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Original Research Article

Assessment of Energy Consumption Patterns and Validation of Predictive Equations among ICU Patients at Muhimbili National Hospital in Dar es Salaam, Tanzania

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Abstract: ***Background:*** Nutritional support in critically-ill patients is one of the most important parameters guarding the prognosis and influencing morbidity and mortality in these patients, owing to that fact, accurate measurement of the resting energy expenditure using Indirect calorimetry is recommended by guidelines as a gold standard. But due to lack of resources and other technicalities predictive equations are conveniently used as surrogates. ***Aims:*** This study was intended to examine the extent of malnutrition, poor nutrition support practices and to validate the common used predictive equations in critically-ill patients in our setting. ***Methodology:*** A hospital-based descriptive cross-sectional study was conducted on consecutively sampled 110 mechanically ventilated ICU patients at Muhimbili National Hospital Mloganzila. Anthropometric measurements, duration of stay in ICU, Temperature and Minute Volumes were recorded so as to estimate resting energy expenditure, REE from different predictive equations. Using Indirect Calorimetry Module patient's REE was measured and recorded then a statistical data analyzed using SPSS software version 23. ***Results:*** The prevalence of poor nutritional support was 69%; underfeeding and overfeeding were observed in 41.8% and 27.3% of all participants respectively. Prevalence of malnutrition was 51.8%; underweight and overweight were found to be in 29.1% and 22.7% of all participants respectively. The accuracy of predictive equation in ±10% difference was 30%, 45.5%, 46.4% and 68.2% in HB, MSJ, ESPEN and PENN respectively. ***Conclusion and Recommendation:*** Malnutrition and Poor Nutritional support are common problems in ICU. Predictive equations have poor accuracy and validity in comparison to indirect calorimetry. Penn State Equation was the most accurate and with the highest agreement with IC.

Keywords: Indirect calorimetry, nutrition, feeding.

INTRODUCTION

The ultimate goal of nutrients' metabolism is the production of energy, this is achieved by extracting the chemical energy from a substrate as it combust with oxygen to form carbon dioxide (CO_2) water (H_2O) and heat energy which is the final common pathway of all cellular fuels, such as carbohydrates, fats, and proteins [1].

The heat generated by biologic combustions is utilized to maintain body temperature. However, the body is unable to use heat as a source of energy because of the presence of different homeostatic mechanisms which maintain body temperature at a fixed state meanwhile using heat as a source of energy requires temperature changes. The chemical energy produced by oxidation is partly trapped in a variety of high-energy compounds such as adenosine triphosphate ATP which later is employed to various cellular metabolisms [2].

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Precision and accuracy in determination of energy expenditure is vitally important and yet often neglected in clinical practice of critically-ill care. Indirect calorimetry (IC) is regarded as a gold standard in provision of the most sensitive, accurate, and noninvasive measurements of resting energy expenditure in critically-ill patients, but in developing countries utilization of IC is still low due to resources limitations, and as a substitute predictive equations are commonly used [3].

There are a lot of predictive equations that differ from one another in terms of the populations they were designed from, where they are meant to be applied, and the parameters needed to give a prediction of the resting energy needed per day(4). Naming a few these are Harris Benedict, Mifflin St Jeor, Swinamer, Ireton-Jones, Penn State, Brandi and ESPEN Guidelines (25-30 calories/kg).). Mifflin St Jeor and Penn State are commonly used in critically ill and mechanical ventilated adults [5].

Evidently, accurate estimating and replenishment of nutritional requirement is important since both underfeeding and overfeeding has been associated with different morbidities and prolongations of ICU stays and eventually hospital stay which has financial and standard of life implications [6].

METHODOLOGY

Study design:

This study was a hospital based descriptive cross-sectional study among mechanically ventilated critically-ill patients admitted in critical care unit at Muhimbili National Hospital Mloganzila in 2019.

Study setting:

This study was conducted at Muhimbili National Hospital Mloganzila, a tertiary teaching and referral hospital in Dar-es-salaam, Tanzania. MNH-Mloganzila has a bed capacity of 571, amongst these 21 beds are located in Medical and Surgical Intensive Care Units and 17 beds are possess ventilator that are capable of measuring energy expenditure by Indirect calorimetry. For a period of 6 months, November 2019 to April 2020 a desired calculated sample of 110 patients was studied.

Study population:

Critically-ill patients in ICU care with mechanical ventilation and a signed participation consent from a proxy/surrogate excluding patients that consents could not be obtained, not on mechanical ventilation, on mechanical ventilation for less than 24 hours, FiO_2 greater than 60%, PEEP more than 12cmH_2O, less than 8 hours from General Anaesthesia, less than 90 minutes from ventilation settings change, less than 3-4 hours of hemodialysis and less than 1 hour from a painful procedure.

Data collection:

Anthropometric measurements such as weight (kg), height (cm), MUAC (cm), duration of stay in ICU (days), Temperature (^{0} C) and Minute Volumes (mls) were collected in order to calculate nutritional status of the patient in Body Mass Index, BMI and also obtain *estimated* resting energy expenditure, REE from Predictive Equations.

Using General Electronics CARESCAPE R860 Indirect Calorimetry Module patient's *measured* resting energy expenditure, REE and Respiratory Quotient, RQ were obtained and then a statistical comparison between means, standard deviations, correlations, concordance and agreements of *estimated* REE from Predictive equations and *measured* REE from Indirect Calorimetry will be compared.

The calorimeter was calibrated before the measurements and before each data collected, researcher and/or research assistant made sure that patients were in a stable condition for at least half an hour, ventilated with FiO2 less than 60% and PEEP less than 12 cm H_2O, with no any discernable air leaks, only measurements that were stable for at least 10 minutes were considered acceptable.

Data was collected by a primary investigator or a qualified research assistant (Trained ICU Registrar) using English-based fillable Questionnaires that inquired data from ICU monitoring charts and Ventilator machines. Before the above data recorded, a written consent had to be obtained from a proxy who was above 18 years of age and is listed as next of kin in the patient's information.

Data management and analysis:

Data was coded and entered into the IBM Statistical package for social science (SPSS) version 23 programs under consultation and assistance of the Biostatics professionals. Data quality check for inconsistence was done on a daily basis to ensure that incomplete and missing data was identified and corrected promptly.

Percentages were used to summarize Categorical variables which includes sex, and admission reasons. Using Pearson's Chi-square test correlation coefficients and Fisher's exact test Demographic data inclusive of Gender, age, BMI, and REE were analysed and P value < 0.05 was considered significant.

In determining the prevalence of *poor nutritional support* (which was regarded as ± 10% difference of the energy measured by indirect calorimeter) data collected was analyzed by proportions and mean.

In determining the prevalence of *Malnutrition* in ICU data collected such as weight and height resulted to BMI which gave out different severities of malnutrition observed in the study.

In assessment of level of *accuracy* of common used predictive Equations *(validation)* data collected from IC module and those calculated by different predictive equation were analyzed by means, proportion and standard deviation. A Predictive equation was regarded as valid if the estimations were within ± 10% difference.

Ethical consideration:

Approval of the study was granted from Muhimbili University of Health and Allied Sciences (MUHAS) administration, MUHAS Institutional Review Board (IRB) (Ref. No. MU/PGS/SAEC/Vol. IX/) and the Muhimbili Nation Hospital ethical review board under the directory of Research. Patients' names or registration numbers were not used to ensure confidentiality and access to participants' information was restricted to researchers only. The tool had demographic parameters such as age, sex, weight and other variables such as day of stay in ICU, food intakes, diagnosis, and indirect calorimetry reading.

RESULTS

Table 1: Demographic Characteristics

	Frequency (n)	Percentage (%)
Sex		
Female	64	58.2
Male	46	41.8
Age		
<20	19	17.3
21-30	16	14.5
31-40	20	18.2
41-50	12	10.9
51-60	22	20.0
60+	21	19.1
Reason for Admission		
Medical	52	47.3
Surgical	58	52.7
Days in ICU		
0-5	43	39.1
6-10	24	21.8
11-15	16	14.5
16-20	13	11.8
21-25	7	6.4
26-30	4	3.6
30+	3	2.7
	110	**100**

During the course of the study, out of 110 participants, 64 (58.2%) were Female, the age of the participants was almost equally distributed throughout the age strata with patients below 20 years being 19 (17.3%) and patients above 60 years being 21 (19.1%), The leading cause of reasons for the admission was surgical consisting of 52.7% of the study's participants *(see Table 1)*.

The mean age of the participants was 42.29 years with a standard deviation of 17.91 and the age of the participants was ranging from 19 years to 77 years, the average weight and height of the participants was 66.33 kg and 168.65 cm respectively. The BMI of the participants had a mean of 23.45 kg/m^2 with the lowest BMI being 19 kg/m^2 and the highest being 38 kg/m^2 *(see Table 2)*.

Table 2: Descriptive statistics of the study participants

Variable	Mean	S.D (range)
Age (y)	42.29	17.91 (19-77)
Weight (kg)	66.33	12.37 (45-98)
Height (cm)	168.65	7.98 (150-187)
Body Mass Index (kg/m^2)	23.45	4.97 (17-38)

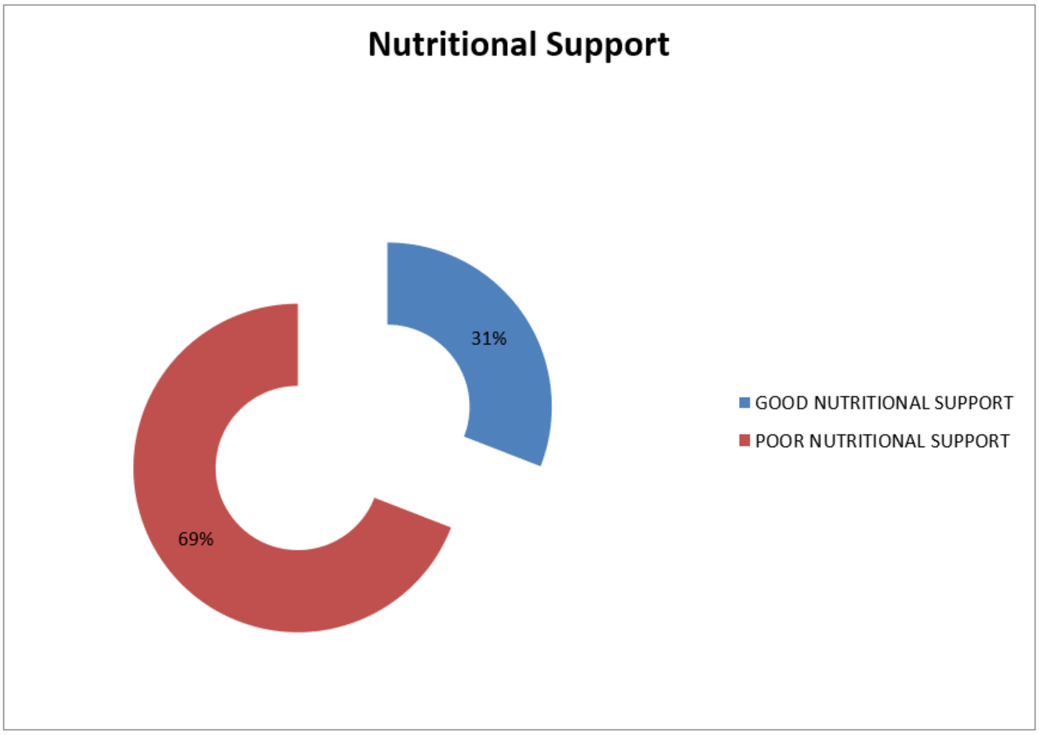


Figure 1: Nutritional support status of Critically-ill patients admitted at MNH.

This study revealed that out of 110 participants, 76 (69%) received poor nutritional support in comparison to their nutritional demand of that day; only 31% of patients were receiving good nutritional support that was within ±10% of measured energy requirement by indirect calorimetry (*see Figure 1).*The prevalent form of malnutrition was underfeeding constituting 41.8% of all the participants, overfeeding was also not uncommon making 39.5% of malnutrition practices and 27.3% of all the Nutritional support given to Critically-ill patient admitted at MNH.

Malnutrition was common in critically-ill patients, this study revealed 51.8% of the all the participants were having malnutrition, Normal nutritional status was found to only 48.20% of the study's participants. Also this study found that underweight was common among the study's participants making 56.1% of the total malnutrition and 29.1% of all the participants, overweight was found in 22.7% of the total study's participants *(see Figure 4)*.

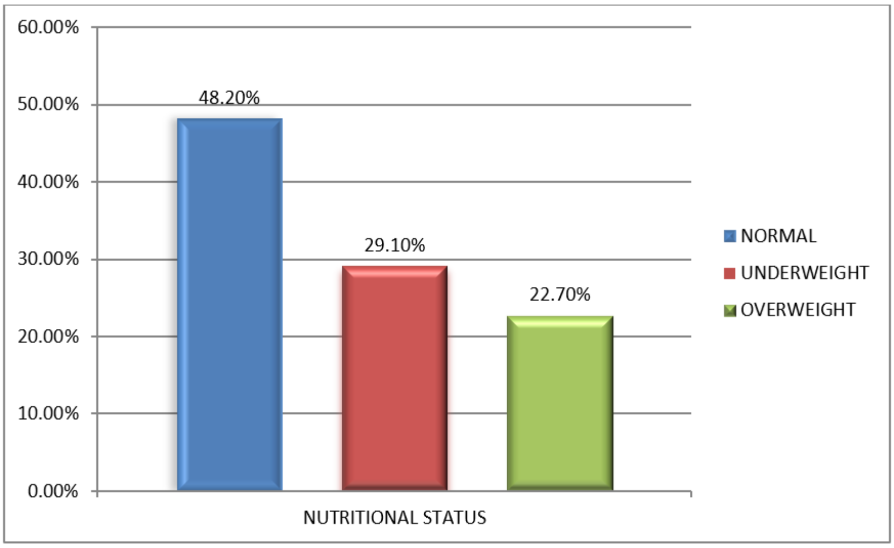


Figure 2: Histogram showing Nutritional Status of Critically-ill patient admitted at MNH

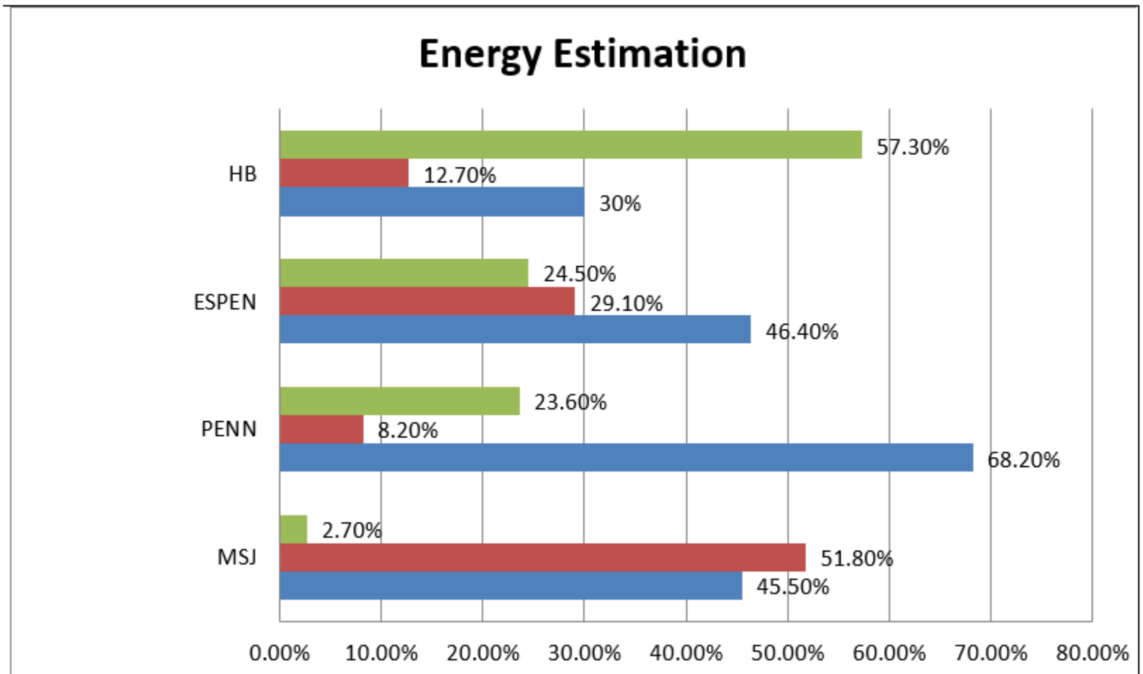
This study revealed that there was a relationship between longevity of ICU stay and malnutrition, it was noted malnutrition prevalence was increasing with increase in duration of stay in ICU, A group of short stay in ICU 0-5 days the prevalence of malnutrition was 49% meanwhile for group above 25 days of stay in ICU, all the patients were showing signs of malnutrition, these findings were not statistical significant (p=0.126).

The mean of measured REE was 1656 ± 284 kcal, while the means of predictive equations from HB, MSJ, ESPEN and PENN were 2003 kcal, 1442 kcal, 1658 kcal and 1692 kcal respectively. ESPEN and Penn State Equations showed a minimal mean difference in comparison with the other equations. All of the equations showed a positive correlation with the measured REE from indirect calorimetry, the weakest correlation was observed from the ESPEN equation (r=0.21, p=0. 95) while the strongest and statistically significant correlation was observed from Penn State equation (r=0.80, p=0.001). *(See Table 3)*.

Table 3: Descriptive statistics of Indirect calorimetry and Predictive Equations

	Mean	S.D	Mean diff.	Correlation	p
Measured (Indirect Calorimetry)	1656	284			
Harris Benedict	2003	525	347	0.38**	.000
Mifflin-St. Jeor (MSJ)	1442	157	-214	0.57**	.000
ESPEN	1658	309	2	0.21	.954
Penn State	1692	246	36	0.80**	.035

** p <0.05



	MSJ	PENN	ESPEN	HB
Overestimation	2.70%	23.60%	24.50%	57.30%
Underestimation	51.80%	8.20%	29.10%	12.70%
Adequate Estimation	45.50%	68.20%	46.40%	30%

Figure 3: A bar chart showing accuracy of energy estimation in different predictive equations

This study found that the accuracy of estimation with predictive equation was generally poor, the accurate prediction of within ± 10% were 30%,45.5%,46.4% and 68.2% in Harris Benedict, Mifflin-St. Jeor, ESPEN and Penn State equations respectively. Overestimation was most common with Harris Benedict's equation with about 57.3% of the estimates being more than 10% of the measured REE. Underestimation was mostly noted with the MSJ equation with about half of all predictions being underestimation *(see Figure 3)*.

The limits of agreement were wide in all the predictive equations suggesting the fact that there was lack of precision and poor agreement between measured REE by Indirect calorimetry and that estimated by Predictive equations. The Penn State equation had the narrowest range to the mean making it the most accurate equation to predict REE in comparison to the rest of the three Predictive equations *(see Figure 4)*.

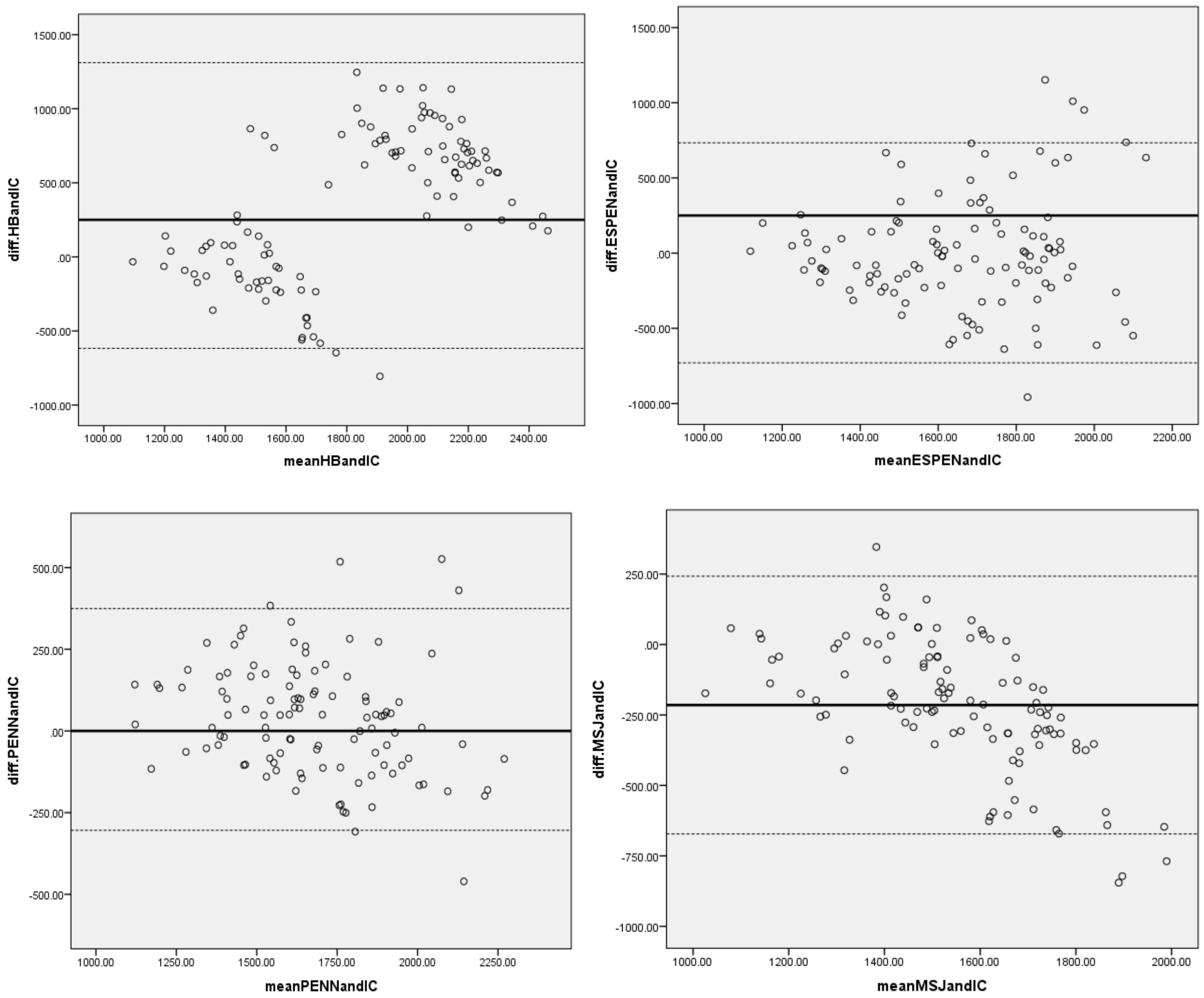


Figure 4: Bland-Altman Plots for comparison of agreement between the estimated REE from Equations and measured REE from Indirect calorimetry

DISCUSSION

This was a cross sectional study among the mechanically ventilated critically-ill patients admitted at Intensive care unit in Muhimbili National Hospital-Mloganzila Dar es Salaam, Tanzania aiming to determine prevalence of poor nutrition support, prevalence of malnutrition and validity of predictive equations.

Prevalence of Poor Nutritional Support

This study found that poor nutritional support which meant nutritional support practices that were out of ±10% margins of measured REE to be 69% and only about a third of the participants were receiving adequate nutritional suppor. A large multi-national cohort study done by Bendavid *et al.*, involving about 10,000 patients revealed the same picture that majority of the patients were underfed or overfed [7].

Another prospective cohort study done in 2012 by Hyunjung Kim and Nancy Stotts, conducted in university hospital in Korea revealed that 62% of patients received inadequate energy and only 29% of patients received adequate energy according to the measured REE [8].

Both sides of malnutrition have been found to have deleterious outcomes to the critically ill patients, It is established that Overfeeding is associated with increased infection rates, poor wound healing, prolonged mechanical ventilation and increased morbidity [9-11] and underfeeding is associated with increased hospital stays, increased length of required ventilatory support, suboptimal medical or surgical treatment and mortality [12, 13].

This study found that prevalence of underfeeding, adequate and overfeeding were 41.8%, 31% and 27.3% respectively, a prospective multicenter trial by McClave *et al.*, revealed 29.2% of patient being adequately fed within the ±10% difference of the measured value [14], furthermore another publication by

Mee-Nin Kan *et al.,* in Taiwan involving 54 subject revealed a similar picture with only about a third of the participants receiving adequate feed but there was still 28% and 35% of patients who were underfed and overfed, respectively [15].

Providing adequate nutritional support has many challenges in critical care settings, a cross-sectional study done in 2003 found that adequate nutritional provision is often hindered by lack of dieticians, altered gastrointestinal functioning, feeding-delay for procedures and tests, and a lack of feeding access [16].

Prevalence of Malnutrition in ICU

Malnutrition is common among critically ill patients, this study found that 51.8% of the all the participants were having malnutrition, Normal nutritional status was found to only 48.20% of the study's participants, underweight and overweight were found in 29.1% and 22.7% respectively.

This study also found that there was a tendency of increasing in malnutrition as the duration of ICU stay increases, it was noted that in early days of ICU stay (0-5 days) the prevalence of malnutrition was 49% meanwhile for group above 25 days of stay in ICU, all the patients were showing signs of malnutrition, these findings were not statistical significant (p=0.126).

A study by Reid *et al.,* found that in surgical patients the incidence of malnutrition was up to 44% also it was noted malnutrition worsens during hospital stay, especially in the intensive care units [17]. A study done by Kimiaei-Asad *et al.,* in Iran revealed a worse picture, it was noted that up to 83% of patients in ICU had malnutrition and the prevalence of malnutrition tend to increase with longevity of hospital stay [18].

Another study done by Hejazi *et al.,* involving 8 ICU facilities in Shiraz, Iran also found that malnutrition prevalence was 58.62 % and as other studies the authors found that the trends were significantly increasing on the day of discharge compared to the day of admission [19].

Although poor nutrition status during hospitalization could have been attributable to many factors such as disease progress, poor appetite and poor gastrointestinal absorption, studies implicates inadequacies in hospital nutritional support being one of the main factors [17].

Validity of Predictive Equations

The findings from this study showed that predictive equations are largely inaccurate, with exception of Penn state equation, all the other tested equation did not predict the REE in a ± 10% difference of the measured REE more than half of the time, the accuracy of the equation were 30%, 45.5%, 46.4% and 68.2% in Harris Benedict, Mifflin-St. Jeor, ESPEN and Penn State equations respectively.

A reflection of the findings was also seen in a study done by McClave and others which found that more than two-third of the patients (69%) who their nutritional support were estimated by the means of predictive equations were inaccurate [14]. Another study in Alabama, United States America found that only Owen and Mifflin were accurate 45% and 50% respectively, this led to a conclusion that predictive equation were not good predictors of energy requirements [20].

Furthermore, a large cohort study conducted in Israel that was published in the Journal of Clinical Nutrition 2018 by Zusman et al found that the level of accuracy of the predictive formulae did not exceed 50% in ICU patient arriving to a conclusion that equations should not be used in place of indirect calorimetry when assessing nutritional requirements in critically-ill population [21].

This study also found that both overestimation and underestimations were prevalent in predictive equations, Harris Benedict's equation was noted to overestimate the energy in 57.3% of the times, this tendency was also noted in McClave *et al.,* and Irons *et al.,* which found that HB equation overestimate 48% and 50% of the times respectively [20, 14].

In this study Penn State was found to be the most accurate by managing to predict REE within ±10% in 68.2% of the times, a study published by Frankenfield in 2004 in Journal of Parenteral and Enteral Nutrition also found the accuracy of Penn State equation to be around 70% [22].

Also this study noted that there was a poor agreement between the predicted REE by the Equations and measured REE by the indirect calorimetry this entails that the predictive equations were poor surrogates of measured REE a finding that was seen in a study by Tammy Song *et al.,* and other studies [23, 21].

The dynamic picture seen in accuracy of predictive equations is thought to be contributed by many factors, a review article by Walker *et al.,* suggested that age, weight variations from edema, obesity, population in which the equation was designed from, and medication are the leading factors that influence Energy Expenditure and Prediction Equations [4].

Recommendations

We recommend there should be a goal directed nutritional support in critically ill patients, also we recommend if present, Indirect Calorimetry should be used as a standard means of measuring Resting Energy Expenditure and whenever absent, and Penn State

Equation can be used to estimate resting energy expenditure in preference to other predictive equations.

Study limitations

This study used only a single Intensive Care Unit from a single tertiary hospital to reflect the findings from other Intensive care units from the general population, a fact that may or may not be true. Also this study examined only one aspect of nutrition (Energy) other crucial aspects of nutrition such as Protein and Micronutrients intake were not examined. Furthermore, this study was a cross-sectional study involving a small, not blinded, not randomized sample, factors that may affect validity of the findings.

CONCLUSION

Malnutrition and Poor Nutritional support are common problems among mechanically ventilated critically-ill patients in ICU.

Predictive equations have poor accuracy in predicting resting energy expenditure and therefore they should not be used to substitute Measured Resting Energy expenditure from indirect calorimetry in mechanically ventilated critically-ill patients.

Whenever indirect calorimetry is not available, Penn State Equation can be used in preference to other equations to estimate resting energy expenditure in this population.

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