difference between measured EE from the first IC to the Curreri equation using admit BW (overweight group) with a mean over calculation of +966kcal (SD ± 567; p = 0.018) and relative error of +33% (SD ± 21; p = 0.018). One participant met the ± 200kcal and 10% calculation error. The use of ideal BW in the Curreri equation compared to the measure EE from the first IC demonstrated a significant
difference with a mean over calculation of +664kcals (SD ± 371; p = 0.018). This was statistically significant by an over calculation error of +23% (SD ± 17; p = 0.018).

There was no significant difference between measured EE from the first IC to the Curreri equation using admit BW in the obese group, with an average over calculation of EE by +1185kcals (SD ± 787; p = 0.067). This equated to an average of +40% (SD ± 26; p = 0.067). There was no significant difference in the use of ideal BW in the Curreri equation compared to the measured EE from the first IC with an average over calculation of +403kcals (SD ± 439; p = 0.144). There was no statistical difference of an over calculation error of +14% (SD ± 14; p = 0.144) from the measured EE.

Of the four (36.3%) participants who qualified for the adjusted ideal BW use in the Curreri equation, one met the ± 200kcals and 10% calculation error. There was no significant difference between Curreri using adjusted ideal BW and the first IC in the sensitivity analysis, with a mean over calculation of +635kcals (SD ± 590; range of 83 to 1438kcals; p = 0.068) and relative error of +22% (SD ± 19; range +2 to +46% over calculation, p = 0.068).

For results tables, refer to Appendix 6.
Chapter 5:

Discussion

The objective of this study was to conduct a retrospective medical record review, to compare energy expenditure estimated by the Curreri predictive equation to the energy expenditure (EE) as measured by IC in overweight and obese burn patients (TBSA > 20%). The secondary objective was to assess which BW (admit, ideal or adjusted ideal) used in the Curreri equation most accurately predicted EE when compared to measured EE by IC in overweight and obese burn patients with TBSA > 20%.

I. Interpretation of Results

\textit{Curreri equation use in Overweight and Obese burn patients TBSA} \geq 20\%

The present study assessed predictive equation accuracy through the occurrence of under or overprediction error. Overall, the Curreri equation using admit BW, ideal BW or adjusted BW overpredicted EE when compared to measured EE by IC. Overprediction of EE was consistent across the first and second IC measure during the first four weeks of ICU admission. The use of admit BW in the Curreri equation demonstrated the largest overprediction of 29\% (799kcal) when compared to the measured EE by IC. Admit BW is used in the ICU to ensure therapeutic interventions are dosed appropriately to avoid under or over dosing\footnote{49}. One reason the use of admit BW in the Curreri equation demonstrated a consistent overprediction of calories in comparison to IC is due to this being the highest weight for the individual and includes all fat and fat free mass. Despite admit BW being closest to the individuals actual BW, it may not be the most appropriate weight for predictive equations as it overpredicts EE in comparison to the gold standard IC measured EE and can be influenced by external factors such as intravenous fluid (IVF)
administration. The use of ideal BW in the Curreri equation resulted in a lower margin of error, on average over predicting by 10%. Regarding the second IC measure, our results showed the Curreri equation using admit BW continued to over predict EE by an average of 35%. Admit BW is collected on admission, usually in the emergency room, this is to reduce error such as falsely high weight measures due to IVF. However, it is important to note that this method isn’t accurate and thermal injury patients can be unpredictable in terms of medications and IVF given in the field and enroute to the hospital. For predictive nutrition equations, a high weight used in a predictive equation means the equation assumes an increased calorie need due to the higher BW being used in the calculation. Another reason why the admit BW consistently over predicts EE is that it includes the lean muscle mass and fat mass. Fat mass contributes poorly to the body’s metabolic activity in comparison to lean muscle mass which can contribute 50-80% of base EE and therefore should not be included in predictive equations. This could explain the significant over prediction in EE when admit BW was used to calculate the Curreri equation as the inclusion of the fat mass could falsely elevate the predictive EE. For the second IC, the use of ideal BW in the Curreri equation, there was an average over prediction of 17% (424kcal). Using admit BW and ideal BW when calculating EE with the Curreri equation during the second IC measure resulted in a greater average EE compared to the first IC measure. This overprediction may be attributed to the small number (n= 6, 46%) of participants who received a second IC measure during the first four weeks of ICU admission, which may have led to wider ranges in EE. When assessed as an entire cohort, our results demonstrated the Curreri equation using ideal BW more closely predicted EE when compared with measured EE. One reason this may have
occurred is that the use of ideal BW aids in reducing falsely elevated EE by subtracting fat mass, which has little to no influence on EE. Thus the predictive equation can predict a similar EE to the measured EE by IC. The study by Stucky et al. reported an average overprediction of EE when using admit BW or fat-free mass, (ideal BW plus 25% of the excess weight when ideal BW is subtracted from admit BW) in burn and trauma patients. This equation is similar to the method of estimating adjusted ideal BW used in the present study. While the Stucky study analyzed different predictive equations (Harris-Benedict, Cunningham and the Diabetic Predictive Equation), their findings are similar to ours in that they reported an overprediction of EE in burn and trauma patients, regardless of the equation used or BW utilized when compared to measured EE.

Our study participants were further analyzed by BMI group (overweight or obese) to assess performance of the Curreri equation for predictive EE. For the overweight participants, the Curreri equation using admit BW or ideal BW compared to the first IC measure overpredicted EE by an average of 33% (966kcal) and 23% (664kcal) respectively. No significant difference was detected despite the predictive equation over predicting beyond the set margins of error. A larger sample size is needed to identify a difference of ±10% relative error or ±200kcal absolute error for overweight participants. Overprediction of EE was consistent for the second IC measure, for admit BW 16% (955kcal) and ideal body weight 31% (775kcal). No statistical significance was detected for the second IC measure and performance of the Curreri equation using either admit BW or ideal BW in overweight participants. This may have been due to the small sample size. For the obese participants only, there was a significant overprediction of EE, using the Curreri equation and admit BW from the measured EE for the first IC, by
approximately 25% (604kcal). There was no significant difference when using ideal BW in the Curreri equation and measured EE, and on average under predicted by 6% (531kcal). Similar results to the use of Ideal BW were found when using adjusted ideal BW in the Curreri equation; on average it overpredicted by 2% (-224kcal), and no significant difference was found between predicted EE using adjust ideal BW and IC for the obese group. Regarding the ideal BW and adjusted ideal BW used during the first IC, our results demonstrated that the adjusted ideal BW more closely met the prediction error margins with stronger statistical significance suggesting that the adjusted ideal BW may be more appropriate to use in the Curreri equation for obese populations should IC not be able to be conducted. Typically, the use of adjusted BW which is subtracting the fat mass could lead to closer predictive EE. However adjusted ideal BW is ≥25% BW than ideal BW alone, therefore you would expect the adjusted ideal BW to actually have a greater over prediction error than ideal BW in obese populations. This did not occur in our study and highlights the need to determine which BW to use in an equation based on overweight or obese status. One explanation why the adjusted ideal BW appears to better match measured EE in obese participants may be because those with the highest BMI’s (40.7 and 59.1) had an average measured EE of approximately 1500kcal more than the predicted EE. There may be a potential threshold for obese patients where the ideal BW begins under predict and therefore the additional 25% BW allowance improves the predictive equations performance. It is important to note in our study obese outliers (40.7 and 59.1) appear to have influenced the average predicted EE and therefore may have caused a reduced mean error associated with Curreri using adjusted ideal BW. For the second IC, in obese participants, using admit BW in the Curreri equation, we observed a
consistent overprediction of EE by approximately 32% (1081kcal). At the second IC measure in the obese population, we found no difference between the predicted EE calculated using ideal BW and measured EE. Furthermore, for the second IC, the adjusted ideal BW overpredicted by 11% (669kcal) and was not statistically significant. With regards to the second IC measure, there were only three participants in the obese group and therefore, likely underpowered to accurately determine which BW is most appropriate for a repeat IC measure in this group.

A study by Mogensen et al\textsuperscript{40} assessed measured EE to predicted EE in obese critically ill patients. They found predictive equations performed better statistically when categorizing participants into BMI groups. Unlike our study, the authors attempted to stratify participants who were classified as obese by obesity classes (class I, II and III), and aimed to show which equations had greater accuracy in the obese class group. The study, however failed to show that there were differences between obesity classes as their sample population was underpowered when participants were divided into analysis groups by obese class.

\textit{Sensitivity Analysis}

A sensitivity analysis was conducted which excluded the highest BMI outliers (n=2). Overall, our results showed that the Curreri equation using admit BW, ideal BW or adjusted BW over predicted EE when compared to measured EE. On average, for the sensitivity analysis sample, the use of admit BW in the Curreri equation saw the largest overprediction of 36% (1046kcal) when compared to the measured EE by IC. The use of admit BW overpredicted EE when the sample was further analyzed by BMI group and therefore shows admit BW having higher probability of resulting in over calculation of
EE. Ideal BW overpredicted EE by 14% (403kcal) which was above the set margin of error. There was no significant difference between predicted and measured EE when using ideal BW. This may have occurred due to small sample size and therefore an underpowered study, or it may show that ideal BW remains too high to accurately predict EE and a need for a lower body weight adjustment, for example 65% of admit BW be used and evaluated, which is consistent with the 2016 ASPEN/SCCM guidelines 35. Although the Wilcoxon sign rank test did not show statistical difference, it was likely underpowered given the results were outside the pre-set ±10% or 200kcal margin of error. To determine if the use of ideal BW in the Curreri equation is genuinely more accurate for obese patients’ further research is needed. Regarding the use of adjusted ideal BW in predictive equations, no significant difference was detected between the predicted EE and the measured EE and for this study, this is most likely due to this study’s small sample size. The average predicted EE was also over the set margins of error, which suggests that while there was no statistically significant difference, a larger sample is needed to validate the use of adjusted IBW in the Curreri equation. A similar study by Stucky et al. also reported small sample sizes were an important limitation when studying obese burn populations. While this study was also underpowered it does demonstrate the complexity of the obese burn population. Since thermal injury is relatively uncommon compared to other types of trauma, multicenter studies have the potential to significantly increase sample size.

Participant Characteristics

In this study, there was a higher percentage of males to females with TBSA > 20%, and therefore our results cannot be generalized to any gender. Males appear to be
more prone to thermal injuries than females. This gender distribution is consistent with studies on thermal injuries$^{53, 54, 55}$ with another study showing men are at 2 to 3 time’s greater risk of unintentional or violent-related injury than females$^{56}$. The high distribution of male thermal injuries may be attributed to males partaking in higher risk-taking behavior in comparison to females$^{57}$. Length of ICU stay was found to be associated with severity of the burn, which was expected; those with a higher TBSA% also had a longer LOS. In addition, the overweight participants were less likely to be mechanically ventilated and when they were mechanically ventilated, experienced fewer days on the ventilator compared to obese participants. This may be due to a lesser likelihood of weight related respiratory issues in comparison to obese individuals. Our study did not have a large enough sample to detect if the difference in need for and length of mechanical ventilation between overweight and obese participants was statistically significant. This trend, however, is reflective in the wider literature showing obese individuals requiring more days due to associated atelectasis (difficulty effectively inflating the bronchioles), related to additional weight located on the trachea area$^{7, 9}$. An increase in weight and therefore pressure on the thoracic wall places an obese critically ill patient at high risk for developing lung atelectasis requiring subsequent ventilation in order to help the patient inflate the lungs for adequate oxygen delivery$^{7, 58}$. Lastly, our study was able to demonstrate changes associated in estimated and measured energy expenditure depending on both BMI and %TBSA. The extent and severity of an individual’s burn surface area directly influences the individuals’ energy expenditure$^{59}$. Our results replicated the work of others in that those with the higher TBSA had an expected higher estimated and measured energy expenditure. This is an important aspect
of nutrition burn care, reflecting the need to include BMI and TBSA in predictive equations in order to provide more accurate energy expenditure assessment.

II. Limitations

This study had several limitations. A major limitation was the small sample size, which was the result of a single center, retrospective convenience sampling design. Because of this, the study also had limited number of burn patients available in the geographic area, limited number of actual beds and limited number of burn surgeons/physicians in the acute care center. This may have affected the significance of the results and ability to detect differences and similarities between the predicted and measured EE. Another limitation was the retrospective design of the study. The inability to mandate protocol to ensure at minimum two IC measures were collected may have affected the ability to show consistency in the results. This study also had a short time frame in which data was collected which may have limited the number of participants for recruitment and thus sample size. Also, there was no way to validate the reported weights and heights available in the medical record and this may have affected the accuracy of final results. Our study did not have a sufficient sample size to detect if the difference in need for and length of mechanical ventilation and days was significant and why. Lastly, our sample was predominantly male and it is well known that due to testosterone levels and lean body mass, males have a higher EE compared to females and thus, the results are not be generalizable to female overweight or obese burn patients

Implications

The results obtained in this study indicate that measured EE by IC remains the most accurate and reliable method for the determination of EE in overweight and obese
burn patients. More research is needed to better assess which body weight to use in the Curreri equation when estimating EE in overweight and obese female burn patients. This study demonstrated that the use of ideal BW in the Curreri equation provided similar EE predictions to measured EE. When IC is not available the Curreri equation using ideal BW in male overweight and obese patients may predict EE within ±10% of measured EE. However, it is important to note the use of ideal BW in the Curreri equation and its ability to predict closely to the measured EE from IC was not able to be replicated in the second IC measure, the sensitivity analysis or when participants were analyzed by BMI group. Therefore, it is important to include subsequent IC measures after the initial IC measurement to ensure calorie provision is accurate and reflects changes in patient recovery. This study demonstrated that TBSA percentage and BMI classification should be considered for inclusion in burn predictive equations.

III. Future Research

Future studies are needed to further evaluate the most appropriate predictive equation for overweight and obese burn patients. In particular, multicenter, high powered studies, evaluating predictive equations based on BMI groups and varying TBSA percentages. Furthermore, prospective protocols to control for IC measurements and improve accuracy on data reported need to be implemented to improve the strength of conclusions made from this type of research.

IV. Conclusions

Indirect calorimetry remains the most appropriate method of EE determination of overweight and obese burn patients as predictive equations overpredict EE. When IC is not available, clinicians should consider the use of the Curreri equation using adjusted
ideal BW for obese male patients. However, more research is needed to determine which BW is most appropriate for overweight burn patients and for female burn patients with a BMI ≥ 25.
References


Appendix 1. Nutrition Assessment Equations

**Body Mass Index (BMI):** Kilograms \(\div\) Height\(^2\) (meters-squared).

Overweight: BMI 25 - 29.99

Obese: BMI \(\geq\) 30

**Curreri:**

\(25 \times \text{body weight (Kg)} + 40 \times \% \text{TBSA burn}\)

**Calculation of Actual Body Weight, Ideal Body Weight and Adjusted Ideal Body Weight.**

**Actual BW:** actual body that which is measured on admittance to the hospital’s emergency room, obtained via the electronic medical record.

**Ideal BW (Hamwi Method):**

Men: 48.1 kg for the first 152.4 cm + 1.1 kg for each additional cm

Females: 45.5 kg for the first 152.4 cm + 0.9 kg for each additional cm

**Adjusted Ideal BW:** (actual body weight - ideal body weight) \(\times\) 0.25 + ideal body weight

**Determination of which BW to use:**

100-109\% IBW: use Actual Body Weight

110-124\% IBW: use Ideal Body Weight

\(>125\%: \text{use Adjusted Ideal Body Weight}\)

**Harris Benedict Equation**

Men: \((10 \times \text{weight in kg}) + (6.25 \times \text{height in cm}) – (5 \times \text{age in years}) + 5\)

Women: \((10 \times \text{weight in kg}) + (6.25 \times \text{height in cm}) – (5 \times \text{age in years}) – 161\)

**Ireton-Jones for Ventilator Dependent**

\(A = \text{age in years}; \ W = \text{actual BW (kg)}; \ S = \text{sex (male =1, female = 0)}; \ T = \text{diagnosis of trauma (present =1, absent =0)} \text{ and } B = \text{diagnosis of burn (present =1, absent =0)}; \ O = \text{obesity (present =1, absent =0)}\)

\(\text{EE (kcal/d): } 1784 – (11 \times A) + (5 \times W) + (244 \times S) + (239 \times T) + (804 \times B)\)
Ireton-Jones, Obesity

EE (kcal/d): 629 – 11 (A) + 25(W) – 609(O)

**Diabetic Prediction Equation**

A is age in years; H is height in cm; W is actual BW (kg); DM is diagnosis of type II diabetes (present =1, absent =0)

Men: 71.761 – 2.337(A) + 257.293 + 9.996(W) + 4.132(H) + 145.959(DM)

Women: 71.761 – 2.337(A) + 9.996(W) + 4.132(H) + 145.959(DM)

**Cunningham Equation**

EE: 370 + 21.6(FFM)

FFM: 1. Ideal BW(kg) = BMI of 25kg/m2
    
    2. Excess Weight = (Actual BW (kg) – Ideal BW (kg)) x 0.25

    3. FFM = Ideal BW + Excess Weight
Appendix 2: Screening tool

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<th>MRN</th>
<th>Admit Date</th>
<th>Admit Diagnosis</th>
<th>Age at time of admission</th>
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### Appendix 3: Data Collection Tool

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<th>Usual Body Weight (if available):</th>
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#### One Time Medical Data:

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#### Medical and Nutrition Data:
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Appendix 4: UNMH Indirect Calorimetry Procedure

DESCRIPTION/OVERVIEW
Metabolic measurements using indirect calorimetry for determination of oxygen consumption (VO₂), carbon dioxide production (VCO₂), respiratory quotient (RQ), and resting energy expenditure (REE) as an aid to patient nutritional assessment and management.

REFERENCES

AREAS OF RESPONSIBILITY
- The Medical Director of Pulmonary Services and Diagnostics will be consulted for approval and will review any revisions of this procedure
- The Director of Pulmonary Services & Diagnostics will oversee this policy implementation
- The Pulmonary Diagnostic Lab personnel will be responsible for implementing the procedure per the guideline
- Physician is responsible for ordering Indirect Calorimetry (individual study or by protocol)

PROCEDURE
1. Assessment:
   1.1. Verify Correct Patient utilizing 2 patient identifiers
       1.1.1. Birth date
       1.1.2. Arm Band
       1.1.3. Verbal Feedback/verification
   1.2. Ensure HIPAA compliance
       1.2.1. Confidentiality observed
       1.2.2. Patient aware of rights
   1.3. Criteria for testing met
       1.3.1. Patient must be in resting state
           1.3.1.1. Ventilator patients
               1.3.1.1.1. No stimulation for minimum of 30 minutes prior to testing
               1.3.1.1.2. Feeds
1.3.1.2.1. No bolus feeding
1.3.1.2.2. NPO 4 hours prior
1.3.1.2.3. If patient is on continuous feeds, do not change, hold or discontinue in the 24 hours prior to testing
   1.3.1.2. No changes to dietary composition >24 hours
      1.3.1.2.1. No ventilator changes 1 to 1.5 hours prior
      1.3.1.2.2. No dialysis 3-4 hours prior to testing
      1.3.1.2.3. No pharmaceutical stimulants/depressants
      1.3.1.2.4. No suctioning 1 hour prior
      1.3.1.2.5. No blood draws 1 hour prior
1.3.1.3. One hour prior to testing patient has
   1.3.1.3.1. Stable blood pressure
   1.3.1.3.2. Stable heart rate
   1.3.1.3.3. Stable oxygen saturation
1.3.1.4. Non-mechanically ventilated patient
   1.3.1.4.1. No supplemental oxygen requirement
   1.3.1.4.2. Fasting 4 hours prior to testing
   1.3.1.4.3. No carbonated drinks for 8 hours prior to testing
   1.3.1.4.4. No aerobic or stressful exercising 8 hours prior to testing
1.3.2. See Protocol for prolonged ventilation patients
1.3.3. See Protocol for patients >20% TBSA Burn
1.4. The following criteria must be met to ensure accurate testing
   1.4.1. Weight >6kg
   1.4.2. Height >66cm
   1.4.3. If patient has artificial airway
      1.4.3.1. Cuffed endotracheal
      1.4.3.2. Cuffed tracheostomy tube
   1.4.4. No pleural leaks/untreated pneumothorax
   1.4.5. FiO2 <0.55
      1.4.5.1. May perform study on FiO2 >0.55
   1.4.5.1.1. Study assumes an RQ of 0.8
   1.4.5.1.2. Select FiO2 >0.55 testing mode in Breeze Software
   1.4.6. Ve >2 lpm
   1.4.7. PEEP <12cmH2O
2. Gather equipment prior to entering patient room
   2.1. Metabolic measurement machine
      2.1.1. Correct pneumotach calibration on day of study
         2.1.1.1. Direct connect: Calibrate med to low-flows only
         2.1.1.2. PreVent: Calibrate all flows
      2.1.2. Verify environmental data
   2.1.3. Analyzer on minimum 30 minutes prior to calibration
   2.1.4. Gas calibration within 1 hour of performing study
2.2. Appropriate adapter
   2.2.1. Direct connect
      2.2.1.1. Ventilator study
      2.2.1.2. Flow-by oxygen study for tracheostomy studies requires use of Oxygen blender device

Page 2 of 5
2.2.2 Non-intubated measurement
  2.2.2.1. Face tent
  2.2.2.2. Neoprene mask
  2.2.2.3. mouthpiece

3. Process:
  3.1. Enter patient demographics into machine
      3.1.1. Must have accurate height
      3.1.2. Must have accurate weight
      3.1.3. Current patient temperature if available
      3.1.4. If on mechanical ventilation
          3.1.4.1. Enter ventilator setting
              3.1.4.1.1. Enter Bias Flow volume
              3.1.4.1.2. Enter Dead space volume
          3.1.4.2. Enter patient’s actual respiratory rate and minute ventilation
  3.2. Ventilator patients: Collect expired air sample
      3.2.1. Use direct-connect flow sensor
      3.2.2. Connect directly to patient airway
      3.2.3. Select Ventilator direct-connect test mode
      3.2.4. GX Vac on for minimum 2 minutes
      3.2.5. Begin test
      3.2.6. Collect data
          3.2.6.1. until steady state is maintained for 8-10 minutes
              3.2.6.1.1. VO2 and VCO2 should be <5% for a 5 minute data collection
              3.2.6.1.2. Ensure stability of VO2, VCO2
              3.2.6.1.3. FiO2 stability: <3% variance
          3.2.6.2. if no steady state, continual monitoring/data collection for 20 minutes
  3.3. RQ should be consistent with the patient’s nutritional intake and at rest the normal physiologic range (0.67 to 1.3)
  3.4. End Test
  3.5. Disconnect pneumotach from patient
  3.6. Non-intubated Study: Collect Data
      3.6.1. Select test mode
          3.6.1.1. Metabolic
              3.6.1.1.1. For Neoprene mask/pre-vent set up
              3.6.1.1.2. For pre-vent/mouthpiece set up
          3.6.1.2. Face Tent/Canopy: for use with dilutional fan set-up
              3.6.1.2.1. Fan speed adjusted as needed
              3.6.1.2.2. Greater than 2% CO2 variance is needed for appropriate wash out
              3.6.1.2.3. Filter may be used in line with fan
      3.6.2. Collect data for approximately 20 minutes or until steady state is maintained for 8 - 10 minutes
          3.6.2.1. Ensure stability of VO2 and VCO2
          3.6.2.2. FiO2 stability: <3% variance

3.7. Disconnect patient
3.8. End test

4. Discharge
   4.1. Ventilator patients
       4.1.1 No ventilator changes were made
       4.1.2 Notify RN that testing is complete
   4.2. Non-intubated patients
       4.2.1 No adverse effects from testing
       4.2.2 Patient has been given appropriate follow-up information

5. Document procedure
   5.1. Test report comments to indicate
       5.1.1 Pre-assessment
       5.1.2 Steady state achieved or not
       5.1.3 Patient cooperation with resting state
       5.1.4 Patient status at discharge or disconnection from devise
   5.2. Set summary parameter to get appropriate
       5.2.1 Resting energy expenditure (REE)
       5.2.2 Respiratory quotient (RQ)
   5.3. Result order with correct procedure preformed
   5.4. Document REE/RQ directly into patient’s electronic medical record
   5.5. Final copy interpreted by Pulmonary Attending physician and sent to EMR

DEFINITIONS
Indirect Calorimetry – Metabolic measurements using indirect calorimetry for determination of oxygen consumption (VO₂), carbon dioxide production (VCO₂), respiratory quotient (RQ), and resting energy expenditure (REE) as an aid to patient nutritional assessment and management

Resting Energy Expenditure (REE) - represents the amount of calories required for a 24-hour period by the body during a non-active period. Weir equation REE = [VO₂ (3.941) + VCO₂ (1.11)] 1440 min/day

Respiratory quotient (RQ) – assessment of the contribution of metabolism to ventilation
VCO₂/VO₂
VO₂ - oxygen consumption
VCO₂ - carbon dioxide production

SUMMARY OF CHANGES
2015 Review
Additions:
• 3.3 RQ is consistent with the patient’s nutritional intake and at rest the normal physiologic range (0.67 to 1.3)
• 1.3.1.1.2.3 If patient is on continuous feeds, do not change, hold or discontinue in the 24 hours prior to testing

KEY WORDS
Indirect Calorimetry, metabolic measurement, resting energy expenditure

RESOURCES/TRAINING
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**DOCUMENT APPROVAL & TRACKING**

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<td>Michelle Harkins, MD; Department of Pulmonary and Critical Care</td>
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**ATTACHMENTS**
None
Indirect Calorimetry Operational Definitions

**Indirect Calorimetry** – Metabolic measurements using indirect calorimetry for determination of oxygen consumption (VO₂), carbon dioxide production (VCO₂), respiratory quotient (RQ), and resting energy expenditure (REE) as an aid to patient nutritional assessment and management.

**Resting Energy Expenditure (REE)** - represents the amount of calories required for a 24-hour period by the body during a non-active period. Weir equation REE = [VO₂ (3.941) + VCO₂ (1.11)] 1440 min/day.

**Respiratory quotient (RQ)** – assessment of the contribution of metabolism to ventilation VCO₂/VO₂ VO₂ – oxygen consumption VCO₂ - carbon dioxide production.
Appendix 5. Range of absolute and relative error for Curreri equation.

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<th>Table 1. Range of absolute and relative error of Curreri predictive equation using actual BW compared to first IC and second IC.</th>
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<td><strong>Curreri absolute error, Range of error (kcal)</strong></td>
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<td><strong>First IC</strong></td>
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<td>Total sample (n = 13)</td>
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<tr>
<td>Overweight (n = 7)</td>
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<td>Obese (n = 6)</td>
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<td><strong>Second IC</strong></td>
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<td>Total sample (n = 6)</td>
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<td>Overweight (n = 3)</td>
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Kcal, calories; BMI, body mass index; IC, Indirect Calorimetry

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<th>Table 2. Range of absolute and relative error of Curreri predictive equation using ideal BW compared to first IC and second IC.</th>
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<td><strong>Second IC</strong></td>
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Kcal, calories; BMI, body mass index; IC, Indirect Calorimetry

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<td>Obese (n = 3)</td>
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Kcal, calories; BMI, body mass index; IC, Indirect Calorimetry
Appendix 6. Sensitivity Analysis (n=11)

Table 1. Sensitivity Analysis. Descriptive results of Curreri predictive equation and first IC sensitivity analysis sample (n = 11) and by different body weight used in equation (actual BW, ideal BW or adjusted ideal BW) and BMI classifications (Overweight n = 7 and Obese n = 6).

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<tr>
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<th>First IC Measure (mean±SD)</th>
<th>First IC Measure (median Kcal)</th>
<th>First IC Measure (range)</th>
<th>Curreri EE (mean±SD)</th>
<th>Curreri EE (median Kcal)</th>
<th>Curreri EE (range)</th>
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<td><strong>Actual BW</strong></td>
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<tr>
<td>Total sample (n = 11)</td>
<td>2972±512</td>
<td>3018</td>
<td>2628-3316kcal</td>
<td>4018±847</td>
<td>3798</td>
<td>3448-4587kcal</td>
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<td>Overweight (n = 7)</td>
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<td>2164-3806kcal</td>
<td>3896±912</td>
<td>3798</td>
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<td>Obese (n =4)</td>
<td>3045±468</td>
<td>3079</td>
<td>2445-3789kcal</td>
<td>4231±795</td>
<td>3903</td>
<td>3718-5400kcal</td>
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<td><strong>Ideal BW</strong></td>
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<td>2628-3316kcal</td>
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<td>3527</td>
<td>3127-3956kcal</td>
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<td>2406-3455kcal</td>
<td>3595±702</td>
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Kcal, calories; BMI, body mass index; IC, Indirect Calorimetry; BW, Body Weight