Feasibility and Acceptability of Implementing Indirect Calorimetry Into Routine Clinical Care of Patients With Spinal Cord Injury

Amy Nevin, BHLthSc (Nutr&Diet,) APD,¹ Hannah Mayr, BHLthSc (Nutr&Diet), APD,²
Sridhar Atresh, FAFRM (RACP),³ Irene Kemp, BNursing,³ Joshua Simmons, BPhy,³
Angela Vivanti, DHLthSc, AdvAPD,^{1,4} and Ingrid J. Hickman, PhD, AdvAPD^{1,5}

¹Department of Nutrition and Dietetics, Princess Alexandra Hospital, Woolloongabba, Queensland, Australia; ²Queensland University of Technology, Kelvin Grove, Queensland, Australia; ³Spinal Injuries Unit, Princess Alexandra Hospital, Woolloongabba, Queensland, Australia; ⁴School of Human Movement and Nutrition Studies, University of Queensland, Queensland, Australia; ⁵Mater Research Institute, University of Queensland, Translational Research Institute, Brisbane, Queensland, Australia

Background: In the absence of reliable predictive equations, indirect calorimetry (IC) remains the gold standard for assessing energy requirements after spinal cord injury (SCI), but it is typically confined to a research setting. The purpose of this study is to assess the feasibility and acceptability of implementing IC into routine clinical care in an Australian SCI rehabilitation facility. **Methods:** Bedside IC (canopy hood) was performed, and patients completed an IC acceptability questionnaire (open-ended; yes/no; 5-point Likert scale). Fasted resting energy expenditure (REE) steady-state criteria were applied to assess data quality, and adherence to a test ≥ 20 minutes was recorded. Staff were surveyed to assess impact of IC on usual care. **Results:** Of 35 eligible patients, 9 declined (7 reported claustrophobia). One patient could not be tested before discharge and 25 underwent IC (84% male, injury level C2-L2, AIS A-D). Anxiety prevented one patient from completing IC, while another failed to fast. The remaining 23 patients achieved a steady-state REE (≥ 5 consecutive minutes with $\leq 10\%$ coefficient of variation for VO_2 and VCO_2). Test-retest ($n = 5$) showed $< 10\%$ variation in REE. Patients deemed the procedure acceptable, with 88% reporting a willingness to repeat IC. Eighty percent of patients and 90% of staff agreed it was acceptable for IC to be integrated into usual care. **Conclusion:** This study found that IC is a feasible and acceptable addition to the routine clinical care of patients recovering from SCI and may serve to improve accuracy of nutrition interventions for this patient population. **Key words:** energy expenditure, feasibility studies, indirect calorimetry, nutritional requirements, spinal cord injuries

It is well established that spinal cord injury (SCI) results in dramatic changes to body composition, including significant muscle atrophy below the level of injury and increased fat mass.¹⁻⁴ As a result, predictive equations that are typically used to determine energy requirements (such as Harris-Benedict or Schofield) are not valid for use in people with SCI.^{1,2,5} There is no reliable energy prediction equation validated for use in SCI patients,⁶ and it remains unclear how best to estimate energy needs in clinical practice.

Achieving accurate energy balance has important implications for individuals with SCI. Consuming adequate amounts of nutrition can be challenging for some, particularly in acute injury where malnutrition rates of up to 40% have been reported.⁷ In the long term, reduced ability to

perform physical activity combined with lower resting energy expenditure (REE)³ sees weight gain as a common result.⁸ Energy expenditure in people with SCI is highly variable⁶ and may be influenced by lean body mass,⁹ injury level and completeness,⁶ bone mineral density,¹⁰ medications,¹¹ and common secondary complications such as urinary tract infections and pressure ulcers.¹² Delivery of targeted nutrition interventions after SCI will continue to be challenging in the absence of a reliable method to assess energy needs.

Indirect calorimetry (IC) is the gold standard for assessing REE and is a recommended component of nutrition assessment for individuals with SCI.¹³ There remains no valid alternative method for measuring REE in clinical practice.⁶ Despite this, use of IC is often confined to the research setting,

Corresponding author: Amy Nevin, Department of Nutrition and Dietetics, Princess Alexandra Hospital, Ipswich Road, Brisbane, QLD 4102, Australia; e-mail: Amy.Nevin@health.qld.gov.au

and there are no data demonstrating attempts to implement IC in an SCI clinical environment. The aim of this prospective observational study was to assess the feasibility and acceptability of implementing IC into the routine clinical care of SCI patients undergoing rehabilitation.

Methods

Subjects

Patients with SCI admitted to the Spinal Injuries Unit at the Princess Alexandra Hospital between August and December 2013 were recruited to the study. The Princess Alexandra Hospital is a tertiary teaching hospital and includes the statewide SCI rehabilitation service. Patients were excluded if they were younger than 18 years, unable to provide informed consent, tracheotomised, ventilated, sedated, reliant on supplemental oxygen, or deemed by the medical team to be unsuitable to participate. If written consent was not possible due to high-level SCI, verbal consent was obtained. Level and completeness of SCI was classified using the International Standards for the Classification of Spinal Cord Injury.¹⁴ The presence of pressure ulcers with a National Pressure Ulcer Advisory Panel category of stage 2 or greater¹⁵ was recorded. The study was approved by the Metro South Human Research Ethics Committee.

The assessment of feasibility encompassed 3 main domains: (1) adherence to protocol-driven measurement of REE in the ward environment using IC and the quality of data obtained; (2) patient-reported acceptability and barriers to undergoing IC as part of routine care; and (3) staff perceptions regarding the impact of IC on clinical care and barriers to implementation of the procedure.

REE measurements

REE was measured by IC (TrueOne 2400 Metabolic Measurement System, Parvo Medics, UT) performed at the bedside by trained dietetic staff. Gas and volume calibration occurred before each measurement. Patients were tested after an overnight fast (≥ 8 hours), in the morning prior to bowel therapy, and at a time negotiated with

the patient to avoid interfering with scheduled rehabilitation. Prior to commencement of the test, patients were asked to rest quietly, lying supine for approximately 20 minutes. A ventilated canopy hood system was then used to measure inspired oxygen and expired carbon dioxide for a minimum of 20 minutes, with the first 5 minutes of data discarded. REE (kcal/day) is calculated by the IC software throughout the test according to the Weir equation.¹⁶ Patients were considered to have reached a steady-state REE if a minimum of 5 consecutive minutes with less than 10% coefficient of variation in VO_2 and VCO_2 was achieved; otherwise repeat testing was indicated.¹⁷ Measured REE was also compared against a stricter steady-state criteria of less than 5% coefficient of variation in VO_2 and VCO_2 for a minimum of 5 consecutive minutes as per previously published data.¹⁸ Repeatability of REE measurements was assessed in 5 patients using a test-retest method whereby IC was performed on 2 consecutive days under the same conditions. Time to complete IC measurements was recorded to assess implications for the dietician workload.

Patient and staff acceptability surveys

Following REE measurements, patients completed a short survey of 7 questions examining acceptability of the procedure (open-ended; yes/no; 5-point Likert scale). Questions focused on the timing and duration of the IC, comfort, and willingness to repeat the procedure. Nursing and medical staff were also invited to complete a 10-question survey (open-ended; yes/no; 5-point Likert scale). Questions focused on the impact of IC on ward activities, staff role in the procedure, and perceived barriers to implementation of IC into usual care. Completion of staff surveys was voluntary and anonymous.

Statistical analysis

Descriptive statistics were used to report patient characteristics, adherence to IC protocol, steady-state criteria, and acceptability survey responses (yes/no, 5-point Likert scale). For test-retest IC measurements, the Mann-Whitney test was used to confirm representativeness of age and baseline

REE, while the Fisher's exact test was used to determine gender representativeness. Percentage difference in test-retest REE figures was calculated using the first IC measurement as the reference; a coefficient of reliability was also calculated. Comparison of group and individual bias between REE measured by calorimetry and REE predicted by Harris-Benedict equation¹⁹ was performed using Bland-Altman analysis.

Results

Of 71 patients admitted to the facility during the 4-month study period, 59 were eligible for recruitment and 35 were approached to participate (**Figure 1**). Nine patients declined (7 due to claustrophobia, including 4 with tetraplegia and 3 with paraplegia), and 1 patient

was unable to be tested before discharge; the remaining 25 patients were included in the study. Patient characteristics are presented in **Table 1**. Median age was 43 years (range, 19-72 years). Age, gender, injury level, and injury completeness of the study group were comparable to nationally available data (which included those aged over 15 years).²⁰ Adherence to the IC testing protocol is presented in **Table 2**. One patient was unable to complete the 20-minute REE testing protocol due to anxiety, and IC data were discarded for another patient due to a failure to fast. The remaining 23 patients successfully completed the IC protocol and achieved a testing period equal to or greater than 5 consecutive minutes with a less than 10% variation in VO_2 and VCO_2 (**Table 2**). The median REE was 1,658 kcal/d (range, 1,128-2,418 kcal/d). Bland-Altman analysis comparing

Figure 1. Patient recruitment.

Table 1. Patient characteristics

Characteristics	n (%)
Gender	
Male	21 (84)
Female	4 (16)
Admission type	
New admission	18 (72)
Readmission	7 (28)
Time since injury	
<1 month	4 (16)
1-12 months	14 (56)
>12 months	7 (28)
Injury level	
Tetraplegia	11 (44)
Paraplegia	14 (56)
Injury completeness	
Complete (AIS A)	9 (36)
Incomplete (AIS B, C, or D)	16 (64)
Current pressure ulcer $\geq$ stage 2	4 (16)
Current infection or febrile	2 (8)
Surgical procedure previous 14 days	4 (16)

Note: AIS = American Spinal Injury Association Impairment Scale.

Table 2. Adherence to resting energy expenditure (REE) testing protocol and comparison with steady-state criteria

	n (%)
REE protocol	(N = 25)
Overnight fast $\geq$ 8 hours	24 (96)
Rest in bed 20 minutes prior to testing	25 (100)
REE test $\geq$ 20 minutes	24 (96)
Steady-state criteria	(N = 23 ^a)
<5% variation in VO_2 and VCO_2 for $\geq$ 5 minutes	16 (70)
<10% variation in VO_2 and VCO_2 for $\geq$ 5 minutes	23 (100)
REE steady-state criteria met within 10 minutes of testing	
<5% variation in VO_2 and VCO_2 for $\geq$ 5 minutes	10 (44)
<10% variation in VO_2 and VCO_2 for $\geq$ 5 minutes	19 (83)

^an = 2 data not included due to non-fasted test (n = 1) and test <20 minutes (n = 1).

measured REE to predicted REE indicated a mean bias of -71.20 and 95% limits of agreement from -516.8 to 374.4. Although group mean bias was low (4.2% group level overestimate by Harris-Benedict equation), individual variation

ranged from -31% to +22% (**Figure 2**). The sample of 5 patients who underwent repeat IC measurements was representative of the group with respect to age ($p = .88$), gender ($p = 1.0$), and baseline REE ($p = .79$). The coefficient of reliability for repeat REE measurements was high ($r = 0.972$), whereas the difference in REE measurements was clinically insignificant (<10%), indicating excellent reliability of IC in SCI (**Table 3**). Average time for the health practitioner to complete each IC test inclusive of calibration and cleaning was 1 hour.

Patient acceptability

All 25 patients completed acceptability surveys. Greater than 80% of respondents reported a willingness to repeat IC ($n = 22$) and agreed it would be acceptable to integrate IC into routine care of SCI patients ($n = 20$) (**Table 4**). The procedure was reported as painless, and no patients had urgent toileting needs while undertaking IC. The main barriers to routine implementation of IC identified by patients in open-ended survey responses were the test duration and time of day testing was performed.

Figure 2. Bland-Altman plot depicting differences in resting energy expenditure (REE) for spinal-injured patients between measured calorimetry (CAL) and predicted Harris-Benedict (HB) equation versus mean REE values ($n=23$). Solid line represents the mean bias between the 2 methods and dotted lines represent ± 2 SD from the mean (limits of agreement).

Table 3. Repeatability of indirect calorimetry measurements across 2 consecutive days

Patient no.	Test 1 REE (kcal/d)	Test 2 REE (kcal/d)	% Difference
1	1,658	1,603	3.4
2	1,627	1,489	8.5
3	1,847	1,723	6.7
4	1,752	1,685	3.8
5	1,289	1,305	1.2

Note: REE = resting energy expenditure.

Table 4. Patient and staff indirect calorimetry acceptability survey responses

Patient survey (<i>n</i> = 25)			
Survey question	% Disagree/ Strongly disagree	% Neutral	% Agree/ Strongly agree
Time required was acceptable	4	12	84
Time of the test was convenient	0	4	96
Privacy was adequate	0	4	96
Willing to repeat testing	4	8	88
Acceptable as part of routine care	0	20	80
	% No	% Yes	
Comfortable during the procedure	8	92	
Room temperature acceptable	4	96	
Able to breathe normally	12	88	
Able to remain still	4	96	
Able to relax	4	96	
Staff survey (<i>n</i> = 15)			
Survey question	% No	% Yes	
Involvement acceptable part of work role	0	100	
Time of the day was acceptable for patients	0	100	
Feasible to incorporate IC into usual care	0	100	
Confident in understanding IC	20	80	
Agree IC is a valuable part of patient care	7	93	

Note: IC = indirect calorimetry.

Staff acceptability

Fifteen staff completed acceptability surveys (nurses, *n* = 13; medical staff, *n* = 2). The tasks in which staff reported they were involved included ensuring the patient remained fasted (92%), adjusting or managing therapy appointments (77%), assisting in patient set up (33%), providing advice to the patient about the IC procedure (25%), and ensuring appropriate setup of equipment (13%). The IC testing inconvenienced 20% of staff

surveyed, and 33% felt it impacted on usual care. Despite this, 93% of staff felt that using IC in SCI patients would be a valuable part of clinical care and 100% agreed it would be feasible to use IC as part of usual care. The main barriers to implementation of IC identified by staff in open-ended survey questions included the impact on morning hospital routines necessitated by the fasting test, the need for space to house the IC equipment, and patient factors such as claustrophobia and willingness to participate.

Discussion

This study demonstrates that incorporating IC into the routine clinical care of SCI patients undergoing rehabilitation is feasible. Patient adherence to protocol-driven measurement of REE using IC was high and reliable REE data were obtained as per steady-state criteria. Further, patient and staff acceptability of the IC procedure was good and was not deemed as a barrier to routine implementation of IC in the SCI rehabilitation setting.

The attainment of valid measures of energy needs in the SCI population using IC provides a valuable addition to nutrition assessment and intervention. Improved accuracy of energy prescription greatly reduces the likelihood of under- or overfeeding and associated sequelae during the rehabilitation journey when energy needs may vary greatly. Inadequate caloric intake places individuals at an increased risk of malnutrition, which can lead to postoperative complications,²¹ pressure injuries,²² and delayed wound healing.²³ This can interrupt SCI rehabilitation and increase length of hospital stay.²⁴ Excessive caloric intake leading to obesity is a recognized phenomenon following SCI^{8,25} and has a negative impact on functional outcomes,²⁶ risk of rehospitalisation,²⁷ and pressure ulcer development.²⁸ Obese individuals with SCI require more nursing time and pose unique challenges for the health care team.^{29,30} As energy needs have been shown to change over time following SCI,^{3,31} repeated use of IC across the course of rehabilitation and the lifespan may facilitate optimal caloric prescription and minimize the risk of adverse health outcomes.

There are limited studies examining the feasibility of using IC in clinical practice and none have been undertaken in the SCI population. One study from an adult intensive care unit showed that nearly two-thirds of patients were ineligible to undergo IC for a variety of reasons, including renal replacement therapy, high oxygen requirement, tracheostomy, or chest tubes/drains.³² The main reason patients declined or were excluded from participating in this study related to the canopy hood system. Alternative models of IC that do not rely on a canopy hood system are available. Mouthpieces or alternative soft mask options

may be useful, although they are possibly more uncomfortable,³³ for patients who are unable to lie supine, are in a halo brace, or are claustrophobic. If adaptive equipment were available and acceptable for patients in this study, it may have reduced the number of ineligible and nonconsenting patients ($n = 19$) by up to 70%, with the added benefit of greater efficiency in testing.

For accurate clinical energy prescription, steady-state criteria must be met. Reaching steady state has shown to be challenging in some populations such as postmenopausal women¹⁸ and patients with traumatic brain injury.³⁴ Our results indicate that valid steady-state data can be obtained from SCI patients, at the bedside, without any changes to usual standard protocols. Similar to published recommendations for healthy individuals,¹⁷ a reduced test duration of 10 minutes may be plausible for SCI patients given the proportion who reached steady state within this timeframe. This may serve to increase the acceptability of the procedure for those who cited the time required as a barrier to undertaking IC, while reducing the amount of dietician time needed to complete the IC test.

The main strengths of this study lie with the IC protocol used to measure REE and the criteria to assess steady state, which were consistent with best practice recommendations.¹⁷ Test-retest methodology further increased confidence in data validity. Intra-individual variation in REE was less than 10%, which is similar to previously published data in a number of patient groups including the elderly^{35,36} and young healthy free-living men.³⁷ In keeping with previous studies,⁶ there was large variation between measured and predicted REE, further highlighting the importance of using IC to assess REE in clinical practice.

The use of qualitative surveys aimed at patient and staff assessment of the acceptability of IC implementation adds further strength to the study. When planning implementation of evidence into clinical practice, it is important to consider the behavior changes required, the health professionals involved, and the barriers and enablers to behavior change.³⁸ Similarly, the patient experience has been shown to be a driving force of evidence implementation and continuation.³⁹ Although minor barriers were identified by both

groups, survey responses were largely positive and supportive of IC as a valuable addition to routine SCI clinical care.

Study limitations

One of the limitations of this study is its confinement to the rehabilitation setting. Accurate measures of energy needs for patients with SCI in acute and outpatient settings are equally valuable, and the feasibility of IC as a tool to capture energy expenditure in both the immediate weeks after injury and repeatedly throughout the lifespan should be pursued. The cost of IC equipment and the time required for its use may be a barrier to routine implementation of IC, but these were not explored in this study as the equipment was freely available for use and staff time was funded through research grants. The clinical use of REE data in energy prescription

requires further validation of appropriate injury and activity factors. These were not examined in the current study and warrant further research.

Conclusion

This study found that IC is feasible and acceptable to implement as part of routine clinical care for patients undergoing SCI rehabilitation and its use aligns with best practice recommendations. Accurate assessment of energy expenditure after SCI provides a fundamental addition to nutrition care and may serve to optimize nutrition-related outcomes in this unique patient population.

Acknowledgments

The authors declare no conflicts of interest.

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