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Penn State equation versus indirect calorimetry for nutritional assessment in patients with traumatic brain injury

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Background: Nutritional assessment can be challenging in patients with traumatic brain injury (TBI), and indirect calorimetry may be a more suitable method than predictive equations. We compared the Penn State equation versus the gold standard of indirect calorimetry for the nutritional assessment of patients with TBI, and quantified the difference between nutritional requirements and actual patient intake.

Methods: This single-centre, prospective cohort study included patients with moderate (Glasgow Coma Scale score 9–12) and severe (Glasgow Coma Scale score 3–8) TBI admitted to the Montreal General Hospital intensive care unit (ICU) between June 2018 and March 2019. Penn State equation estimates and indirect calorimetry measurements were collected, and actual intake was drawn from medical records. We compared the 2 assessment methods using a Spearman correlation coefficient.

Results: Twenty-three patients with TBI (moderate in 7 and severe in 16) were included in the study. Overall, there was a moderate positive correlation between the Penn State equation estimate and indirect calorimetry readings (correlation coefficient 0.457, $p = 0.03$); however, the correlation was weaker in severe TBI (correlation coefficient 0.174, $p = 0.5$) than in moderate TBI (correlation coefficient 0.929, $p = 0.003$). When compared to indirect calorimetry assessment, patients received 5.4% ($p = 0.5$) of required intake on the first day and 43.9% ($p = 0.8$) of required daily intake throughout their ICU stay.

Conclusion: Patients with moderate or severe TBI in the ICU received less than 50% of their nutritional requirements. The difference between the Penn State equation and indirect calorimetry assessments was most noticeable for patients with severe TBI, which indicates that indirect calorimetry may be a more suitable tool for assessment of nutritional needs in this population.

Contexte : L'évaluation nutritionnelle peut être compliquée chez les patients qui ont subi un traumatisme crânien (TC), et dans ce contexte, la méthode appelée calorimétrie indirecte pourrait être mieux adaptée que les équations prédictives. Nous avons comparé l'équation de Penn State à la norme en matière de calorimétrie indirecte pour l'évaluation nutritionnelle de patients victimes d'un TC, et calculé la différence entre les besoins nutritionnels des patients et leur apport nutritionnel réel.

Méthodes : Cette étude de cohorte prospective menée dans un seul centre a inclus des patients présentant des TC modérés (score de 9–12 à l'échelle de Glasgow) et graves (score de 3–8 à l'échelle de Glasgow) admis à l'unité des soins intensifs (USI) de l'Hôpital général de Montréal entre juin 2018 et mars 2019. Les estimations de Penn State et les mesures de calorimétrie indirecte ont été recueillies et les apports réels ont été tirés des dossiers médicaux. Nous avons comparé les 2 méthodes d'évaluation au moyen du coefficient de corrélation de Spearman.

Résultats : Vingt-trois patients victimes de TC (7 cas modérés et 16 cas graves) ont été inclus dans l'étude. Dans l'ensemble, on a noté une corrélation positive modérée entre les estimations fournies par l'équation de Penn State et les lectures de calorimétrie indirecte (coefficient de corrélation 0,457, $p = 0{,}03$); toutefois, la corrélation était plus faible dans les cas de TC graves (coefficient de corrélation 0,174, $p = 0{,}5$) que dans les cas modérés (coefficient de corrélation 0,929, $p = 0{,}003$). Comparativement aux évaluations de calorimétrie indirecte, les patients ont reçu 5.4 % ($p = 0{,}5$) de l'apport requis le premier jour, et 43,9 % ($p = 0{,}8$) de l'apport quotidien requis pendant le reste de leur séjour à l'USI.

Conclusion : Les patients victimes de TC modérés ou graves hospitalisés à l'USI ont reçu moins de 50 % de l'apport nutritionnel recommandé. La différence entre l'équation de Penn State et les évaluations de calorimétrie indirecte était plus manifeste chez les patients victimes de TC graves, ce qui indique que la calorimétrie indirecte pourrait mieux convenir à l'évaluation des besoins nutritionnels chez cette population.

A vast amount of resources are used by patients who are admitted in the intensive care setting, particularly those with a high acuity of illness. Along with continuous monitoring, regular imaging and procedures, multiservice consultations and major operations, patients in the critical care setting require special attention to nutrition support. Often, the medical team focuses on other aspects of medical care, such as ventilation, hemodynamic stability and treatment of underlying condition, and nutrition is addressed in a delayed manner.

The standard of care for nutritional assessment and metabolic needs in the intensive care unit (ICU) takes the form of predictive equations, such as the Penn State equation. In patients with traumatic brain injury (TBI), estimating caloric needs can be challenging, particularly in severe cases. There is evidence that established predictive equations lack accuracy in particular subgroups such as patients with obesity and those with burns.[1] A recent study highlighted the inaccuracy of predictive equations as nutritional assessment tools in patients with trauma in particular.[2]

Indirect calorimetry, the study of resting metabolic rate through measurements of oxygen used and carbon dioxide released through a ventilator, has been established as the gold standard of nutritional assessment.[3] This method compiles breath-by-breath measurements, using an algorithm to estimate average daily caloric needs.[4] However, it is subject to many circumstantial limitations, such as ventilator settings, anesthesia and excessive movement.[3]

We aimed to compare the Penn State equation against the gold standard of indirect calorimetry for the assessment of nutritional needs of patients with TBI. We also aimed to quantify the difference between nutritional requirements and the actual caloric intake for patients with moderate or severe TBI.

METHODS

This study was a single-centre prospective cohort study for which research ethics board approval was obtained. Patient recruitment was carried out between June 2018 and March 2019 in the ICU of the Montreal General Hospital. The sample population included patients with TBI categorized as moderate (Glasgow Coma Scale score 9–12) or severe (Glasgow Coma Scale score 3–8) on presentation to the emergency department. Adult (age ≥ 18 yr) patients who were receiving mechanical ventilation, were expected to receive nutritional support and were co-followed by nutritionists were eligible for the study. We excluded patients who were expected to become organ donors, those who were moribund and those with an air leak in the ventilation circuit.

Patient selection was conducted by a research assistant through daily admissions data. Patient recruitment was completed through further chart review, and informed consent was obtained. A target sample size of 20–25 patients was deemed sufficient to yield results, taking into account single-centre case volume as well as desired study duration.

The nutritionist calculated the nutritional needs of patients using the Penn State equation 2003b[5] within 48 hours of admission to the ICU. An initial indirect calorimetry reading was obtained with the Quark RMR metabolic rate machine (COSMED) 24–72 hours after admission to the ICU; subsequent readings were obtained every 3 days for a maximum of 14 days, or until the ventilator was removed or the patient was discharged from the ICU. All indirect calorimetry readings were obtained between 2000 and 2300, when the likelihood of interventions and stimulation, which could increase patients' metabolic rates, would be minimal.

The data sources used for data collection were the patient's electronic medical record, the medical chart, the nursing flow chart and direct measurements. The variables collected included age, sex, height, weight, diagnosis, Injury Severity Score and comorbidities. In most cases, actual body weight was used; however, in cases in which actual body weight could not be obtained or the patient presented with body mass index (BMI) less than 19 or greater than 30, ideal body weight was used instead, at a BMI of 22.

Statistical analysis

We created a Microsoft Excel database containing patient demographic characteristics, laboratory values, Penn State equation calculations and indirect calorimetry measurements. We performed statistical analyses using SAS, version 9.4 (SAS Institute), and Python 3.0. We summarized baseline patient characteristics using proportions, means with standard deviations and medians with ranges, as appropriate. We used the Kruskal–Wallis and χ^2 tests to compare clinical variables between the moderate and severe TBI groups. We compared the Penn State equation estimate to the mean indirect calorimetry measurements using a Spearman correlation coefficient.

RESULTS

Fifty-three patients with head injury were screened, of whom 30 were excluded (owing to a circuit connection air leak [9 patients], not receiving mechanical ventilation [8], ventilator removed before indirect calorimetry assessment [5], not receiving nutritional support [4], expected to be an organ donor or moribund [3] and < 18 yr [1]). The remaining 23 patients, 7 with moderate TBI and 16 with severe TBI, were enrolled in the study. The median age was 42 (range 18–87) years; it was 72 (range 42–87) years in the moderate TBI group and 38 (range 18–83) years in the severe TBI group (Table 1). The patients with severe TBI

Table 1. Demographic and clinical characteristics of patients with traumatic brain injury, overall and by severity

	Group; no. (%) of patients*			
Characteristic	All *n* = 23	Moderate *n* = 6	Severe *n* = 17	*p* value
Age, median (range), yr	42 (18–87)	72 (42–87)	38 (18–83)	0.03
Age group, yr				
18–45	13 (56)	2 (33)	11 (65)	0.2
46–65	2 (9)	0 (0)	2 (12)	
> 65	8 (35)	4 (67)	4 (24)	
Male sex	16 (70)	3 (50)	13 (76)	0.09
Hypertension	6 (26)	2 (33)	4 (24)	0.6
Alcohol/substance use	5 (22)	1 (17)	4 (24)	0.7
Diabetes mellitus	4 (17)	1 (17)	3 (18)	1.0
Coronary artery disease	2 (9)	2 (33)	0 (0)	0.01
Dyslipidemia	3 (13)	2 (33)	1 (6)	0.09
Hyperthyroidism/hypothyroidism	4 (17)	2 (33)	2 (12)	0.2
Injury Severity Score, median (range)	17.0 (1–75)	11.5 (1–57)	20.0 (4–75)	0.2
Multiple trauma	16 (70)	4 (67)	12 (71)	0.9
Glasgow Coma Scale score, median (range)	7 (3–10)	10 (9–10)	6 (3–8)	< 0.001
Height, median (range), m	1.77 (1.52–1.97)	1.62 (1.52–1.83)	1.78 (1.58–1.97)	0.02
Actual weight, median (range), kg	74 (52–105)	68 (52–98)	74 (58–105)	0.6
Ideal weight, median (range), kg	67.6 (53.1–82.4)	60.0 (53.1–73.7)	70.4 (56.1–82.4)	0.04
First-day caloric intake, median (range), kcal	196.0 (0.0–881.7)	443.0 (0.0–881.7)	196.0 (60.5–417.0)	0.3
Penn State equation estimate, median (range), kcal	1680 (960–2330)	1430 (960–1800)	1726 (1180–2330)	0.08
Caloric intake during ICU stay, median (range), kcal	1073 (828–1493)	1025 (983–1349)	1116 (828–1493)	0.2
First-day indirect calorimetry reading, median (range), kcal	1776 (971–2750)	1344 (971–2189)	1865 (1167–2750)	0.2
Indirect calorimetry reading, median (range), kcal	1833 (1090–2631) *n* = 12	1488 (1090–2264) *n* = 3	1865 (1167–2631) *n* = 9	0.2

ICU = intensive care unit.
*Except where noted otherwise.

were taller (median height 1.77 m) and weighed more (median 74.5 kg) than those with moderate TBI (1.62 m and 68.0 kg, respectively). The median Injury Severity Score was higher in the severe TBI group than in the moderate TBI group (20.0 v. 11.5).

Overall, there was a moderate correlation coefficient of 0.457 ($p = 0.03$) between the Penn State equation estimate and the mean indirect calorimetry readings (Table 2). This indicated that, overall, the 2 assessment tools provided similar estimates of nutritional energy needs. For moderate TBI, the correlation coefficient was 0.929 ($p < 0.01$), indicating that the 2 methods gave almost identical estimates. However, for severe TBI, the correlation coefficient was 0.174 ($p = 0.5$), which indicated that the estimates provided by the 2 methods were different. Given that the null hypothesis was that there was no correlation between the estimates provided by the 2 assessment tools, the large *p* value for severe TBI supports the argument of a poor correlation. Considering that indirect calorimetry is the gold standard, this result shows that the Penn State equation may not be a strong method to assess nutritional energy needs in patients with severe TBI. When we compared the Penn State equation estimate to the first indirect calorimetry reading in the severe TBI group, the correlation coefficient was slightly higher, at 0.232 ($p = 0.4$); however, the difference between the 2 correlation coefficients was not statistically significant.

Table 2. Spearman correlation coefficients for comparison between the Penn State equation estimate and indirect calorimetry readings

Comparison; group	Correlation coefficient	*p* value
Penn State equation v. mean indirect calorimetry		
Overall	0.457	0.03
Moderate TBI	0.929	0.002
Severe TBI	0.174	0.5
Penn State equation v. first-day indirect calorimetry		
Overall	0.483	0.02
Moderate TBI	0.929	0.002
Severe TBI	0.232	0.4

TBI = traumatic brain injury.

Twelve patients, 3 with moderate TBI and 9 with severe TBI, stayed in the ICU long enough to receive at least 2 indirect calorimetry readings. Overall, the median variance in nutritional needs as measured with indirect calorimetry over the entire ICU stay was 436 kcal (range 179–660 kcal). The corresponding values for the moderate TBI

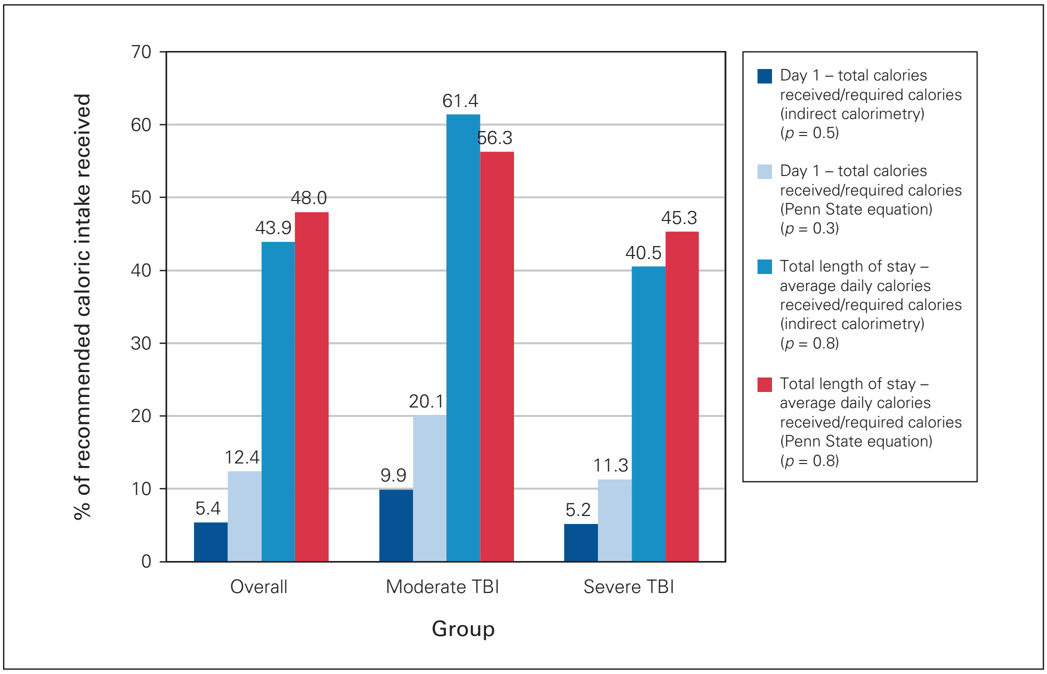

Fig. 1. Proportion of required calories received by patients with traumatic brain injury (TBI) on day 1 of their intensive care unit (ICU) stay and throughout their ICU stay, overall and by severity.

group and the severe TBI group were 576 kcal (range 306–586 kcal) and 434 kcal (range 179–660 kcal); there was no significant difference between the 2 groups. The nutritional needs varied noticeably between sequential indirect calorimetry readings.

The overall trend in actual intake showed marked underfeeding (Figure 1). Patients received on average 5.4% ($p = 0.5$) of required calories predicted by indirect calorimetry on the first day of their ICU stay. Throughout their entire ICU stay, patients received on average 43.9% ($p = 0.8$) of their daily intake predicted by indirect calorimetry. The corresponding Penn State equation estimates were 12.4% ($p = 0.3$) and 48.0% ($p = 0.8$). Regardless of which assessment method actual intake was compared to, or whether patients had moderate or severe TBI, patients were uniformly underfed. The small sample limited the statistical significance of these results.

Discussion

Nutritional assessment of patients in the hospital setting has been a long-standing challenge, as evidenced by the multiple different predictive equations developed to account for different populations. In particular, along with patients with extreme BMI, those with trauma are well documented to be poorly assessed by established predictive equations, such as the Harris–Benedict equation, the Penn State equation and the World Health Organization equation.[6] Various studies present contradictory conclusions about which predictive equation is most accurate in the ICU,[5,7] resulting in a lack of consensus for nutritional assessment in this patient population. For this study, we opted to evaluate the Penn State equation, in part because the nutritionists at our institution are familiar with this tool, as it is what they use regularly in the ICU of the Montreal General Hospital. Along with the Harris–Benedict equation, the Mifflin–St Jeor equation and the Ireton-Jones equation, the Penn State equation is a commonly used and validated nutritional assessment tool in ICUs, although it was originally derived from a heterogeneous population that included patients without trauma.[8,9] The accuracy of the Penn State equation has been found to be quite variable.[5] The A.S.P.E.N. guidelines confirm that equations derived from testing inpatients are no more accurate than those derived from healthy volunteers.[10] We used indirect calorimetry as the comparator because it is considered the gold standard for guiding nutrition support.[11] This noninvasive technique allows for personalization of nutritional plans, accounting for effects from the natural course of disease, individual inflammatory and immune system response, and medical treatments,[12] and is associated with better outcomes.[13]

Although the nutritional assessments in the moderate TBI population correlated very well between the 2 assessment tools in our study, those in the severe TBI group did not. This difference was likely due to a combination of factors, including the natural evolution of TBI, and individual inflammation and immune responses that the Penn State equation may not account for. The moderate TBI population may more closely resemble the sample population used to derive the Penn State equation, whereas the metabolic consequences in patients with severe TBI may extend beyond the Penn State equation's breadth. The Penn State equation factors in body weight, height, sex, age, minute ventilation and body temperature.[14] According to the most recent A.S.P.E.N. guidelines, the reduced accuracy of predictive equations is related to many nonstatic variables affecting energy expenditure in critically ill patients, such as weight, medications, treatments and body temperature.[3] In our study, in which actual body weight was used in most cases, patients with severe TBI were taller and weighed more than those with moderate TBI. Given the complex presentation of patients with TBI, it remains difficult to determine the roles of height and weight in altering the accuracy of Penn State equation estimates. In patients with severe TBI, in whom inflammation, trauma and immune response are heightened, the factors taken into consideration in predictive equations may not represent the patient's complete metabolic state.

Critically ill patients in the ICU have highly variable nutritional needs. One study showed a daily variation of 4%–56% in the nutritional needs of this population.[15] In addition, since indirect calorimetry is a direct measurement of the metabolic needs of the patient at 1 time, it is important to reduce confounding factors such as agitation, procedures, pain and mobilization that might cause the assessment to be unrepresentative.[16] In the present study, indirect calorimetry was conducted every 3 days, between 2000 and 2300, when the likelihood of interventions and stimulation to the patient would be minimal, and the sequential assessments showed variations. Although the time frame for our indirect calorimetry measurements was intentional, perhaps an average of measurements obtained throughout the day, during times of both stimulation and nonstimulation, would provide a more representative overall assessment. The standard of practice at our institution — using the Penn State equation once, on admission — does not account for variations in nutritional requirements over time.

Indirect calorimetry is not as commonly used as predictive equations in clinical settings. However, evidence shows that the use of indirect calorimetry in the clinical setting affects outcomes by promoting correct energy provision and protein supplementation.[17] Known barriers to implementation include machine cost, lack of trained personnel and difficulty in data interpretation. The additional time required for indirect calorimetry assessment may also limit the routine use of this tool. However, in their small study, Nevin and colleagues[18] reported positive feedback regarding feasibility and patient acceptability. Also, protocols already exist for certain patient populations. For instance, respiratory therapists at our institution have an established indirect calorimetry protocol for assessing nutritional needs in patients with extreme BMI.

The variance observed through multiple indirect calorimetry readings raises a secondary concern about the current standard of care for nutritional assessment. Although the Penn State equation may assess the nutritional needs of patients with moderate TBI adequately, performing only 1 assessment on admission may not account for important changes in patients' nutritional needs.

The 2016 A.S.P.E.N. guidelines recommend that critically ill patients receive 25 kcal/kg/d of energy; patients with obesity should receive no more than 70% of their total caloric requirements, with a diet more focused on high protein intake.[3] Even with these reduced targets, patients in our study were regularly receiving less than 50% of their caloric requirements. As first-day caloric intake was found to be most noticeably under target requirements, part of these discrepancies may be explained by the often chaotic first few hours after admission to the ICU. However, according to the A.S.P.E.N. guidelines, enteral nutrition should be initiated within 24–48 hours in critically ill patients unable to maintain volitional intake.[3] Furthermore, the guidelines recommend that patients at high risk for poor nutrition should reach more than 80% of estimated goal energy within 48–72 hours of admission.[3] Enteral nutrition is most often interrupted because of procedures, imaging and surgery, which occur frequently for patients in the ICU.[19] This can potentially lead to malnutrition, which is documented to be associated with death in critically ill patients.[20] In light of the results from the present study, as well as data from other studies, early initiation of enteral feeds may be a key area of improvement to avoid or minimize the effects of underfeeding and malnutrition.

Limitations

This study is limited by its small sample. Although the trends observed were consistent, the statistical significance could not be confirmed for all results. In addition, given the heterogeneity of the patient presentation and course, it was not recorded whether the minute ventilation in each case was generated by the patient or set by the respiratory therapist. This distinction may have affected the accuracy of the Penn State equation estimates.

Conclusion

The Penn State equation did not adequately predict the nutritional needs of patients with severe TBI. Therefore, we suggest the more routine use of indirect calorimetry in patients with TBI, particularly those with severe TBI. In the absence of access to indirect calorimetry, the Penn State equation appears to be an adequate nutritional assessment tool in patients with moderate TBI. In addition, we found that patients with TBI are underfed. Strategies to mitigate this, such as early feeding, should be implemented.

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