

ORIGINAL ARTICLE

Estimating the Basal metabolic rate from fat free mass in individuals with motor complete spinal cord injury

SM Chun¹, H-R Kim² and HI Shin¹

Study design: Cross-sectional study.

Objectives: This study aimed to validate the existing basal metabolic rate (BMR) predictive equations that include fat free mass (FFM) as an independent variable and, based on the FFM assessment, to develop a new SCI population-specific equation.

Setting: Outpatient clinic in a general hospital.

Methods: Our study group was formed of 50 individuals with chronic motor complete SCI: 27 patients with tetraplegia and 23 with paraplegia. Both BMR and FFM values were measured by indirect calorimetry (IC) and the whole-body dual energy X-ray absorptiometry, respectively. The BMR values measured by IC were compared with the values estimated from the Cunningham equation. Multiple linear regression analysis was performed to develop a new FFM-based, BMR predictive equation.

Results: The mean value of BMR measured by IC was 1274.8 (s.d. = 235.2) kcal day⁻¹. The intra-class correlation coefficient (ICC) between values measured by IC and estimated from the Cunningham equation was 0.845 and the limits of agreement ranged from -30.6 to 241.3 kcal. SCI population specific BMR predictive equation was developed; $BMR \text{ (kcal day}^{-1}\text{)} = 24.5 \times FFM \text{ (kg)} + 244.4$. The newly developed equation showed ICC of 0.866 with the limits of agreement from -229.0 to 233.1 kcal day⁻¹.

Conclusions: A considerable bias from the BMR values measured by IC was still observed, which warrants clinical consideration when applying FFM-based BMR prediction equations to individuals with SCI.

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INTRODUCTION

In individuals with a spinal cord injury (SCI), a positive energy balance increases the risk of obesity and is associated with numerous adverse metabolic sequelae, including glucose intolerance and cardiovascular disease.^{1,2} By contrast, reduced caloric intake could lead to further reduction in the level of physical activity and may affect activities of daily living.³ Basal metabolic rate (BMR) accounts for ~70% of the total daily energy expenditure in sedentary individuals⁴ and, therefore, a reliable estimation of BMR would be clinically important to inform and to appropriately adjust caloric intake in individuals with SCI.

Previous studies reported mean BMR to range from 1256 to 1855 kcal day⁻¹ in the SCI subjects.⁵ Specifically, Yilmaz *et al.*⁶ and Gorgey and Gater⁷ reported a difference in BMR between paraplegic and tetraplegic subjects of 370 and 224 kcal day⁻¹ respectively, while Collins *et al.*⁸ reported no difference between the two groups.

BMR is often estimated as a function of body weight and/or height, using predictive equations that have been validated in able-bodied subjects. When used for individuals with SCI, these equations have been reported to overestimate 4–92% of the measured values of BMR.⁵

Researchers suggested that lower than predicted BMR in individuals with SCI could be because of reduced fat free mass (FFM).⁹ After adjustment for FFM done by dividing BMR by FFM (kcal kg⁻¹), the BMR in individuals with SCI was found to be comparable to that

of able-bodied individuals.¹⁰ Therefore, it might be necessary to predict the BMR on the basis of FFM in individuals with SCI.⁵

However, available reports estimating BMR in individuals with SCI based on the assessment of FFM are scarce. In one of them, Sedlock and Lavature¹¹ measured FFM using hydrodensitometry in four men with SCI and reported that, in three of these patients, the predicted BMR values were higher than the measured values (by 24%, 16%, 9%, respectively), whereas, a 3% lower value was observed in the remaining fourth subject.

In this study, we compared the BMR values measured by indirect calorimetry (IC) with those estimated from FFM, assessed by dual X-ray absorptiometry (DXA). Through this comparison, we aimed to validate the existing BMR predictive equation which includes FFM as an independent variable¹² in the motor complete SCI population; our second objective was to develop a new SCI population-specific equation based on the FFM assessment.

METHODS

Participants

A total of 50 individuals (38 males, 12 females) with motor complete SCI presenting to the outpatient clinic of the authors' institute, a tertiary level general hospital, were recruited for the study. All participants were over 18 years of age (Table 1). Participants with psychologic problems, a history of infection, such as urinary tract and respiratory tract infections, within one month of the assessment were excluded. Participants were classified with regards to the level and severity of neurological impairment on the

¹Department of Rehabilitation Medicine, Seoul National University Hospital, Seoul, Korea and ²Department of Rehabilitation Medicine, National Rehabilitation Hospital, Seoul, Korea

Correspondence: Professor HI Shin, Department of Rehabilitation Medicine, Seoul National University Hospital, 101 Daehak-ro, Jongno-gu, Seoul 110-744, Korea.
E-mail: hyungik1@snu.ac.kr

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Table 1 Characteristics of participants

	Total	Tetraplegia	Paraplegia
Number	50	27	23
Age (yr, mean \pm s.d.)	41.9 \pm 10.7	42.1 \pm 9.4	41.7 \pm 12.2
Sex (M:F)	38:12	23:4	15:8
Duration of injury (yr, mean \pm s.d.)	12.2 \pm 7.4	13.4 \pm 7.6	10.8 \pm 7.1
BMI (kg m ⁻² , mean \pm s.d.)	22.0 \pm 3.7	22.7 \pm 4.2	21.2 \pm 3.1
FFM (kg, mean \pm s.d.)	42.1 \pm 8.4	44.2 \pm 7.9	39.8 \pm 8.5
BFP (% , mean \pm s.d.)	33.1 \pm 9.7	33.4 \pm 9.9	32.7 \pm 9.6
BMR (IC) ^a per FFM (kcal kg ⁻¹ , mean \pm s.d.)	30.5 \pm 3.3	29.7 \pm 2.8	31.4 \pm 3.7

Abbreviations: BFP, body fat percentage; BMI, body mass index; BMR, basic metabolic rate; DXA, dual energy X-ray absorptiometry; FFM, fat free mass; IC, indirect calorimetry.
^aBasal metabolic rate measured by indirect calorimetry.

American Spinal Injury Association Impairment Scale (AIS), based on an assessment performed by an experienced rehabilitation physician during clinic visits. The methods used in the present study were approved by the institutional review board of the Seoul National University Hospital (IRB No. 1412-115-634), and all participants provided written informed consent.

Indirect calorimetry

Participants underwent BMR measurements using IC between 0800 and 1000, following an overnight fast after dinner the previous day was provided, with no intake of food, caffeine, nicotine, or medications. All BMR measurements were completed at a room temperature of 25 \pm 1 °C. Before the BMR measurement, bladder was emptied by catheterization, as all participants were not able to void voluntarily. After catheterization, the participants rested in the supine position for 20 min. The Quark CPET system (Cosmed, Italy) was calibrated according to the manufacturer's guidelines. After calibration, the canopy system was placed over the participants' heads, with the subjects resting in the hood for an additional 5 min before the start of the data collection. Following this accommodation period, the gas exchange data were recorded for 30 min. However, only the data from the lowest 10 min were selected and then averaged as the final BMR data for each subject. Oxygen consumption (VO₂) and carbon dioxide production (VCO₂) were automatically recorded every 5 s, with a variability within 10% of the mean VO₂ and VCO₂, indicative of a steady state gas exchange.

Dual energy X-ray absorptiometry

Body composition was measured using a whole-body DXA scanner (GE Lunar Prodigy, WI, USA). The participants were transferred from the wheelchair to an adjustable height stretcher car and then subsequently moved to the scanner bed using a transfer board. All scans were performed and analyzed by a trained technician using the Lunar software (version 13.31) and whole body fat mass and FFM (lean mass and bone mineral content) were calculated. The BMR value was estimated, based on the FFM values using the Cunningham equations; $BMR = 21.6 \times FFM + 370$.¹²

Statistical analysis

To develop a new BMR predictive equation for the persons with motor complete SCI, a multiple linear regression model with backward elimination was used. Age, sex, level of injury (paraplegia or tetraplegia), duration, fat mass, and FFM were included in the model as possible predictors of BMR. The residual was examined to assess modeling assumptions. The differences between the measured values of BMR and those estimated from the new equation, as well as the existing equation, were calculated. The limits of agreement (mean difference \pm 2 s.d.) were calculated and denoted on Bland-Altman plots.

The percent difference between the estimated and the measured values of BMR was calculated using equation (1):

$$\% \text{ diff} = \frac{(\text{BMR values estimated} - \text{BMR values measured})}{\text{RMR values measured} \times 100} \quad (1)$$

Intra-class correlation coefficients (ICCs) were also computed to evaluate the agreement between the measured and the estimated BMR values.

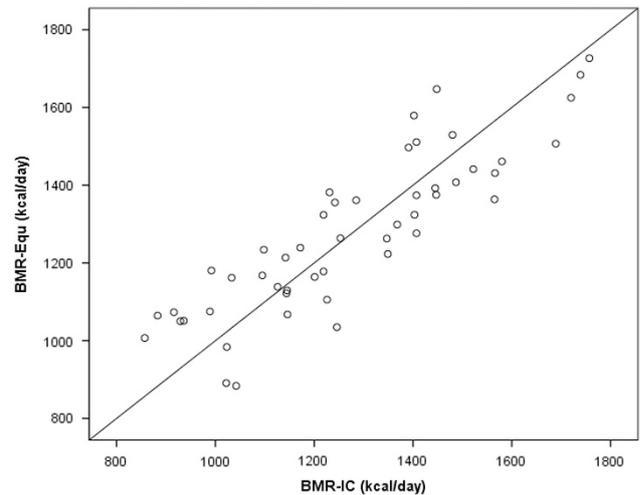


Figure 1 Basal metabolic rate (BMR) predicted by the developed equation (BMR-Equ) and BMR measured by indirect calorimetry (BMR-IC) with the line of equality shown.

All analyses were performed using the Statistical Package for the Social Science (SPSS, version 20.0, IBM, NY, USA); a *P*-value < 0.05 was considered to be statistically significant.

RESULTS

Of the 50 participants included in the final analysis, 27 had a cervical spine lesion and 23 had a thoracic spine lesion, with 29 participants categorized as class 'A' on the AIS and 21 as class 'B'. The characteristics of the participants are summarized in Table 1. The mean value of BMR measured by IC was 1274.8 (range: 857–1757, s.d. = 235.2) kcal day⁻¹.

Validation of the existing equation

The mean value of BMR predicted by the Cunningham equation was 1280.1 (range: 933.6–1676.8, s.d. = 181.0) kcal day⁻¹ and the ICC between values measured by IC and estimated from the equation was 0.845.

The mean of differences was 5.4 (s.d. = 118.0) kcal day⁻¹ and the limits of agreement ranged from -230.6 to 241.3 kcal day⁻¹. The mean of % difference was 1.62 (s.d. = 10.1) % with the limits of agreement ranged from -18.5 to 21.8%.

Development of the prediction equation

Using the previously described multiple linear regression model, equation (2) was developed to estimate BMR in motor complete SCI patients. Predictors other than FFM were eliminated and the equation included only FFM and a constant with the R-square value of 0.76.

$$BMR(\text{kcal}) = 24.5 \times FFM(\text{kg}) + 244.4 \quad (2)$$

The mean value of BMR predicted by the newly developed equation in this study was 1276.8 (range: 883.8–1726.8, s.d. = 205.3) kcal day⁻¹ and the ICC between values measured by IC and estimated from the equation was 0.866 (Figure 1).

The mean value of differences was 2.1 (s.d. = 115.5) kcal day⁻¹ and the limits of agreement ranged from -229.0 to 233.1 kcal day⁻¹ (Figure 2a). The mean of % difference was 1.0 (s.d. = 9.76) % with the limits of agreement ranged from -18.5 to 20.6% (Figure 2b).

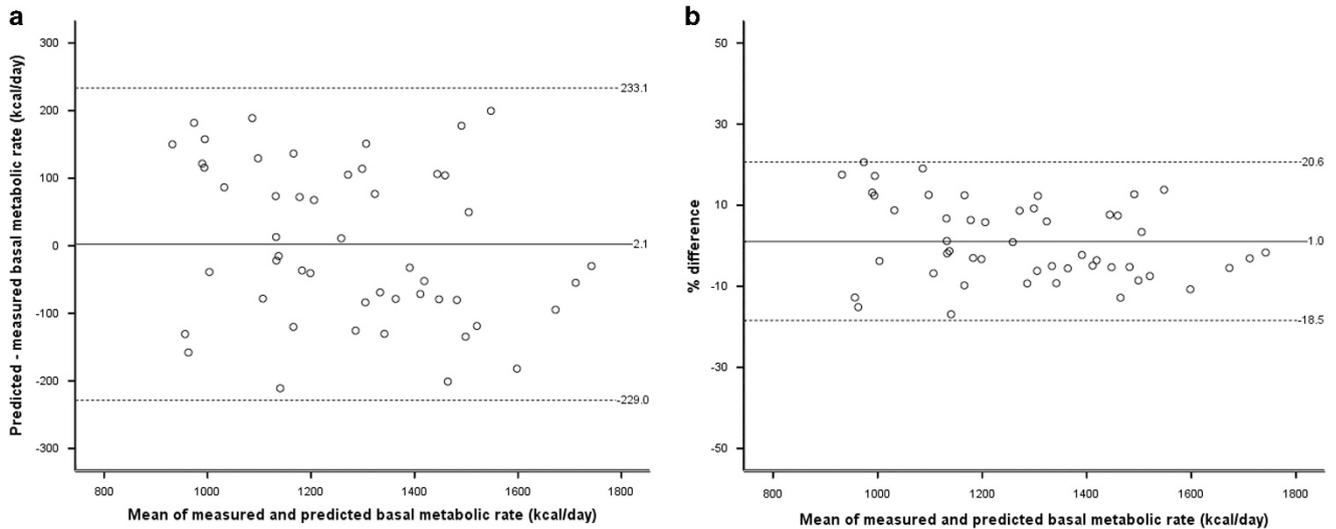


Figure 2 Bland–Altman plot. The differences between predicted and measured values of the basal metabolic rate (BMR) when the developed equation was applied were plotted. Horizontal solid line represents the mean value and horizontal dashed lines the 95% confidence interval; (a) difference in BMR (kcal day⁻¹); (b) difference in percent ratio.

DISCUSSION

When the newly developed equation and the Cunningham equation were applied, the mean values of predicted BMR were 1276.8 kcal day⁻¹ and 1280.1 kcal day⁻¹ respectively for 50 subjects with SCI. These mean values were very close to the measured BMR value of 1274.8 kcal day⁻¹. However, the limits of agreement where 95% of individual differences lie between these limits ranged from -229.0 to 233.1 kcal day⁻¹ in the newly developed equation and from -230.6 to 241.3 kcal day⁻¹ in the Cunningham equation. These results suggest that at individual level, there is a considerable amount of bias from the BMR values measured by IC when applying FFM-based BMR prediction equations to persons with SCI.

Gorgey *et al.*¹³ suggested that body weight can be primarily used to predict whole body FFM in men with chronic complete SCI and proposed the following prediction equation: whole body FFM = 0.288 × body weight (kg) + 26.3. When this equation was applied to our 38 male participants, the mean value of the estimated FFM amounted to 45.6 ± 4.0 (mean ± s.d.) kg and no statistical difference between the estimated and the DXA measured values of FFM in this study (mean value of 45.3 and s.d. of 6.8 kg) was observed. Furthermore, the ICC of the agreement between the predicted and the DXA measured values of FFM was 0.833. Therefore, the combined use of both the FFM prediction equation proposed by Gorgey *et al.*¹³ and the BMR prediction equation based on the FFM developed in this study could be considered in clinical environment where the body composition analysis techniques, such as DXA, are not available for male persons with chronic motor complete SCI.

In the present study, the mean FFM of 50 subjects was 42.1 (s.d. = 8.4) kg, which was lower than the values reported in previous studies. For example, Gorgey *et al.*¹³ reported an FFM of 49.9 (s.d. = 7.3) kg in 21 subjects with motor complete SCI, while Spungen *et al.*¹⁴ reported a lean mass of 45.9 (s.e. = 0.1) kg in 67 subjects with paraplegic SCI. These differences might be due to ethnic differences. All participants recruited in the present study were East Asian and their average body mass index (BMI) was lower (22.0 kg m⁻²), as compared with the average BMI values in Gorgey *et al.*¹³ and Spungen *et al.*¹⁴ (26 kg m⁻² and 25.8 kg m⁻², respectively). On the other hand, in their analysis of 44 Japanese SCI

patients (that is, ethnically closer to the subjects of the present study), Maruyama *et al.*¹⁵ reported the lean mass of 38.5 ± 6.38 (mean ± s.d.) kg, which was also lower than those reported in previous studies.^{13,14}

The limitations of this study need to be acknowledged. First, spasticity, which is commonly observed in individuals with SCI, might influence the BMR values measured by indirect calorimetry. However, in our study, we did not assess the distribution and severity of spasticity, nor did we control for pharmacological anti-spasticity treatment. Moreover, as the severity of spasticity can vary according to a patient's physical and emotional condition,¹⁶ a single measurement of BMR by IC might be inappropriate for the evaluation of BMR in individuals with SCI having severe spasticity.¹⁷ Second, although DXA is becoming more accessible and widely accepted as a technique to measure body composition, the variabilities among manufacturers of the DXA instruments, different beam technologies within the same manufacturer and different software versions still remain issues.¹⁸ For example, significant mean differences of the total body fat proportion of 2.6–6.3% in able-bodied volunteers were observed between pairs of the DXA instruments.¹⁹ Therefore, when comparing the results of the present study with past or future studies on the BMR estimations using body composition measurement techniques in SCI populations, these variabilities in the FFM measurements should be taken into account.

Although there is a high level of correlation between BMR and FFM, as demonstrated by Gorgey *et al.*,¹⁷ the BMR–FFM models might be too general and thus unsuitable for individual BMR prediction, as gender- and age-related, as well as ethnic, hormonal, and other sources of variations in the BMR–FFM relationship should be considered on the individual level.²⁰ Alternative methods for the measurement of BMR in individuals with SCI, such as a hand held IC might be considered useful in future research. As compared with traditional IC systems, hand-held IC systems only measure VO₂, with the reserve quotient assumed to be 0.85, and require less expertise for use.²¹ Although the data from hand held devices are limited in terms of validity and clinical utility, these systems might provide more accurate measures of BMR than the predictive equations.^{22,23}

CONCLUSIONS

A considerable amount of bias from the BMR values measured by IC was still observed, which necessitates clinical consideration when applying FFM-based BMR prediction equations to individuals with SCI.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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- 1 Bauman WA, Adkins RH, Spungen AM, Waters RL. The effect of residual neurological deficit on oral glucose tolerance in persons with chronic spinal cord injury. *Spinal Cord* 1999; **37**: 765–771.
- 2 Garshick E, Kelley A, Cohen SA, Garrison A, Tun CG, Gagnon D *et al*. A prospective assessment of mortality in chronic spinal cord injury. *Spinal Cord* 2005; **43**: 408–416.
- 3 Gorgey AS, Caudill C, Sistrun S, Khalil RE, Gill R, Castillo T *et al*. Frequency of Dietary Recalls, Nutritional Assessment, and Body Composition Assessment in Men with Chronic Spinal Cord Injury. *Arch Phys Med Rehabil* 2015; **96**: 1646–1653.
- 4 Ravussin E, Bogardus C. A brief overview of human energy metabolism and its relationship to essential obesity. *Am J Clin Nutr* 1992; **55**: 242S–245S.
- 5 Nevin AN, Steenson J, Vivanti A, Hickman IJ. Investigation of measured and predicted resting energy needs in adults after spinal cord injury: a systematic review. *Spinal Cord* 2016; **54**: 248–253.
- 6 Yilmaz B, Yasar E, Goktepe AS, Onder ME, Alaca R, Yazicioglu K *et al*. The relationship between basal metabolic rate and femur bone mineral density in men with traumatic spinal cord injury. *Arch Phys Med Rehabil* 2007; **88**: 758–761.
- 7 Gorgey AS, Gater DR. Regional and relative adiposity patterns in relation to carbohydrate and lipid metabolism in men with spinal cord injury. *Appl Physiol Nutr Metab* 2011; **36**: 107–114.
- 8 Collins EG, Gater D, Kiratli J, Butler J, Hanson K, Langbein WE. Energy cost of physical activities in persons with spinal cord injury. *Med Sci Sports Exerc* 2010; **42**: 691–700.
- 9 Buchholz AC, McGillivray CF, Pencharz PB. Differences in resting metabolic rate between paraplegic and able-bodied subjects are explained by differences in body composition. *Am J Clin Nutr* 2003; **77**: 371–378.
- 10 Jeon JY, Steadward RD, Wheeler GD, Bell G, McCargar L, Harber V. Intact sympathetic nervous system is required for leptin effects on resting metabolic rate in people with spinal cord injury. *J Clin Endocrinol Metab* 2003; **88**: 402–407.
- 11 Sedlock DA, Laventure SJ. Body composition and resting energy expenditure in long term spinal cord injury. *Paraplegia* 1990; **28**: 448–454.
- 12 Cunningham JJ. Body composition as a determinant of energy expenditure: a synthetic review and a proposed general prediction equation. *Am J Clin Nutr* 1991; **54**: 963–969.
- 13 Gorgey AS, Dolbow DR, Gater DR Jr. A model of prediction and cross-validation of fat-free mass in men with motor complete spinal cord injury. *Arch Phys Med Rehabil* 2012; **93**: 1240–1245.
- 14 Spungen AM, Adkins RH, Stewart CA, Wang J, Pierson RN Jr, Waters RL *et al*. Factors influencing body composition in persons with spinal cord injury: a cross-sectional study. *J Appl Physiol* 2003; **95**: 2398–2407.
- 15 Maruyama Y, Mizuguchi M, Yaginuma T, Kusaka M, Yoshida H, Yokoyama K *et al*. Serum leptin, abdominal obesity and the metabolic syndrome in individuals with chronic spinal cord injury. *Spinal Cord* 2008; **46**: 494–499.
- 16 Sköld C. Spasticity in spinal cord injury: self- and clinically-rated intrinsic fluctuations and intervention-induced changes. *Arch Phys Med Rehabil* 2000; **81**: 144–149.
- 17 Gorgey AS, Chiodo AE, Zemper ED, Hornyak JE, Rodriguez GM, Gater DR. Relationship of spasticity to soft tissue body composition and the metabolic profile in persons with chronic motor complete spinal cord injury. *J Spinal Cord Med* 2010; **33**: 6–15.
- 18 Nana A, Slater GJ, Stewart AD, Burke LM. Methodology review: using dual-energy X-ray absorptiometry (DXA) for the assessment of body composition in athletes and active people. *Int J Sport Nutr Exerc Metab* 2015; **25**: 198–215.
- 19 Tothill P, Avenell A, Love J, Reid DM. Comparisons between Hologic, Lunar and Norland dual-energy X-ray absorptiometers and other techniques used for whole-body soft tissue measurements. *Eur J Clin Nutr* 1994; **48**: 781–794.
- 20 Wang Z, Heshka S, Gallagher D, Boozer CN, Kotler DP, Heymsfield SB. Resting energy expenditure-fat-free mass relationship: new insights provided by body composition modeling. *Am J Physiol Endocrinol Metab* 2000; **279**: E539–E545.
- 21 McDoniel SO. Systematic review on use of a handheld indirect calorimetry to assess energy needs in adults and children. *Int J Sport Nutr Exerc Metab* 2007; **17**: 491–500.
- 22 Hipskind P, Glass C, Charlton D, Nowak D, Dasarathy S. Do handheld calorimeters have a role in assessment of nutrition needs in hospitalized patients? A systematic review of literature. *Nutr Clin Pract* 2011; **26**: 426–433.
- 23 Spears KE, Kim H, Behall KM, Conway JM. Hand-held indirect calorimeter offers advantages compared with prediction equations, in a group of overweight women, to determine resting energy expenditures and estimated total energy expenditures during research screening. *J Am Diet Assoc* 2009; **109**: 836–845.