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The comparison of total energy and protein intake relative to estimated requirements in chronic spinal cord injury

Gary J. Farkas[1]*, Arthur S. Berg[2], Alicia Sneij[1], David R. Dolbow[3,4], Ashraf S. Gorgey[5] and David R. Gater, Jr[1,6]†

[1]*Department of Physical Medicine and Rehabilitation, University of Miami Miller School of Medicine, Miami, FL, USA*
[2]*Department of Public Health Sciences, Penn State College of Medicine, Hershey, PA, USA*
[3]*Department of Physical Therapy, William Carey University, Hattiesburg, MS, USA*
[4]*College of Osteopathic Medicine, William Carey University, Hattiesburg, MS, USA*
[5]*Spinal Cord Injury and Disorders Center, Hunter Holmes McGuire VA Medical Center, Richmond, VA, USA*
[6]*The Miami Project to Cure Paralysis, University of Miami Miller School of Medicine, Miami, FL, USA*

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Abstract
In chronic spinal cord injury (SCI), individuals experience dietary inadequacies complicated by an understudied research area. Our objectives were to assess (1) the agreement between methods of estimating energy requirement (EER) and estimated energy intake (EEI) and (2) whether dietary protein intake met SCI-specific protein guidelines. Persons with chronic SCI (n = 43) completed 3-day food records to assess EEI and dietary protein intake. EER was determined with the Long and Institute of Medicine (IOM) methods and the SCI-specific Farkas method. Protein requirements were calculated as 0·8–1·0 g/kg of body weight (BW)/d. Reporting accuracy and bias were calculated and correlated to body composition. Compared with IOM and Long methods (P < 0·05), the SCI-specific method did not overestimate the EEI (P = 0·200). Reporting accuracy and bias were best for SCI-specific (98·9 %, −1·12 %) compared with Long (94·8 %, −5·24 %) and IOM (64·1 %, −35·4 %) methods. BW (r = –0·403), BMI (r = –0·323) and total fat mass (r = –0·346) correlated with the IOM reporting bias (all, P < 0·05). BW correlated with the SCI-specific and Long reporting bias (r = –0·313, P = 0·041). Seven (16 %) participants met BW-specific protein guidelines. The regression of dietary protein intake on BW demonstrated no association between the variables (β = 0·067, P = 0·730). In contrast, for every 1 kg increase in BW, the delta between total and required protein intake decreased by 0·833 g (P = 0·0001). The SCI-specific method for EER had the best agreement with the EEI. Protein intake decreased with increasing BW, contrary to protein requirements for chronic SCI.

Keywords: Spinal cord injury: Total energy intake: Dietary protein: Estimated energy requirements: Obesity

A spinal cord injury (SCI) results in permanent neurological deficits and premature ageing, contributing to accelerated morbidity and mortality throughout the lifespan[1–3]. After an SCI, a decrease in body weight (BW) is commonly ascribed to substantial depletion of body protein with a subsequent increase in fat mass. This phenomenon instigates a compromised musculoskeletal system[4,5] and results in diminished whole-body energy expenditure, characterised by a decline in basal metabolic rate (BMR)[6–8] and physical activity[9–11], with conflicting evidence on dietary thermogenesis[10,12–14]. In individuals with chronic SCI, BMR is significantly reduced by as much as 27 %[13], mainly through the loss of fat-free mass (FFM) primarily driven by skeletal muscle denervation and atrophy below the injury level[7,15,16].

In persons without SCI, the loss of FFM and inadequate dietary protein intake are associated with weight gain and regain[17,18]. This weight regain is not only due to a reduced resting metabolism but also because of the triggering effect of FFM loss to stimulate an increased energy intake to restore FFM to an optimal level, a theory referred to as the 'collateral fattening' concept[19,20]. This concept suggests the importance of adapting energy and dietary protein intake to the SCI-specific needs for FFM maintenance to avoid additional loss and gains in fat mass. Consequently, while persons with SCI sustain a decrease in energy expenditure, it is seldom complemented by a similar reduction in energy intake[21] despite consuming less energy than persons without SCI[7,10].

Abbreviations: AND, Academy of Nutrition and Dietetics; BMR, basal metabolic rate; BW, body weight; EEI, estimated energy intake; EER, estimating energy requirements; FFM, fat-free mass; IOM, Institute of Medicine; LOA, level of agreement; MSE, mean squared error; SCI, spinal cord injury.

* **Corresponding author:** Gary J. Farkas, Ph.D., email gjf50@med.miami.edu

† Passed away in August 2022.

The energy requirement of an individual is the habitual level of energy intake from food that will balance energy expenditure. Determining appropriate energy requirements relies on the assumption of energy balance, attained when total energy expenditure equals total energy intake. Investigating energy intake relative to energy expenditure rests on the fundamental equation of energy balance (equation 1) and the assumption that in stable-weight adults at the group level, changes in body energy stores can be ignored in non-growing and non-lactating adults (equation 2)[22,23].

$$\text{Energy intake} = \text{Energy expenditure} \pm \text{changes in body stores} \quad (1)$$

$$\text{Energy intake} = \text{Energy expenditure} \quad (2)$$

The determination of energy expenditure, and thereby energy requirements, is based on doubly labelled water[24,25], the reference standard method that is limited by cost, technical experience and equipment and generalisability of findings to special populations, such as those with SCI. Surrogate energy metabolism and dietary assessment tools, such as indirect calorimetry[26], dietary food records[21,27] and prediction equations[21,28,29], have been widely used to estimate energy needs and intake in persons with and without SCI. Methods of estimation to assess these requirements include regression equations from the Institute of Medicine (IOM) of the National Academies[29] and the simplified factorial method[23]. In the factorial method, dietary thermogenesis is ignored because of its small magnitude and minimal contribution to total energy expenditure, and physical activity is calculated or estimated as an activity factor[23,30]. Using this principle, calculated total energy expenditure and, consequently, the associated energy requirements are derived as the product of BMR and a factor representing physical activity. While several authors have published SCI-specific equations to estimate BMR[26], most equations used to determine energy requirements have been developed in and for persons without SCI and do not factor in the metabolic changes resulting from the injury. Recently, Farkas and colleagues[21] developed an SCI-specific activity coefficient. When multiplied by BMR, this coefficient yields an estimate of energy requirements[21]. However, this tool has yet to be tested against estimated energy intake (EEI) in chronic SCI.

Dietary protein is essential to energy intake to maintain skeletal muscle during a sedentary lifestyle with low physical demands, like after SCI[31]. Regarding nutrient deficits, injury-induced changes in body composition also increase the risk of weakness, fatigue and vulnerability to illness and acute stress in chronic SCI, suggesting that dietary protein is vital for protecting and preventing health ailments. An individual's protein requirement is defined as the lowest amount of habitual dietary protein intake that will balance body nitrogen losses in individuals maintaining energy balance[31]. Research regarding SCI-specific protein requirements is primarily limited to the acute injury phase[32–34], and only the Academy of Nutrition and Dietetics (AND) provides protein guidelines for chronic SCI in the amount of 0·8–1·0 g/kg of BW/d[35]. Protein intake in chronic SCI has not been examined against guidelines regarding protein requirements by BW to determine if this population is meeting guidelines, especially in the presence of reduced energy intake[36] and diminished FFM[13].

The objective of this paper was twofold. Our first objective was to assess the agreement between methods of estimating energy requirements (EER) and EEI in persons with chronic SCI. Second, we wanted to determine whether dietary protein intake was within the SCI-specific guidelines for estimated protein requirements by BW. We hypothesised (1) that non-SCI-specific methods used to estimate energy requirements will overestimate EEI and (2) that most persons with SCI would not meet protein requirements when evaluated according to BW.

Materials and methods

Participants

This study was a secondary analysis of a larger clinical trial (NCT00957762) that aimed to evaluate different methods of measuring body composition and determine relationships between body composition and other medical problems (i.e., excessive energy intake) associated with SCI[37]. In this study, we used a subset of the participants with dietary data ($n = 43$) and that were free of any pressure injuries. This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Institutional Review Board (#01399). Written informed consent was obtained from all participants. Each participant underwent a physical and a neurological[38] examination by a physiatrist board certified in SCI medicine. Inclusion criteria were (1) men and women aged 18–65 years; (2) C4 to L2 American Spinal Injury Association Impairment Scale A and B injuries[38] and (3) at least 12 months post-injury[39]. Exclusion criteria were as follows: (1) smokers; (2) individuals with excessive alcohol consumption (greater than 2 drinks/d); (3) those with pressure injuries, hypothyroidism, renal disease and/or (5) recent (≤ 3 months) deep vein thrombosis or uncontrolled autonomic dysreflexia (hypertensive event following the removal of the noxious stimuli). Table 1 demonstrates participant characteristics.

Physical characteristics and body composition

Before assessing height and BW, each participant was asked to void their bladder. Height was determined using an anthropometer (Holtain Anthropometry) on the left side after aligning the head, torso and lower extremities. Every effort was made to keep the knees in full extension[37]. BW was quantified with a wheelchair scale (PW-630U; TanitaHeights). Participants propelled themselves onto the wheelchair scale with total BW determined by subtracting the weight of the wheelchair from the weight of the wheelchair plus the individual[37]. BMI was calculated as BW divided by height squared (kg/m^2). According to previously published methods, total body fat percentage, fat mass and FFM were measured using a whole-body scan on a dual-energy X-ray absorptiometry machine (Table 1)[21].

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Table 1. Demographic and injury characteristics, body composition and dietary intake of the participants (n = 43)

Demographic and injury characteristics	Mean	SD
Age (years)	45·7	11·4
Gender (% male)	81	
Height (cm)	175·0	9·2
Body weight (kg)	82·7	20·1
BMI (kg/m^2)	27·0	6·2
Time since injury (years)	14·9	11·2
Level of injury	C4-L1	
Body composition		
Total body fat percentage (%)	39·3	8·8
Total body fat (kg)	32·5	12·6
Fat-free mass (kg)	50·7	10·7
Basal metabolic rate (kcal)	1455·4	429·5
Dietary intake		
Absolute protein intake (g)	63·6	24·7
Relative protein intake (%)	17·4	4·9
Absolute fat intake (g)	59·3	27·4
Relative fat intake (%)	33·6	6·2
Absolute carbohydrate intake (g)	182·5	63·0
Relative carbohydrate intake (%)	47·5	7·0
Absolute alcohol intake (g)	3·3	9·2
Relative alcohol intake (%)	1·6	3·8

Dietary records

Dietary records were collected according to previously published methods[21,27]. Each participant and their caregiver (as available) were instructed to maintain a 3-day dietary record to monitor the amount and types of food consumed for a week over three non-consecutive days. Participants were instructed to record their daily consumption of all food and drink for breakfast, lunch and dinner and any food consumed as a snack between meals. No nutritional guidance was provided on meal frequency, cooking instructions or portion sizes, but participants were instructed to provide detailed information about their food and drink intake. After completing the dietary records, they were returned to study personnel. Each day was analysed using the Nutrition Data System for Research software (v2012–2018; University of Minnesota) under the supervision of a registered dietitian. After the dietary analysis was completed, the average EEI and the absolute (in grams) and relative (%) macronutrient intakes (dietary protein, carbohydrate, fat and alcohol) were calculated for 3 days (Table 1)[21,27].

Basal metabolic rate

Participants were instructed to refrain from exercising for 24 h and abstain from eating and drinking (besides water) 12 h before the BMR was completed. Following an overnight stay at the local Clinical Research Center, BMR was measured at approximately 06.00 in a thermoneutral environment[40,41]. Participants were in a dark room in a supine position for 20 min to achieve a steady resting state. During this time, BMR was measured using indirect calorimetry with a portable K4b2 (COSMED Inc.) and a canopy that covered the head and neck[42]. BMR was calculated after discarding the first five minutes and averaging the remaining 15 min (Table 1). BMR was recorded before the study commencement to avoid the possible influence of the measurement on EEI and dietary records[40,41].

Estimated energy requirements and protein requirements

EER were determined using the Long[28] (equation 3) and SCI-specific methods[21] (equation 4) by the simplified factorial method as follows:

$$EER_{Long} = BMR \times 1.\cdot 2 \quad (3)$$

$$EER_{SCI-specific} = BMR \times 1.\cdot 15 \quad (4)$$

where EER is the estimated energy requirements in kcal, BMR is measured in kcal and 1·2 and 1·15 are activity factors for persons without[28] and with[21] SCI, respectively. The activity factor of 1·2, as developed by Long et al.[28] and corroborated by Black et al.[43], was utilised as the value for persons that are ‘confined to bed’ and ‘chair-bound or bed-bound,’ respectively. The SCI-specific activity factor of 1·15[21] was established based on the SCI-specific and general (non-SCI) metabolic equivalent of task of 2·7 ml/kg/min and 3·5 ml/kg/min, respectively[44]. EER were also determined according to the IOM[29]:

$$EER_{IOM-men} = 662 - (9.\cdot 53 \times age) + PA \times [(15.\cdot 91 \times weight) + (539.\cdot 6 \times height)]$$

$$EER_{IOM-women} = 354 - (6.\cdot 91 \times age) + PA \times [(9.\cdot 36 \times weight) + (539.\cdot 6 \times height)]$$

where EER is the estimated energy requirements in kcal, age is measured in years, weight is in kilograms, height is in meters and PA is the physical activity coefficient. We assigned the physical activity coefficient of one (defined by the IOM as sedentary[29]) to the entire sample of participants because of a largely inactive (whether adopted or imposed) sedentary lifestyle after the injury. Additionally, this coefficient was chosen because persons living with SCI are among the most physically deconditioned individuals[45,46], as many do not achieve sufficient oxygen consumption to perform activities of daily living[47].

Protein requirements were calculated according to the AND guidelines at 0·8–1·0 g/kg of BW/d (using the scale-acquired BW) to maintain protein status in the absence of infection and pressure injuries[35].

Statistical analysis

All statistical analyses were performed using R (R Foundation for Statistical Computing). Data were graphically evaluated using beeswarm and Bland–Altman plots to visually present the agreement. A beeswarm graphic was created using ggplot2 (v3.3.5)[48] for R by graphing the EEI values by the EER for SCI-specific, Long and IOM methods. Bland–Altman plots (mean of measurement difference ± 2 standard deviations) were used to measure the mean bias and level of agreement (LOA) against the methods of determining EER and EEI[49,50]. The delta (difference) between each method of EER and EEI was calculated, and Wilcoxon signed-rank exact test assessed differences between the EER and EEI. The interclass correlation coefficient (one-way fixed effects, agreement and multiple measures) was also used to determine the agreement between the three estimation methods and the EEI.

Measures of error, accuracy and bias were also assessed. Error was examined with the mean squared error (MSE). Reporting accuracy was evaluated with the following formula[51]:

$$\text{Reporting Accuracy} = \left(\frac{\text{Total Energy Intake}}{\text{Estimated Energy Requirements}}\right)100\%$$

where total energy intake was the EEI, and estimated energy requirements were calculated using the SCI-specific, Long and IOM methods. Reporting bias on the dietary records was determined according to Trabulsi and Schoeller[52] as

$$\text{Reporting Bias} = \left(\frac{\text{Reported Energy Intake} - \text{Total Energy Expenditure}}{\text{Total Energy Expenditure}}\right)100\%$$

where reported energy intake is the EEI and total energy expenditure was considered equivalent to EER using the SCI-specific, Long and IOM methods. Pearson correlations were used to examine the association between reporting bias and BW, BMI, fat mass and total body fat percentage.

Regarding protein requirements, linear regression was used to examine the association between dietary protein intake (dependent variable) and BW (independent variable). We graphed protein intake together with the AND required range of protein by increasing BW of the study participants using ggplot2 (v3.3.5)[48]. We calculated the delta between protein intake and the midpoint of the required range of protein and then graphed these differences by BW with a best-fit regression line. The minimum and maximum required protein intake values were also graphed by BW and included in the graphic. A BW threshold that maximised the differences in protein intake patterns (overconsumption, adequate consumption and under-consumption) was identified before and after the threshold.

A bootstrap resampling method was used to compare the MSEs of SCI-specific, Long and IOM methods. The observed MSE for each method is defined as the squared differences between the EER and EEI. The MSE is then calculated over a million bootstrap samples to estimate the distribution of the MSE under repeated sampling yielding 95 % CI of the MSE for each method. To compare the relative MSE performance of the three methods, the ratio of MSE for each pair of methods was similarly bootstrapped, yielding bootstrap-based p-values under the null that the ratio of MSE values equals one.

All values were presented as mean ± standard deviation, and the significance level was set at alpha < 0·05.

Power analysis

A power analysis was performed using R to understand the ability of our study to detect a significant effect. A hypothetical EEI estimate whose MSE relative to the MSE of the Long method was set to be λ. This parameter λ represents the effect size that we are interested in detecting. Let μ represent the MSE of the Long estimate, and let σ^2 represent the variance of the Long estimate. Two datasets were repeatedly jointly simulated following a multivariate normal distribution, ensuring the preservation of the underlying statistical properties observed in the real-world data. Specifically, the first dataset, representing the hypothetical estimate, has a mean value of $\lambda\mu$ and a variance of σ^2, and the second dataset, representing properties of the Long estimate, has mean μ and variance σ^2. The correlation between these two datasets is the sample correlation between the Long and SCI-specific methods, specifically, $\rho = 0. \cdot 977$. We then conducted our bootstrap resampling procedure on the simulated datasets across different values of the effects size λ, thereby producing different levels of statistical power. The specific value of λ that provided a power of 80 % is 0·964. With the sample size of 43 as in the analysed dataset, the observed effect size of 0·907 has 98·4 % power to identify a statistically significant improvement in MSE over the Long method.

Results

Estimated energy intake and estimated energy requirements

Figure 1(a) demonstrates the assessed EEI and EER. EEI was 1520·1 ± 534·9 kcal. The EER, according to the SCI-specific method, was 1673·7 ± 493·9 kcal, 1746·4 ± 515·4 kcal according to the Long method and 2486·53 ± 346·82 kcal according to the IOM method. Fig. 1(b) demonstrates the delta between each method of EER and EEI. The mean and standard deviation for the delta between the EER and EEI were 153·6 ± 644·6, 226·3 ± 657·3 and 896·1 ± 669·2 kcal for the SCI-specific, Long and IOM methods, respectively (Fig. 1(b)). Compared with the EEI, the SCI-specific method did not overestimate the EER (P = 0·200), whereas both the IOM (P < 0·0001) and Long (P = 0·03) methods significantly overestimated it (Fig. 1(b)). Bland–Altman analysis (Fig. 2) demonstrated that the SCI-specific method (mean bias: –154, LOA: –1443, 1135) had the best agreement with EEI compared with the Long (mean bias: –226 LOA: –1541, 1088) and IOM (mean bias: –896, LOA: –2235, 442) methods. The interclass correlation coefficient between EEI and the SCI-specific (interclass correlation coefficient = –0·366, P = 0·078), Long (interclass correlation coefficient = 0·173, P = 0·129) and IOM (interclass correlation coefficient = –0·211, P = 0·999) methods were not significant.

MSE for the SCI-specific, Long and IOM methods were 429 282·0 (95 % CI: 312 504·8, 553 873·6), 473 226·7 (95 % CI: 345 439·1, 608 231·4) and 1 240 426·3 (95 % CI: 909 718·4, 1 594 371·7), respectively. Table 2 demonstrates the relative MSE performance of the three methods. Reporting accuracy was 98·9 % for the SCI-specific method, 94·8 % for the Long method and 64·1 % for the IOM method. Reporting bias was –1·12 % for the SCI-specific method, –5·24 % for the Long method and –35·4 % for the IOM method.

Figure 3 illustrates scatter plots for the correlations between reporting bias and measures of body composition. BW (r = –0·403, P = 0·007), BMI (r = –0·323, P = 0·035) and fat mass (r = –0·346, P = 0·025) significantly correlated with the IOM reporting bias. BW significantly correlated with SCI-specific and Long reporting bias (both r = –0·313, P = 0·041). All other correlations were not significant (r = –0·286 to –0·070, P > 0·05).

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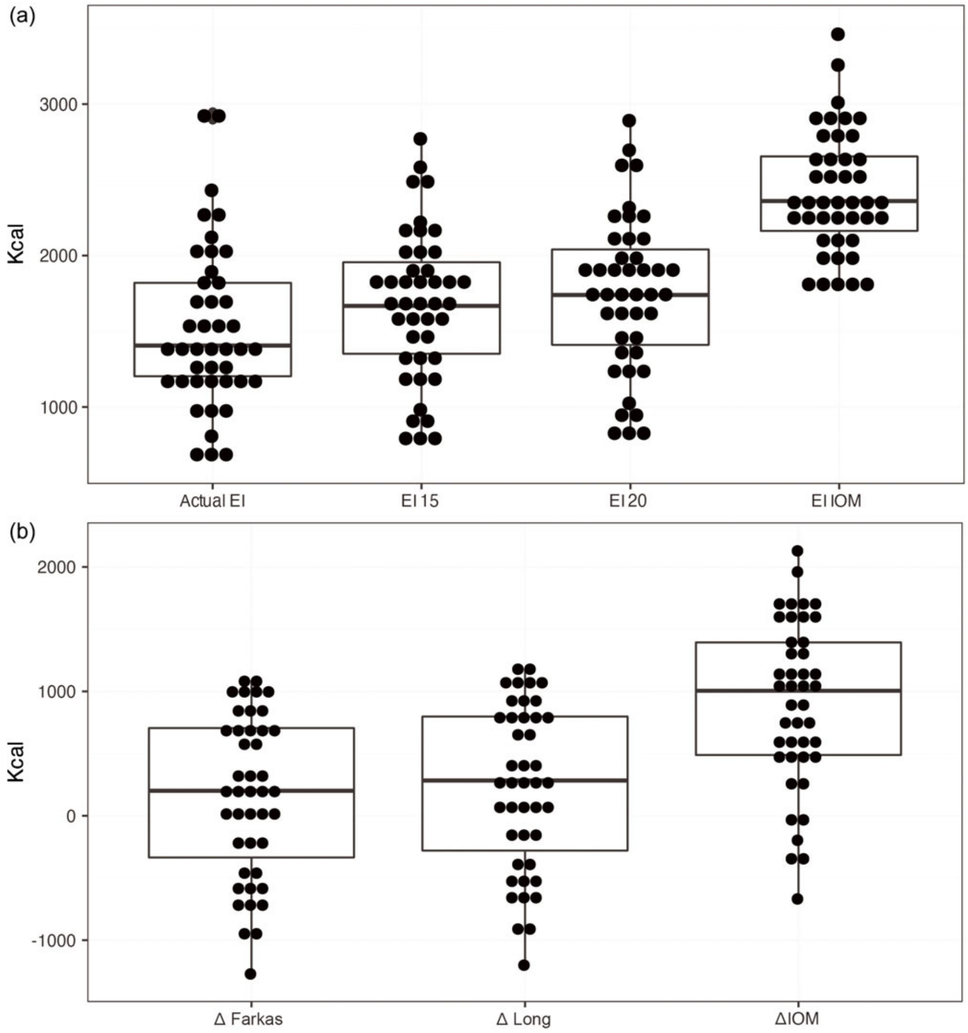

Fig. 1. Estimated energy intake (actual EI) and the SCI-specific (EI 15, Farkas), Long (EI 20) and Institute of Medicine (EI IOM) methods to estimate energy requirements (a). The delta between the SCI-specific, Long and IOM methods to estimate energy requirements and estimated energy intake (b). The solid block circles represent individual study participants (*n* 43). The thick solid black line is the mean of the delta between the estimated energy requirements and the estimated energy intake. SCI, spinal cord injury.

Dietary protein intake and requirements

Figures 4 and 5 present dietary protein intake. Seven of the forty-three (16 %) participants with SCI met AND protein requirements (Fig. 4). The regression of protein intake on BW demonstrated no significant association between the variables ($\beta = 0{\cdot}067$, $P = 0{\cdot}730$) (Fig. 5(a)). However, for every one-kilogram increase in BW, the delta between protein intake and protein requirements decreased by 0·833 g ($P = 0{\cdot}0001$) (Fig. 5(b)).

At the BW threshold of 72·4 kg, protein intake moved from within required ranges and overconsumption to underconsumption, with the degree of underconsumption increasing with BW (Fig. 5(b)). Of the sixteen individuals who weighed less than 72·4 kg, nine (56 %) overconsumed protein, four (25 %) consumed the required amount and 3 (19 %) underconsumed dietary protein. In contrast, of the twenty-seven individuals who weighed more than 72·4 kg, 23 (85 %) underconsumed protein, three (11 %) consumed the required amount and one (4 %) overconsumed protein ($P = 0{\cdot}0001$) (Fig. 5(b)).

Discussion

To the authors' knowledge, this is the first study to examine EEI assessed with food records against EER by several common prediction methods and the adequacy of dietary protein intake in chronic SCI. The main findings indicate that relative to the Long and the IOM methods, the SCI-specific method for EER had the best agreement with EEI and did not significantly overestimate it. Nevertheless, despite its performance over the Long and IOM methods, the SCI-specific approach does exhibit a certain degree of variability and error. Additionally, only 16 % of the participants with chronic SCI met dietary protein guidelines by BW, and dietary protein intake decreased with increasing BW.

Estimated energy intake and estimated energy requirements

Compared with the SCI-specific method for EER, both the Long and IOM methods significantly overestimated energy needs and

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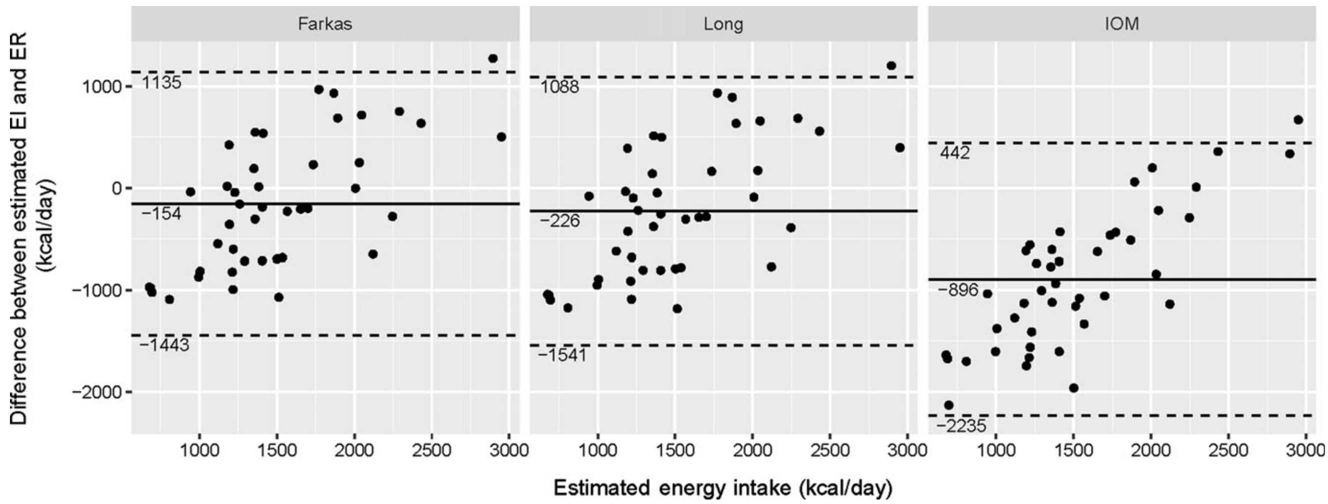

Fig. 2. Bland–Altman plots measuring the level of agreement against estimated energy intake (EI) and the SCI-specific (Farkas), Long and Institute of Medicine (IOM) methods to estimate energy requirements (ER). Solid block circles represent individual study participants ($n = 43$). The solid line represents the mean difference between the two measurements, while the dashed lines represent the 95 % CI (mean ± 2 standard deviations above and below the mean difference). SCI, spinal cord injury.

Table 2. Comparison of the relative mean squared error (MSE) performance of the SCI-specific, Long and Institute of Medicine methods to estimate energy requirements

	MSE Ratios	Bootstrap p-value	Rho Correlation
SCI-Specific/Long	0·907	0·001	0·977
SCI-Specific/IOM	0·346	< 0·001	0·228
Long/IOM	0·382	< 0·001	0·344

SCI, spinal cord injury; IOM, Institute of Medicine.

demonstrated poor LOA with EEI assessed using food records. While acknowledging the presence of errors and substantial variability in the LOA within the SCI-specific and Long methods, it is essential to note that the IOM method exhibited comparably less favourable performance. These present findings likely originate from differences in the use of BMR, demographic and physical characteristics and the reporting and knowledge of physical activity estimates. While appealing owing to its simplicity, the IOM method to estimate energy requirements relies on the readily available weight, height and age measures. These demographic and physical characteristics cannot accurately discriminate between fat mass and FFM. FFM is the largest determinant of BMR[53], such that the size of the FFM explains 70–80 % of the variance in BMR[8], but does not account for individual effects of different organs, tissues and their interplay[54,55]. The IOM method also requires people to quantify their physical activity to define the appropriate PAL and physical activity coefficient. Thus, it is unsurprising that methods used to predict energy requirements directly incorporating BMR with a low activity factor had better agreement with EEI than methods relying on a higher activity factor and demographic and physical characteristics. Nevertheless, even though the SCI-specific method performed better than the Long and IOM methods in terms of bias, accuracy and MSE, its clinical applicability on an individual level could be hampered by the pronounced variability observed in its estimations. This tool should be used with caution in clinical practice. Subsequent investigations ought to delve into the specific factors underpinning this variability and consider supplementary strategies that can be employed to mitigate the extent of these fluctuations.

A direct comparison of our findings with those from previous reports within the SCI field is limited. Many investigators have examined EEI with various dietary assessment instruments and TEE separately[39], whereas EER after SCI have historically focused on the acute injury phase[32–34,56,57]. In studies with acute SCI, differences in injury characteristics make comparisons dubious or inappropriate and findings non-generalisable to chronic SCI. To the authors' knowledge, only Gorgey et al.[27] compared the Long factorial method to EEI using inferential statistics in chronic SCI. The authors reported a negative energy balance in sixteen participants with chronic motor complete SCI but hypothesised that participants were underreporting dietary intake on food records[27].

It is well established that dietary assessment methods underreport true energy intake in persons without SCI[58,59], and a similar phenomenon is probable after SCI (reviewed in Farkas et al.[39])[21,27]. While the proportion of under-, acceptable- and over-reporters was not quantified, reporting bias, a surrogate marker for underreporting, was presented. The reporting bias of −1·12 % for the SCI-specific method was less than the reporting biases of −5·24 % and −35·4 % for the Long and IOM methods, respectively. The SCI-specific and Long methods were also less than the −10 to −32 % bias reported for 3-day food records (validated against doubly labelled water) in persons without SCI[52]. A slight difference in the reporting bias between persons with and without SCI may stem from a reduced heteroscedastic error (an unequal variance across a range of values), an error associated with underreporting. The heteroscedasticity in dietary records may be minimised in SCI because intake is less than those without an injury[36]. These findings may be deceptive, however, as underreporting and overreporting for each participant may negate their independent effects

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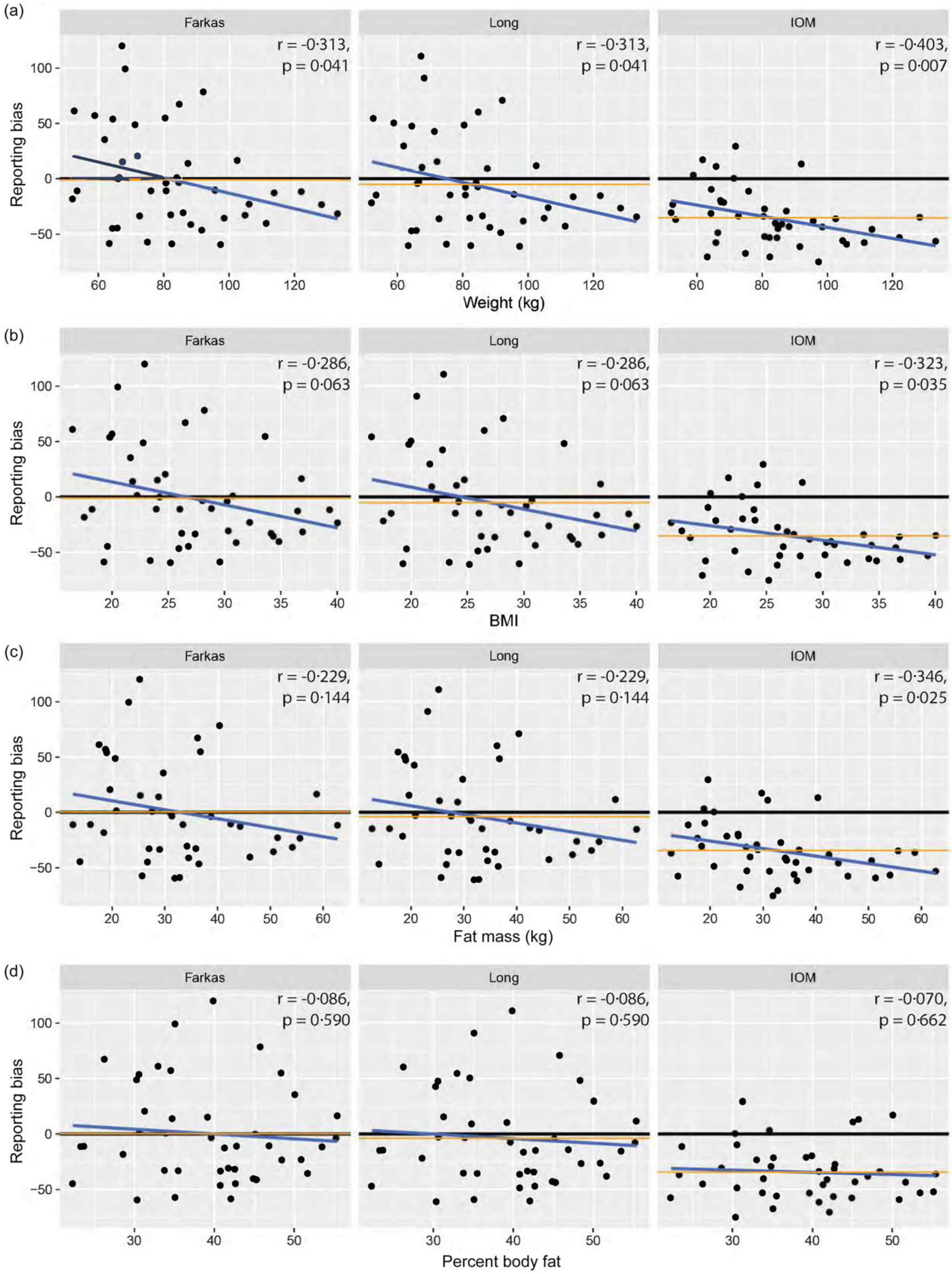

Fig. 3. Scatter plots for the Pearson rho (r) correlations between body weight (a), BMI (b), fat mass (c) and percent body fat (d) and reporting bias (calculated by the SCI-specific (Farkas), Long and Institute of Medicine (IOM) methods to estimate energy requirements). The solid block circles represent individual participants (*n* = 43). Positive and negative values represent overreporting and underreporting, respectively. The solid black, orange and blue lines are the average reporting bias, zero (estimated energy intake is equivalent to estimated energy requirements) and best-fit line. SCI, spinal cord injury.

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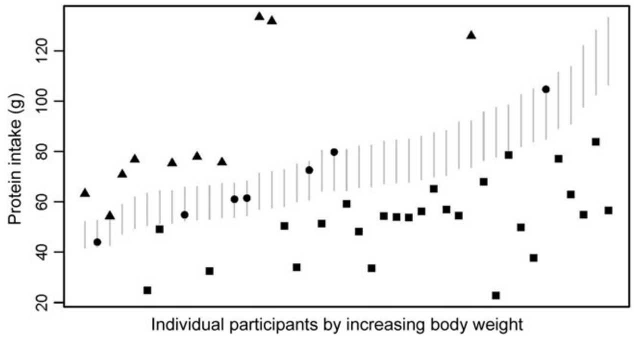

Fig. 4. Dietary protein intake with the Guidelines of the Academy of Nutrition and Dietetics required a range of 0·8–1·0 g of protein intake/kg of body weight (vertical grey lines)/d by the study participants (n = 43) plotted according to increasing body weight. Triangles, squares and circles represent persons overconsuming, underconsuming and that are within the required range of dietary protein intake, respectively.

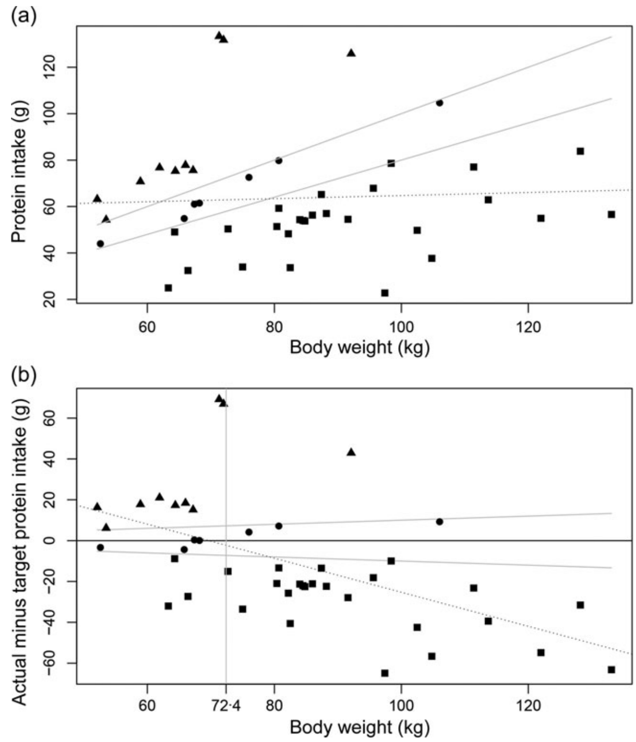

Fig. 5. The regression analysis demonstrated no significant association of dietary protein intake on body weight ($\beta = 0{\cdot}067$, $P = 0{\cdot}730$) (a). In contrast, for every one-kilogram increase in body weight, the delta between total and required dietary protein intake decreased by 0·833 g ($P = 0{\cdot}0001$) (b). At the body weight threshold of 72·4 kg (solid vertical grey line), dietary protein intake moved from within required ranges and overconsumption to underconsumption, with the degree of underconsumption increasing with BW. Grey lines represent the Academy of Nutrition and Dietetics guidelines required range of 0·8–1·0 g of protein intake/kg of body weight/d. The dashed line corresponds to the best-fit line. Triangles, squares and circles represent participants overconsuming, underconsuming and within the required range of dietary protein consumption, respectively. Of the sixteen individuals who weighed less than 72·4 kg, nine (56 %) overconsumed, 3 (19 %) underconsumed and 4 (25 %) consumed the required amount. Of the twenty-seven individuals who weighed more than 72·4 kg, 1 (4 %) overconsumed, 23 (85 %) underconsumed and 3 (11 %) consumed the required amount ($P = 0{\cdot}0001$) (b).

(i.e., cancel each other out). However, by using a Bland–Altman analysis, delta calculation, MSE and reporting accuracy, we provided several alternative approaches that offered greater insight into the accuracy of the estimation methods.

In persons without SCI, prior literature has demonstrated that adiposity is strongly associated with underreporting EEI[60,61]. Individuals with obesity underreport more than individuals without obesity[62]. In the present study, the reporting bias for the IOM method was related to several measures of body composition; in contrast, the reporting biases for the SCI-specific and Long methods were related to BW. Research suggests that persons with obesity that underreport typically do not report foods perceived to be unhealthy and high in fat[63,64]. Reporting of added sugars is also reduced due to the typical exclusion of snack foods[65]. In persons with chronic SCI, carbohydrates comprise the greatest portion of the diet[36] and may therefore be the most underreported macronutrient, although additional research is needed. Consequently, obesity after SCI, along with the consequences of paralysis, likely instigates the underreporting of dietary intake on food records, such that their true intake may be closer to the SCI-specific method of EER when considering the unrecorded food items. This may further help improve the agreement between the SCI-specific method and EEI.

Protein intake

At the population level, Farkas et al.[36] reported in a meta-analysis that dietary protein surpassed the 2015-2020 Dietary Guidelines for Americans recommendations in chronic SCI. However, this finding may be a consequence of Simpson's paradox (a finding in a population emerges but disappears when subpopulations are formed). When examining dietary protein intake by BW, we demonstrated that approximately 40 % of our participants meet current protein guidelines or overconsumed protein. At a BW threshold of 72·4 kg, dietary protein intake moved from within required ranges and overconsumption to underconsumption such that below and above the threshold, 19 % and 85 % underconsumed protein, respectively. Importantly, no significant association was observed for the regression of dietary protein intake on BW, contrary to the AND's formula that dietary protein intake increases with BW. In contrast, for every kg increase in BW, the delta between dietary and required dietary protein intake significantly decreased by 0·833 g, supporting that when BW increases, protein is underconsumed by 17 %.

The underconsumption of protein as a function of BW may result from persons with chronic SCI that are overweight/obese underreporting dietary intake (as described above) or consuming a diet predominantly composed of fat and carbohydrate (i.e., convenience and snack food). This dietary pattern is of concern because high-fat and sugary diets contribute to obesity and cardiovascular disease risk after SCI[66]. With time, underconsumption of dietary protein may contribute to the loss of FFM and an increase in fat mass as BMR decreases. Alternatively, FFM is spared in high-protein diets with energy restriction, suggesting BMR remains unaffected[67,68]. This is evident following weight loss with bariatric surgery, as a higher preservation of lean body mass was reported when protein intake was above 60 g/d or when the protein-to-energy intake ratio was > 20 %[69,70]. After SCI, protein underconsumption may be associated with obesity. Alternatively, a high-protein diet may protect body composition following SCI, as recently documented by Li et al.[71] High-protein intake in persons with SCI with lower BW may be obesoprotective through the satiating effect of protein[72]. Thus, increased consumption of high-protein foods may help modulate energy intake, promoting weight/fat loss and BW maintenance.

We demonstrated that below a BW of 72·4 kg, 9 % of persons with SCI overconsumed dietary protein, compared with 4 % that overconsumed protein at a BW above 72·4 kg. Protein guidelines post-SCI hinge on BW, but given the decline in skeletal muscle mass, these guidelines could be called into question when addressing the altered body composition in chronic SCI. Consequently, these recommendations might encompass a greater proportion of fat mass *v.* FFM in determining dietary protein needs, potentially resulting in an overestimation and overconsumption of protein. However, the excess is metabolised if more dietary protein is ingested than is required for metabolic purposes. In particular, the nitrogen from the amino group is excreted as urea, while the fate of the carbons hinges on whether an individual follows a gluconeogenic or ketogenic pathway. In contrast to energy, the evidence is equivocal on protein's effects on body fat[73], but no detrimental effect has been identified with dietary protein intake *moderately above* the guidelines. Some caution, however, is needed with diets high in dietary protein[74]. High-protein diets have been associated with elevated blood pressure and may harm the kidneys[75]. These harmful effects are especially prevalent in persons with subclinical renal dysfunction because of metabolic syndrome or type 2 diabetes mellitus, metabolic conditions common after SCI[66]. Yet, the link between dietary protein intake and renal disease lacks sufficient evidence in persons with and without SCI, implying additional research is needed[68].

Study limitations

This study has limitations. First, because participants self-reported their dietary intake, they may have modified their eating behaviour during the study period or consumed foods perceived as healthy. Second, rather than collecting dietary records every day, participants completed 3 days. This approach was chosen to mitigate potential misreporting, which could be intensified due to prolonged reporting periods, ultimately placing a higher demand on study participants. This phenomenon was demonstrated by Nightingale et al.[11] and Gorgey et al.[27] as participants with SCI recorded consuming less energy with time. Lastly, we did not measure TEE and protein requirements using the reference standard of doubly labelled water and nitrogen balance, respectively. The expense and technical skills required for these criterion methods have generally restricted their use[52]. Still, we EER according to several published methods[21,28,29]. While BMR was the only component of energy expenditure that was measured, it is the most critical factor and, therefore, EEI because BMR does not drastically change on a day-to-day basis[11,29]. Relative to the other methods of estimation tested in this paper, the SCI-specific method of determining energy requirements in chronic SCI has potential; however, its clinical relevance could be hampered by the variability noted in its estimations and future research will need to determine the factors contributing to its variability and strategies to mitigate it.

Conclusion

Our findings indicate that the SCI-specific method for EER had the best agreement with EEI, likely because it uses BMR with a low activity factor compared to the Long and IOM methods. Although, its clinical applicability could be impeded by the variability observed in its estimations and should be used with prudence. Additionally, persons with SCI inadequately consume dietary protein such that protein intake decreases with increasing BW, contrary to AND protein guidelines for chronic SCI. The shift from adequate- and overconsumption of dietary protein to underconsumption occurred at a BW of 72 kg. The present study's findings should be used to establish new energy and dietary protein intake clinical guidelines as a prevention technique against neurogenic obesity for persons with chronic SCI.

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