



ARTICLE

Comparison of segmental lean tissue mass in individuals with spinal cord injury measured by dual energy X-ray absorptiometry and predicted by bioimpedance spectroscopy

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Abstract

Study design Observational.

Objectives To compare two methods for predicting segmental (arms, legs, trunk) lean tissue mass (LTM: non-bone fat-free mass) from bioimpedance spectroscopy (BIS) against LTM measured from dual energy X-ray absorptiometry (DXA) in individuals with acute spinal cord injury (SCI).

Setting Austin Health Victorian Spinal Cord Service, Victoria, Australia.

Methods Fourteen participants (two female), within 8 weeks of traumatic SCI had BIS measured following an overnight fast and within 24 h of DXA scanning. Total body fat-free mass (FFM, body weight minus fat mass) and segmental LTM were predicted from BIS using manufacturer's proprietary software and a previously established SCI-specific prediction method. Appendicular LTM (ALM) was calculated from the sum of the LTM of the arms and legs. Agreement and strength of relationships with DXA for predicted LTM measures using both approaches were assessed using Lin's concordance coefficient and limits of agreement analysis (LOA).

Results The BIS proprietary method performed better than the SCI-specific prediction method in predicting DXA LTM, demonstrating substantial concordance for total body FFM ($rc = 0.80$), ALM ($rc = 0.78$), arm ($rc = 0.76$) and leg LTM ($rc = 0.65$) and a smaller bias and LOA for ALM (+0.8 vs. −3.4 kg; LOA −4.9–6.4 vs. −11.9–5.1 kg), arm (+0.02 vs. −0.3 kg; LOA −1.1–1.1 kg vs. −2.2–1.6 kg) and leg (+0.4 vs. −1.4 kg; LOA −2.0–2.8 vs. −5.6–2.8) LTM.

Conclusions BIS can be used to accurately predict total body FFM, segmental LTM and ALM in individuals with acute SCI.

Introduction

Rapid loss of skeletal muscle and increasing adiposity occur following spinal cord injury (SCI) [1, 2], which influence energy expenditure and long-term metabolic health [3, 4]. Body composition assessment provides information on

nutritional status at a given time, and when measured longitudinally is a surrogate measure of the adequacy of nutrition interventions [5]. Body composition terminology is described in Table 1. Most body composition studies in individuals with SCI are cross-sectional describing differences in whole-body composition between individuals with chronic SCI and controls [6–9]. These studies report that individuals with chronic SCI have a total body fat-free mass (FFM) 3.4–11 kg lower [6–9], a greater trunk fat mass (+3.7 kg) [10] and a percentage body fat up to 12% higher than non-SCI controls [6–9]. However, both whole-body and segmental body composition are profoundly affected by the neurological level of injury and degree of sensory and motor impairment. Individuals with chronic tetraplegia have a lower total body and decreased arm lean tissue mass (LTM) [9, 11, 12], but a higher percentage body fat in the arms compared to those with paraplegia [9]. In contrast, lower arm, leg and total body LTM have been described in individuals with chronic complete compared with incomplete tetraplegia. Likewise, lower trunk, leg and total

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Table 1 Body composition terminology.

Body composition compartment	Description
Lean tissue mass (LTM)	Sum of all lean tissue excluding bone mineral content
Segmental lean tissue mass	LTM of the individual five body compartments including trunk, arms and legs
Appendicular lean tissue mass	Sum of the LTM of the two arms and two legs (excluding pelvis)
Fat-free mass	LTM plus bone mineral content
Fat mass	Lipid content, forms 80% of the adipose tissue compartment

Adapted from [17].

body LTM have been reported in individuals with complete versus incomplete paraplegia [9]. Hence monitoring changes in segmental body composition is important as the body composition in individuals with different types of SCI is heterogeneous.

To the authors' knowledge only one study has investigated longitudinal changes in segmental body composition following acute SCI. Singh et al. [13] found differential changes in the composition of the body segments measured by dual energy X-ray absorptiometry (DXA); a 20.5% and 15.1% loss of LTM in the legs and trunk respectively, and a 17.3% increase in fat percentage in the lower limbs after 1 year. Furthermore, individuals with tetraplegia compared to individuals with paraplegia had a significant decrease in arm LTM (20.0% vs. 8.3%, $P < 0.01$) and fat percentage (10.7% vs. 2.6%, $P < 0.01$) [13]. Although DXA is ideal for the assessment of segmental body composition, it is impractical for individuals with impaired mobility such as SCI due to its poor accessibility.

Bioelectrical impedance analysis (BIA) is an alternative, inexpensive, non-invasive portable bedside method of body composition assessment (total body water, FFM, fat mass and body fat percentage) [14] and shows promise as a valid tool for the assessment of whole-body composition in individuals with acute SCI [15]. Panisset et al. [15] used a derivative of BIA known as bioimpedance spectroscopy (BIS), which measures impedance over a range of frequencies and allows the current to pass through and around the cell membrane that provides more precise measures of extracellular and intracellular fluid volume [16]. BIS can also be used to predict FFM and LTM of the body segments [15]. However, the underlying theory for prediction of segmental body composition is poorly described and based on proprietorial and undisclosed 'commercial in-confidence' information of impedance device manufacturers [17]. To the authors' knowledge, only one study has compared prediction of LTM of the body segments from BIS with DXA-measured segmental LTM [11] in individuals

with *chronic* SCI. Ciriigliaro et al. [11], found that BIS-derived extracellular and intracellular volume impedance quotients could be used to generate a model for the prediction of arm and leg LTM. However, whether this model can be used to predict segmental LTM from BIS in individuals with *acute* SCI has not been explored.

The aims of this study were to compare the prediction of segmental LTM and ALM using BIS against these LTM measures using DXA in individuals with acute SCI (within 8 weeks post injury), and to compare the prediction of segmental LTM and ALM using a proprietary method with the method of Ciriigliaro et al. [11].

Methods

Participants

Fourteen participants (12 men) were recruited from the Austin Health Victorian Spinal Cord Service. Individuals with an acute traumatic complete (AIS A) or incomplete SCI (AIS B, C, D) above T12, according to the American Spinal Injury Association (ASIA) Impairment Scale (AIS) [18] criteria within 8 weeks of SCI were eligible for the study. Participants were medically stable and cleared medically and surgically to participate. Participants with a pacemaker, aged <18 years, with multiple trauma, an intercurrent illness (e.g. urinary tract infection or pressure injury), pregnant or breastfeeding, in ICU or ventilator-dependent were excluded.

Study design

This was a cross-sectional observational study. Participants received usual care provided to inpatients with SCI including a regular hospital diet, supplementary oral nutrition support if indicated and regular passive movement of the paralysed limbs, wheelchair mobility skills and standing and walking with or without assistive devices. The study was approved by the Austin Health Human Research Ethics Committee and registered with the Australian and New Zealand Clinical Trials Registry (ANZCTR): ACTRN 12615000178549. Informed consent was obtained.

Anthropometry

Body weight was measured to the nearest 100 g, using either a hoist scale (Wedderburn Rinstrum R320, Sydney, Australia) or a platform scale (Wederburn 2100, Sydney, Australia) within 24 h of the BIS and DXA measurements. Height was assessed from supine length, heel to crown between metal bookends, to the nearest 5 mm using a rigid tape measure as recommended by Garshick et al. [19].

DXA body composition

Whole-body and segmental body composition was determined using a GE-Lunar Prodigy DXA scanner (GE Healthcare, Cleveland, USA; enCORE software v13.60, Madison, USA). Participants were scanned in the morning, were not fasted but had refrained from undertaking exercise within the prior 90 min. Standardised segmentation was performed by one experienced DXA operator. Owing to contractures and impaired mobility of some participants, it was not always possible to achieve standardised positioning for scanning. In three participants where small regions of the body were outside the scan region, the limb was excluded and the values from the contralateral limb were used [20]. One participant had a hip replacement and scan values for the opposite leg were substituted. Data were obtained for bone mineral content (BMC, g), fat mass (FM, kg) and lean tissue mass (LTM, kg). FFM was calculated as bone mineral content (BMC) + LTM.

Bioimpedance spectroscopy (BIS)

Bioimpedance data were obtained using a tetra-polar bioimpedance spectrometer (SFB7, ImpediMed Ltd., Brisbane, Australia). Participants were measured in the morning following an overnight fast within 24 h of DXA scanning. The measurement protocol has been described previously [15]. Briefly, participants reclined supine for 60 min prior to their measurement. Skin-surface EKG-style Ag/AgCl gel electrodes (ImpediMed Ltd., Brisbane, Australia) were placed at the base of the fingers and toes and at the midpoint of the dorsal surface between the malleoli at the ankle and the head of the radius and ulna at the wrist. Impedance measurements were obtained for the whole-body, wrist to ankle, on both sides and for each limb according to the principle of equipotentials [21].

The SFB7 records impedance (Z), resistance, (R) and reactance (X_c) at each of 256 logarithmically-spaced frequencies in the range 3–1000 kHz. Measurements were obtained in triplicate and measurement time was ~5 s for each body segment. Data were uploaded to a computer and analysed using Bioimp 4.18.0 software (ImpediMed Ltd., Brisbane, Australia). R and X_c data for each measurement were fitted to the Cole model describing the impedance response of biological tissue [21]. The resistance at zero frequency (i.e. of extracellular water) and at infinite frequency (i.e. of total body water) were obtained by extrapolation. The resistance of intracellular water (ICW) was calculated from R_0 and R_∞ as

$$R_i = \frac{R_0 \times R_\infty}{R_0 - R_\infty}. \quad (1)$$

Data analysis

Impedance measurements were transformed to estimates of body water volumes according to the generic equation

$$\text{Volume} = \rho \frac{L^2}{R}, \quad (2)$$

where volume is the volume of the water compartment (mL), ρ is the resistivity (ohm cm) of water in that compartment, L is the inter-electrode length (cm) and R is the measured resistance (ohm) [22]. If R is R_0 then the predicted volume is that of extracellular water (ECW), R_i , ICW and R_∞ , total body water (TBW).

Two approaches were used for the prediction of LTM for comparison with DXA measures of LTM.

1. Apparent resistivity coefficients for each arm and leg were calculated from the intracellular data published by Ciriigliaro et al. [11] for individuals with either tetraplegia or paraplegia. These authors also used an SFB7 impedance device and software to provide measurements of R_i for each arm and leg expressed as the impedance quotient, L^2/R_i . The inter-electrode length was determined directly from DXA scans using the linear measurement cursor function. Since values for LTM were also provided in this study [11], ρ could be calculated according to Eq. 2. These ρ values were then used in Eq. 2 with R_i and L values to predict LTM (in kg) for participants in the present study. L was calculated as percentage of height using the fractional coefficients calculated from the data of Ciriigliaro et al. [11] for participants with tetraplegia and paraplegia separately.
2. Total body and segmental body composition was determined using proprietary software provided by ImpediMed Ltd. (Brisbane, Australia). Required input was height and weight and R_0 , R_∞ and R_i for whole-body and each body segment. The data output was TBW, ECW, ICW and LTM for each body segment and TBW, ECW, ICW, FFM and FM for whole body. Body water volumes are in litres (L) and tissue masses in kg. DXA does not provide data on body water, so to enable interpretation of the BIS body water output, data for ECW:ICW ratios were obtained from an age and sex-matched cohort of 47 healthy subjects drawn from a database maintained at the University of Queensland [23]. Mean ECW:ICW ratios were also calculated from the data of Ciriigliaro et al. [11] for comparison.

Appendicular LTM (ALM) using both approaches was calculated from the sum of LTM of both arms and legs.

Statistical analyses

Descriptive data are presented as mean \pm standard deviation (SD). Comparison of LTM between DXA (as the reference) and that predicted by either of the two BIS methods was assessed using Lin's concordance correlation coefficient and limits of agreement (LOA) analysis as previously described [15]. Since the LOA method only assesses agreement between pairs of data, agreement between all three methods was assessed using median absolute percentage error analysis as described elsewhere [24]. Paired *t* tests were performed to determine differences between predicted body composition and the reference DXA data. Statistical analysis was undertaken using Medcalc version 19.1.5 (Medcalc Software bvba, Ostend Belgium).

Results

Characteristics of the participants with SCI are listed in Table 2. All participants were Caucasian apart from one Asian female. The mean age was 48.9 ± 20.5 years and the mean number of days post injury was 37 ± 15 days. Nine participants had high tetraplegia (one AIS A), two had low tetraplegia (nil AIS A) and three had paraplegia (two AIS A). Mean BMI was $24.8 \pm 4.8 \text{ kg/m}^2$, within the normal reference range (BMI $20\text{--}24.9 \text{ kg/m}^2$) [25], although six participants (43%) were classified as overweight ($n = 4$) or obese ($n = 2$). As previously reported estimated energy intake was 107% of measured total energy expenditure [26].

The resistivity coefficients for the body segments calculated from the published data of Cirmigliaro et al. [11] and the current study used for the prediction of LTM for comparison with DXA-measured data are shown in Table 3. Although differing in absolute magnitude in both sets of data, resistivity coefficients for participants with paraplegia were less than those with tetraplegia. There were no differences in resistivity values between the right and left limbs, unlike the published data of Cirmigliaro et al. where there was a significant difference in the resistivity coefficient between the arms for participants with tetraplegia [11].

Table 4 compares the BIS predicted total body FFM, total body LTM and LTM of body segments to the measured values by DXA based on the different methods. Although the SCI-specific prediction of Cirmigliaro et al. [11] exhibited a smaller bias than the proprietary equation, the LOA were substantially larger for total body.

Predictions of LTM in the arms by either the proprietary equation or the SCI-specific prediction method of Cirmigliaro et al. [11] were not significantly different from the DXA reference values. However, the mean difference (bias) and LOA were smaller for the proprietary equation than the

Table 2 Participant characteristics of the 12 men and 2 women with SCI and their DXA body composition measurements.

Variable	Mean \pm SD	Range
Age (years)	48.9 ± 20.5	18–82
Days post injury	37.0 ± 14.8	17–65
Height (cm)	175.6 ± 0.7	153.5–190.0
Weight (kg)	76.4 ± 16.0	62.1–89.6
BMI (kg/m^2)	24.8 ± 4.8	20.3–32.5
Albumin (g/L)	28 ± 6	24–35
Reference body composition by DXA		
Total body		
LTM, kg	51.98 ± 3.15	35.93–66.13
Fat mass, kg	20.64 ± 14.23	7.55–32.04
BMC, g	3.34 ± 0.51	2.28–4.38
Appendicular		
LTM, kg	22.24 ± 1.42	15.71–29.08
Fat mass, kg	8.07 ± 4.77	2.67–13.82
BMC, g	1.73 ± 0.19	1.30–2.20
Arm		
LTM, kg	3.00 ± 0.23	1.80–4.24
Fat mass, kg	0.92 ± 0.89	0.25–1.70
BMC, g	0.23 ± 0.04	0.11–0.30
Leg		
LTM, kg	8.12 ± 0.94	5.94–10.44
Fat mass, kg	3.11 ± 1.50	1.04–5.90
BMC, g	0.64 ± 0.06	0.38–0.80

Appendicular = sum of both arms and both legs.

LTM lean tissue mass, BMC bone mineral content, Arm average of arms, Leg average of legs.

Table 3 Apparent resistivity coefficients for body segments in individuals with acute SCI.

	Cirmigliaro et al. [11]		Present study	
	Tetraplegic	Paraplegic	Tetraplegic	Paraplegic
Number	14	16	11	3
Apparent resistivity (ohm cm)				
Total body	3.34	2.33	3.26	3.09
Right arm	0.864	0.623	0.858	0.782
Left arm	0.508	0.642	0.856	0.760
Right leg	1.056	1.143	0.975	1.086
Left leg	1.041	1.174	0.966	1.088

Cirmigliaro et al. [11] method. For leg LTM and ALM, the proprietary equation performed better than the Cirmigliaro et al. [11] SCI-specific prediction, exhibiting a smaller bias (leg LTM 0.4 kg; ALM 0.8 kg) and LOA. For both leg LTM and ALM, there was a significant difference between the Cirmigliaro SCI-specific predictions and the DXA-measured values for LTM ($p = 0.002$ and $p = 0.02$, respectively).

Table 4 Agreement between predictions of lean tissue mass of body segments from BIS measurements and measured by DXA in individuals with acute SCI.

BIS method	Number	Lin's concordance correlation coefficient	LOA ^a (kg, %)	Pearson correlation coefficient	Bias (DXA-BIS) (kg, %)	MAPE ^b	<i>P</i> ^c
Total body							
Cirnigliaro ^c	14	0.59	−27.6–23.4 (−49.1–51.0)	0.82	−2.1 (−1.0)	21.0	0.55
Proprietary ^d	14	0.80	−9.7–14.8 (−14.9–26.9)	0.89	2.6 (6.0)	4.8	0.66
Arms ^e							
Cirnigliaro	14 ^e	0.54	−2.2–1.6 (−64.6–59.0)	0.68	−0.3 (2.8)	21.0	0.16
Proprietary	14 ^e	0.76	−1.1–1.1 (−31.2–36.3)	0.79	0.02 (2.6)	12.7	0.86
Legs ^e							
Cirnigliaro	14 ^e	0.35	−5.6–2.8 (−62.1–34.8)	0.52	−1.4 (13.6)	16.8	0.00
Proprietary	14 ^e	0.65	−2.0–2.8 (−24.1–35.2)	0.68	0.4 (5.5)	9.6	0.11
Appendicular ^f							
Cirnigliaro	14 ^f	0.54	−11.9–5.1 (−45.0–18.8)	0.73	−3.4 (−13.1)	15.6	0.02
Proprietary	14 ^f	0.78	−4.9–6.4 (−20.3–28.8)	0.81	0.8 (4.2)	10.7	0.37

^aTwo standard deviation (SD) limits of agreement (LOA).^bMedian percentage absolute error.^cComparison of LTM.^dComparison of FFM.^eBoth limbs combined.^fSum of arms and legs.^gPaired *t* test, predicted versus reference DXA.

The relative volumes of ECW and ICW expressed as a percentage of total tissue fluid provided by the proprietary equations for the acute participants with SCI, the Cirnigliaro et al. [11] study and age- and sex-matched healthy controls are presented in Fig. 1. A difference of between 3.9 and 6.5% was observed in all reported body segments and the whole body in participants with SCI compared to healthy controls. The difference in ECW% of acute SCI participants in the arms (mean 4.1%) was lower than that observed in the legs (mean 6.4%) while the difference in whole-body ECW% was 5.2%. Participants with chronic SCI had a greater percentage difference in ECW % (11.9%) in the legs compared with controls than the participants with acute SCI (6.3%).

Discussion

The measurement of body composition is important when assessing nutritional status in clinical populations including acute SCI as the results can inform nutritional diagnosis, guide nutritional prescriptions and be used to monitor the outcomes of nutrition and exercise interventions [5]. Minimising loss of LTM and avoiding fat mass gain are important goals to avoid secondary morbidity following SCI. Body weight is commonly used to assess effects of nutritional interventions and is a crude measure that does

not discern between alterations in LTM or fat mass. The aim of SCI dietetic management is to minimise LTM loss via the provision of a high energy and protein diet acutely and to prevent weight and fat gain by providing dietary counselling regarding weight management during rehabilitation. The use of BIS to monitor segmental changes in body composition, specifically LTM is important to adjust dietetic therapy, specifically when to modify the focus of interventions to avoid the detrimental fat gain associated with poor metabolic outcomes.

This study in participants with acute SCI compared the prediction of segmental LTM from BIS using a proprietary method and the published method of Cirnigliaro et al. [11] in people with chronic SCI against LTM measured using DXA. The significant correlations and high levels of agreement with DXA measures in our participants with acute SCI suggest that BIS can be used to predict segmental LTM and ALM. With the exception of leg LTM, either the proprietary equation or the Cirnigliaro et al. [11] estimates of LTM were not significantly different to the DXA reference values. However the proprietary equation predicted leg LTM and ALM better than the Cirnigliaro et al. [11] method as evidenced by the smaller mean bias, lower mean absolute percentage error and LOA.

To our knowledge, only one other study has tested the validity of bioimpedance to predict TBW, FFM and FM and considered segmental parameters in people with SCI.

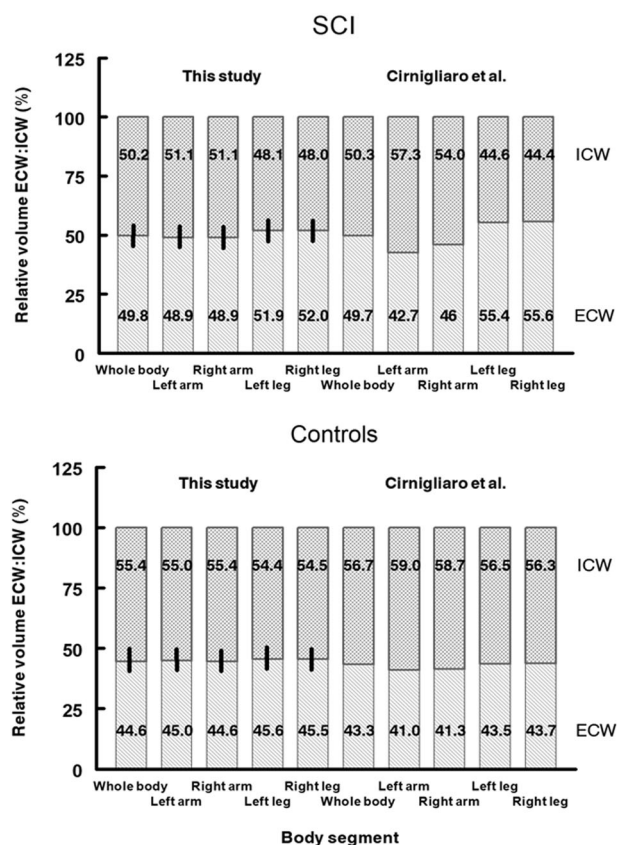


Fig. 1 Ratio of extracellular water (ECW) and intracellular water (ICW) volumes in body segments of spinal cord injury (SCI) participants ($n = 14$) and controls ($n = 58$) for this study. Data are also presented for comparison from Cirnigliaro et al. [11]. ECW volume and ICW volume calculated as percentage of total tissue water.

Buchholz et al. [27] compared single frequency whole body and segmental BIA and multifrequency whole-body BIA with deuterium dilution in 31 participants with chronic paraplegia and 62 healthy controls. They reported that low frequency BIA was no better at predicting ECW in participants with paraplegia than BIA at 50 kHz. Predicted ECW using BIA was strongly correlated with measured ECW using deuterium dilution and there was no significant bias or difference between the two methods. The only reported segmental data were resistance and reactance and these were significantly higher in the group with paraplegia for the leg, trunk and whole body, indicative of a lower TBW, hence lower FFM in these body segments compared with controls. In contrast, arm resistance in the participants with paraplegia was lower than the control group and reactance higher suggestive of greater TBW and body cell mass. Unfortunately, deuterium dilution only enables determination of whole-body ECW, so segmental body composition using bioimpedance was not validated in that study [27].

We hypothesised that the Cirnigliaro population-specific method [11] for predicting segmental LTM developed in people with chronic SCI would more closely predict

segmental LTM in participants with acute SCI than the proprietary method. BIA assumes that the body is a homogenous conductive cylinder of uniform length and cross-sectional area, however the body shape is better represented by five inter-connected cylinders (trunk, two legs and two arms) [14, 21]. We theorised that muscle wasting following SCI would change the body geometry, i.e. the cross-sectional area of the arms and legs, and therefore the method developed in chronic SCI using BIS would be more accurate than the proprietary method. However, a possible explanation for our contrary findings is that the participants in our study were 37 ± 15 days post injury compared with 9 ± 11 years and 20 ± 14 years for participants with paraplegia and tetraplegia in the Cirnigliaro et al. [11] study. Muscle wasting occurs progressively for up to 6 months post injury [1] and may not have occurred to a sufficient degree in our SCI participants to adversely influence prediction. Cirnigliaro et al. [11] also had a greater proportion of participants with paraplegia and motor complete injuries than our study and as previously described the level and severity of SCI affects total body and segmental LTM [9]. While details of the proprietary segmental body composition method are not known, it is possible that a body proportionality factor accounting for limb shape is incorporated into the prediction algorithms as is the case for whole-body BIS methods [23] and therefore accounts better for changes in body geometry than the model adopted by Cirnigliaro et al. [11].

In addition to monitoring changes in LTM, the use of BIS provides the opportunity to assess and monitor the presence of extracellular fluid or oedema from the extracellular fluid volume to the intracellular fluid volume (R_e/R_i) ratios [22, 28]. The observed increases in ECW/ICW ratio in the limbs of participants in our study are consistent with the findings of Cirnigliaro et al. [11] and Tanaka et al. [29] who also reported higher ECW/ICW ratios in the limbs of individuals with tetraplegia compared with non-injured controls. The presence of oedema in our participants may be explained by the low serum albumin levels which are reflective of the stress-induced response to trauma or acute illness [30]. Hypoalbuminaemia causes a decrease in colloid oncotic pressure in the vascular space and ensuing accumulation of extracellular fluid [30].

The population-specific method used to predict LTM in our acute cohort differed slightly to that of Cirnigliaro et al. [11] in people with chronic SCI. Prediction of LTM by Cirnigliaro et al. [11], was based on the resistivity values and resistance of the intracellular compartment (R_i). Cirnigliaro et al. [11] also predicted LTM from the extracellular resistivity and extracellular measured resistance (R_0). Since people with acute SCI are prone to the development of oedema [27], only the intracellular resistivity coefficients for each body segment were used to predict

LTM as the use of the extracellular resistivity coefficients could artificially predict an elevated LTM.

Limitations associated with this study include lack of knowledge of the proprietary segmental body composition equations and participation of individuals with metal implants, though current information suggests that the potential impact that metal surgical implants have on the prediction of body composition is small and of minimal clinical importance [31]. Additionally neither method enabled the prediction of trunk LTM and fat mass. Furthermore, the small and heterogeneous sample in regards to gender, level of injury and AIS classification may limit the generalisability of the findings. However, despite the participant heterogeneity we showed that BIS can be used clinically to predict segmental LTM and ALM in people with acute SCI. The heterogeneous sample is reflective of the SCI population and highlights the challenges in assessing and monitoring nutritional status in clinical practice.

This study indicates that BIS can be used to predict total body, appendicular and segmental LTM in participants with acute SCI and to monitor the presence of oedema. Accurate assessment of body composition is essential to assess outcomes of nutrition and exercise interventions in individuals with SCI. These findings support the use of BIS for the routine assessment of LTM in SCI. However, additional studies in larger numbers of patients with SCI and with different levels of injury/AIS classification are needed to confirm and extend these results. Future research should also investigate longitudinal changes in total, appendicular and segmental body composition and whether BIS can be used to inform nutrition and activity prescriptions and monitor outcomes in individuals with acute and chronic SCI.

Data availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions KJD participated in the design of the study, performed data collection, data entry, and analysis and contributed to paper preparation. MGP participated in the design of the study,

performed data collection and contributed to paper preparation. LCW advised on the design of data collection protocol, performed quality assurance on the data, contributed to statistical analyses and paper preparation. MPG developed the concept for and designed the study, contributed to grant procurement and paper preparation. NK and RMD contributed to the interpretation of the results and preparation of the paper. All authors read and approved the final version of the paper.

Compliance with ethical standards

Conflict of interest Author LCW consults to Impedimed Ltd. All other authors have no conflicts of interest to declare.

Ethical approval Ethical approval for this study was obtained from the Austin Health Human Research Ethics Committee (H2013/05117) and all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed.

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