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Segmental Body Composition in Athletes with Spinal Cord Injury: A Pilot Study

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Abstract
The purpose of this study was to compare the anthropometric methods by body segment with the values predicted by dual energy radiological absorptiometry (DXA) in athletes with spinal cord injury. Eight quadriplegic and six paraplegic athletes participated in this study. Body circumferences were measured at seven sites, skinfold thickness was measured at nine sites (on the right side of the body), and body composition was measured using DXA. Linear regression analysis was used to verify the associations between body composition and anthropometric measurements. Segmental measures that best explain fat mass as predicted by DXA were: a sum of the skinfold thickness in the arm ($R^2 = .66$; $p < .01$); in the trunk, subscapular ($R^2 = .75$, $p < .01$), midaxillary axillary ($R^2 = .67$, $p < .01$) and abdominal skinfolds ($R^2 = .67$, $p < .01$), and sum of trunk skinfold thickness ($R^2 = .67$, $p < .01$); and in the leg, the calf skinfold and the sum of the skinfolds of the leg ($R^2 = .70$, $p < .01$; $R^2 = .68$, $p < .01$). The circumferences of the relaxed and tensed arms showed relevant relationships ($R^2 = .52$, $p < .01$, and $R^2 = .57$, $p < .01$, respectively) with the fat mass predicted by DXA. This suggests that segmental analysis of body composition through circumferences and skinfold thickness may be a good option for the accurate determination of body composition in athletes with spinal cord injury. The sum of cutaneous folds per segment strongly and significantly expressed fat mass predicted by DXA.

Keywords: anthropometry, body composition, spinal cord injuries.

Introduction

The search for sports excellence is a common objective in both adapted and conventional sports, and among the factors that interfere with the desired sports performance is body composition (Borges et al., 2016; Nikolaidis, 2013), which is positively associated with regular sports practice (Cavedon et al., 2020; Gorla et al., 2016).

The evaluation and monitoring of body composition is strongly related to sports performance because it establishes goals, identifies the development of athletes, and plans for subsequent work. In the spinal cord injury (SCI) population, the importance of body composition assessment and monitoring is even greater because after the injury there is a "redistribution" of the components of the body composition represented by the increase and accumulation of fat (Beck et al., 2014),decrease of the lean mass in the central regions (trunk) and lower extremities, and increased lean mass (Maggioni et al., 2003; Yarar-Fisher et al., 2013) and decreased fat mass higher regions; determining the relevance of assessing body composition in a segmented way, that is, by body segment (arms, trunk and legs).

Among the numerous methods of evaluation of body composition, we highlight the dual energy radiological absorptiometry (DXA) method which is considered valid for analysis of body composition in individuals with SCI (Jones et al., 1998) and the anthropometric method of skinfold thickness, which stands out for its low cost and easy applicability, which makes it possible to obtain large samples and set parameters (Heyward & Stolarczyk, 2000).

However, prediction equations through skinfold thickness validated for athletes with different injury levels (paraplegia and quadriplegia) have not yet been described in the literature. In addition, the generalized prediction equations validated for people without disabilities have underestimated the percentage of body fat in the population with SCI (Maggioni et al., 2003; Spungen et al., 1995); however, there is evidence that the sum of skinfold thickness can predict changes in body fat in this population (Goosey-Tolfrey et al., 2020; Willems et al., 2015). In this context, the aim of this study was to compare the anthropometric methods of body circumference and skinfold thickness by body segment with the values predicted by DXA in athletes with spinal cord injury.

Materials and Methods

Participants

Fourteen male athletes with SCI of which eight tetraplegic athletes of wheelchair rugby and six paraplegic athletes practicing wheelchair handball. Participant characteristics are presented in Table 1.

Table 1
Characteristics of the participants.

Participants	Age (years)	Level of injury	Duration of injury (years)	Body mass (kg)	Heigth (m)	BMI (kg/m^2)
1	25	C6-C7	4	62.15	1.78	17.46
2	38	C6-C7	11	65.20	1.76	18.52
3	29	C5-C6	10	57.80	1.70	17.00
4	27	C6-C7	6	64.15	1.75	18.33
5	35	C6-C7	12	62.40	1.70	18.35
6	38	C6-C7	5	75.00	1.86	20.16
7	24	C6-C7	7	60.00	1.69	17.75
8	25	C5-C6	4	92.00	1.82	25.27
9	29	L1	5	71.95	1.70	21.16
10	35	T8-T12	17	83.75	1.57	26.67
11	34	T7	11	42.80	1.69	12.66
12	43	T7-T8	30	83.75	1.72	24.35
13	44	T8	7	96.00	1.85	25.90
14	37	T3	18	86.60	1.71	25.30
Mean	33.10		10.50	71.70	1.74	20.60
±SD	6.60		7.20	15.10	0.08	4.20

Note. BMI: Body Mass Index.

Athletes were required to practice sports at least three times a week with the minimum duration of a two-hour training session. In addition, they were required to have had at least one year of practice in the modality.

This study was approved by the Ethics Committee of the Faculty of Medical Sciences of the State University of Campinas (no. 3.092.352) in 2018 and all participants provided written informed consent prior to participation in this study.

Anthropometry

Body mass (kg) was measured using a digital wheelchair scale (Líder®) with a capacity of 500 kg and a reading scale of 50 g. To verify body mass, athletes first measured their mass in their wheelchair, and then the mass of the wheelchair was measured separately. The weight of each athlete was calculated by the difference between these measurements, that is, the subtraction of the total mass and the wheelchair mass. The height (m) of the participants was evaluated using a stadiometer with a reading scale in millimeters, in the supine position.

Body circumferences

Circumferences were assessed using an anthropometric tape with a reading scale in millimeters (Gulick-WCS, Cardiomed). For segmental analysis, the arm circumference of the tensed arm (point of greatest circumference of the fully tensed arm), the relaxed arm (average distance between the most lateral edge of the acromion and the olecranon), and the forearm (point of greatest circumference of the forearm) were related to the body composition predicted by DXA of the arm region. The waist circumference (average distance between the last rib and the iliac crest, in a horizontal plane) and abdominal circumference (point of greatest anterior bulge of the abdomen usually on the umbilical scar) were related to the trunk region. The thigh circumference (the average distance between the inguinal line and the upper edge of the patella) and medial calf circumference (point of greater leg circumference, that is, greater perimeter of the calf muscle) were related to the leg region. Three measurements were made at each point by a single evaluator, and the abdominal and supra iliac skinfolds were measured in the supine position.

Skinfold thickness

Skinfold thickness was measured using Harpenden calipers (John Bull, British Indicators Ltd., St Albans, UK) at nine sites on the right side of the body. The skinfold thickness of triceps (mean distance between the superolateral edge of the acromion and the olecranon process of the ulna) and biceps (point of greatest apparent circumference of the biceps) were used to analyze the body composition of the upper arm region. The skinfold thickness of the middle axillary (obliquely at the point of intersection between the mid-axillary line and an imaginary transverse line at the height of the xiphoid appendage of the sternum), chest (mean distance between the anterior axillary line and the nipple), subscapular (obliquely to the longitudinal axis, in the portion immediately below the lower edge of the scapula, on average 2 cm), supra iliac (above the antero-superior iliac crest, at the height of the mid-axillary line) and abdominal (approximately 2 cm to the right of the lateral border of the umbilical scar) regions represented the trunk region. The skinfold thickness of the thigh (over the rectus femoris muscle, in the upper third of the distance between the inguinal ligament and the upper border of the patella) and calf (performed laterally at the point of greatest leg circumference) represented the leg region.

Dual-energy X-ray absorptiometry

Body composition was measured using dual-energy X-ray absorptiometry (Hologic QDR 4500A, software version 11.1:3, Waltham, MA, USA). The bone mineral content, lean mass, and fat mass in grams were measured throughout the body and by segment (trunk, leg, and arm). All measurements were performed with individuals instructed to wear light clothing, and their shoes were removed before the test. The athletes were asked to remove all metal objects (e.g., rings, necklaces, etc.). The measurements of all the athletes were performed in the afternoon between 2 and 3 pm.

Statistical analysis

The data were tabulated using Microsoft Excel 2007® package. The normality analysis of all study variables was performed using the Shapiro-Wilk test, and non-normal variables were inserted into the logarithmic transformation (Log^{10}). In addition to descriptive statistics, mean, and standard deviation, the relationship between anthropometric and body composition variables was analyzed using Pearson's correlation coefficient. The inclusion criteria for regression analysis were used to verify the relationship between the two variables. The data were analyzed using R-Plus Software version 2.15.0® (2012) for Microsoft Windows® through the R-Studio® graphical interface. The significance value was set at $p < .05$.

Table 2
Mean (±SD) of anthropometric variables and body composition.

Anthropometric								
Arm			Trunk			Leg		
BS (mm)	7.03	(± 3.30)	MS (mm)	19.66	(± 12.54)	TS (mm)	19.73	(± 9.61)
TS (mm)	11.49	(± 6.99)	CS (mm)	9.84	(± 6.09)	CalfS (mm)	16.70	(± 8.83)
∑AS (mm)	18.60	(± 9.70)	SiS (mm)	23.32	(± 11.95)	TC (mm)	42.87	(± 6.41)
CAT (cm)	33.68	(± 4.32)	AS (mm)	27.35	(± 13.16)	CC (mm)	30.28	(± 3.60)
CAR (cm)	30.57	(± 4.26)	SubS (mm)	19.62	(± 11.03)	∑LS (mm)	36.44	(± 17.97)
FC (cm)	27.36	(± 2.74)	∑TS (mm)	99.82	(± 49.31)			
			WC (cm)	89.26	(± 8.31)			
			AC (cm)	95.52	(± 11.35)			
Body composition								
Arm			Trunk			Leg		
FM (kg)	1.18	(± 0.58)	FM (kg)	9.45	(± 4.43)	FM (kg)	3.78	(± 1.89)
LM (kg)	3.86	(± 1.01)	LM (kg)	23.57	(± 3.60)	LM (kg)	6.23	(± 1.93)
TM (kg)	5.26	(± 1.54)	TM (kg)	33.72	(± 6.91)	TM (kg)	10.32	(± 3.13)
%BF	21.48	(± 6.02)	%BF	27	(± 7.85)	%BF	35.5	(± 11.2)
BMC (kg)	0.22	(± 0.06)	BMC (kg)	0.70	(± 0.21)	BMC (kg)	0.31	(± 0.14)
BMD (g/cm^2)	0.891	(± 0.08)	BMD (g/cm^2)	1.124	(± 0.392)	BMD(g/cm^2)	0.996	(± 0.15)

Note. BS: bicipital skinfold; TS: tricipital skinfold; ∑AS: sum of the arm (bicipital and tricipital) skinfolds; CAT- circumference of arm tensed; CAR: circumference of arm relaxed; FC: forearm circumference; MS: midaxillary skinfold; CS: chest skinfold; SiS: suprailiac skinfold; AS: abdominal skinfold; SubS: subscapular skinfold; ∑TS: Sum of the trunk (midaxillary, chest, suprailiac and abdominal) skinfolds; WC: waist circumference; AC: abdominal circumference; TS: thigh skinfold; CalfS: calf skinfold; TC: thigh circumference; CC: calf circumference; ∑LS: Sum of the leg (thigh and calf) skinfolds; FM: fat mass; LM: lean mass; TM: total mass; %BF: percent body fat; BMC: bone mineral content; BMD: bone mineral density.

Table 3
Linear regression models comparing body composition variables of the predicted DXA and anthropometry (Arm and Leg).

Arm					
Model	Cor (*p*)	Int.	B	R^2	SEE (kg)
FM~Log BS	.81**	2.24	0.61	.64**	0.35
FM~Log TS	.80**	2.00	0.82	.61**	0.36
FM~∑AS	.83**	0.05	0.26	.66**	0.37
FM~CAR	.75**	0.10	1.94	.52**	0.40
FM~CAT	.77**	0.10	2.35	.57**	0.38
%BF~ Log BS	.70**	0.20	0.01	.46**	4.43%
%BF~SSA	.71**	0.44	0.01	.47**	4.39%
TM~Log BS	.76**	5.55	0.82	.55**	1.02
TM~Log TS	.72**	4.73	0.53	.47**	1.11
TM~∑AS	.73**	0.12	3.09	.50**	1.08
TM~RAC	.73**	0.26	2.83	.50**	1.08
TM~ACC	.72**	0.26	3.39	.48**	1.10

Note. The symbol ~ represents the relationship between the variables being the left side of the table (dependent variable) and right side of the table (independent variable). COR: Correlation; INT: Intercept; B: Beta; FM: fat mass; SEE: standard error of estimate; Log BS: logarithm bicipital skinfold; Log TS: logarithm tricipital skinfold; ∑AS: sum of the arm (bicipital and tricipital) skinfolds; CAR: circumference of arm relaxed; CAT: circumference of arm tensed; %BF: percent body fat; TM: total mass;
** Denotes significant correlation of $p < .01$.

Table 3 (Continuation)
Linear regression models comparing body composition variables of the predicted DXA and anthropometry (Arm and Leg).

			Leg		
Model	Cor (*p*)	Int.	B	R^2	SEE (kg)
BMC ~ CalfS	.72	0.01	0.13	.48**	0.10
BMC ~ TC	.71	0.02	-0.35	.47**	0.10
BMC ~ CC	.72	0.03	-0.53	.49**	0.10
FM ~ TS	.79	0.16	0.69	.60**	1.19
FM ~ CalfS	.85	0.18	0.73	.70**	1.03
FM ~ ∑LS	.84	0.09	0.54	.68**	1.06
FM ~ TC	.71	0.21	-5.23	.46**	1.38
FM ~ CC	.78	0.41	-8.65	.57**	1.23
LM ~ CC	.73	0.39	-5.73	.50**	1.36
TM ~ CalfS	.70	0.25	6.13	.46**	2.30
TM ~ TC	.82	0.40	-7.00	.66**	1.82
TM ~ CC	.95	0.83	-14.91	.91**	0.92

Note. The symbol ~ represents the relationship between the variables being the left side of the table (dependent variable) and right side of the table (independent variable). COR: Correlation; INT: Intercept; B: Beta; SEE: standard error of estimate; FM: fat mass; BMC: bone mineral content; CalfS: calf skinfold; ∑LS: Sum of the leg (thigh and calf) skinfolds; TC: thigh circumference; CC: calf circumference; TS: thigh skinfold; LM: lean mass; TM: total mass.
** Denotes significant correlation of $p < .01$.

Table 4
Linear regression models comparing body composition variables of the predicted DXA and anthropometry (TRUNK).

Model	Cor (*p*)	Int.	B	R^2	SEE (kg)
BMC ~ SubS	.78**	0.01	0.41	.57**	0.13
BMC ~ MS	.81**	0.01	0.44	.63**	0.13
BMC ~ SiS	.71**	0.01	0.41	.47**	0.15
BMC ~ AS	.79**	0.01	0.36	.59**	0.13
BMC ~ ∑TS	.75**	0.00	0.38	.54**	0.14
FM ~ SubS	.87**	0.35	2.52	.75**	2.20
FM ~ MS	.83**	0.30	3.63	.67**	2.51
FM ~ SiS	.71**	0.27	3.23	.47**	3.21
FM ~ AS	.83**	0.28	1.76	.67**	2.54
FM ~ ∑TS	.83**	0.08	1.96	.67**	2.54
FM ~ AC	.71*	0.28	-17.22	.47**	3.22
LM ~ SiS	.70**	0.21	18.60	.45**	2.65
LM ~ AS	.75	0.21	17.92	.53**	2.46
LM ~ ∑TS	.73	0.05	18.25	.49**	2.56
TM ~ SubS	.93	0.58	22.26	.85**	2.61
TM ~ MS	.90	0.50	23.86	.81**	2.99
TM ~ SiS	.85	0.49	22.24	.70**	3.79
TM ~AS	.95	0.50	20.04	.89**	2.20
TM ~∑TS	.93	0.13	20.59	.87**	2.49
TM ~ AC	.70	0.43	-7.21	.45**	5.11
%BF ~ SubS	.73	0.52	16.7	.50**	5.54%

Note. The symbol ~ represents the relationship between the variables being the left side of the table (dependent variable) and right side of the table (independent variable).
COR: Correlation; INT: Intercept; B: Beta; SEE: standard error of estimate; BMC: bone mineral content; SubS: subscapular skinfold; MS: midaxillary skinfold; SiS: suprailiac skinfold; AS: abdominal skinfold; ∑TS: Sum of the trunk (midaxillary, chest, suprailiac and abdominal) skinfolds; FM: fat mass; AC: abdominal circumference; LM: lean mass; TM: total mass; %BF: percent body fat.
** Denotes significant correlation of $p < .01$

Results

The descriptive statistic was used in order to identify the anthropometric characteristic of the participants, who had average body mass of 71.70 ± 15.10 kg, height 1.74 ± 0.08 m, body mass index 20.60 ± 4.20 kg/m² and body fat percentage 28.30 ± 7.40 %.

The anthropometric and segmental body composition variables are presented in Table 2.

To analyze the relationship between anthropometric variables and body composition (DXA), a correlation matrix was created. Variables with a correlation > .70 (*r*) were included in linear regression models to verify the possible predictors of segmental body composition. This value was chosen because it is considered acceptable for the validation of measurement instruments according to Guedes & Guedes (2006). The results of the linear regressions for the body composition variables of the arm region and leg are presented in Table 3.

Through the analysis we can observe that the biceps, triceps skinfolds, and the sum of these skinfolds can best explain the fat mass predicted by DXA ($R^2 = 64$, $p < .01$; $R^2 = .61$, $p < .01$; and $R^2 = .66$, $p < .01$, respectively) in the arm region.

In the leg region, an expressive relationship was observed between calf skinfold and the sum of leg skinfolds ($R^2 = .70$. $p < .01$, and $R^2 = .68$, $p < .01$, respectively) with the leg fat mass, where the calf circumference presented the smallest measurement error (SEE = 0.92 kg).

Regarding trunk variables, it is worth mentioning that the results of the Subscapular skinfolds ($R^2 = .75$, $p < .01$) and the sum of the trunk skinfolds ($R^2 = .63$, $p < .01$) can predict trunk fat mass by DXA, however, they showed high estimation error values.

Discussion

The present study aimed to analyze the applicability of anthropometric methods of body circumference and skinfold thickness per body segment in comparison with the results predicted by DXA. Thus, the study showed that models of body composition prediction can be created in a segmental way, mainly through the sum of skinfold thickness of each region that expresses strong degrees of determination with the fat mass.

In the arm region, we can identify that the biceps, triceps skinfolds, and the sum of these skinfolds represent more than 60 % of the fat mass predicted by DXA, but with considerable estimation error. The relationship between these skinfolds and fat mass has been widely explored, since it is used as a reference for the risk of obesity in children and adolescents and in predictive equations in adults without disabilities (Marrodán et al., 2017; Nickerson et al., 2020; Wang et al., 2000). The significant estimation error observed may be related to the heterogeneity of the sample, which showed, for example, a large standard deviation for the sum of skinfolds of 18.6 ± 9.7 mm.

In reference to the prediction of body composition by skinfolds in the trunk region, it was initially observed that the subscapular, middle axillary, abdominal skinfolds, and sum of the trunk skinfolds were possible predictors of fat mass in this region. However, it showed significant estimation errors, which may also be closely related to heterogeneity of the sample, which showed significant values of standard deviation for the subscapular (19.6 ± 11 mm), abdominal (27.3 ± 13.2 mm), middle axillary skinfolds (19.7 ± 12.5 mm), and the sum of skinfolds (99.8 ± 49.3 mm).

Moreover, in the trunk region, only the subscapular skinfold showed a correlation greater than $R^2 = .70$, with trunk fat mass. According to Willett (2012), subscapular skinfolds can be used as an indicator of central adiposity in addition to expressing centralized fat in the trunk. It was inserted in the equation of Steinkamp et al. (1965), which was used in the study by Spungen et al. (1995), where no significant difference in the percentage of fat predicted by DXA was observed in individuals with quadriplegia.

In the lower limbs, calf skinfold thickness and calf circumference should be highlighted ($R^2 = .70$, $p < .01$; $R^2 = .57$, $p < .01$) which can predict the change in leg fat mass. However, significant estimation errors of calf skinfold thickness (SEE = 1.03 kg) and calf circumference (SEE = 1.23 kg) were identified, which may be related to muscle atrophy in the thigh and calf region and the greater fat accumulation, which raises the measurement error due to the difficulty in "separating" subcutaneous fat from muscle mass.

These results are relevant because they present an alternative of low-cost body composition evaluation, easy applicability, and segmental analysis, which is fundamental in people with SCI, as after acute and chronic SCI, there are numerous changes in body composition (Beck et al., 2014; Cirnigliaro et al., 2013; Dionyssiotis et al., 2009) that are directly related to the affected limbs. Whether focused on the sports or the health of these individuals, reliably identifying the body region in which changes occur is essential for diagnosis, monitoring, and effective intervention.

Regarding the circumference, it can be verified whether they can also be used in models of prediction of fat mass by body segment, although they have lower correlations than skinfold thickness. The central circumferences already have scientific support for its use in the population with SCI, highlighting the waist circumference that can be used as an indicator of cardiovascular disease risk, having a strong correlation with body fat mass, abdominal fat, and biomarkers (Ravensbergen et al., 2014; Sumrell et al., 2018; Sutton et al., 2009). In our study, the abdominal circumference (measured 1 cm above the umbilical line) represented 50 % of the trunk fat mass variation, which emphasizes the feasibility of using circumference as a predictor of central fat.

Concerning the low correlations of lean mass predicted by DXA with skinfolds of all body regions, it may be explained by the fact that the skinfolds estimate the total body fat, as approximately half of the total body fat content is located in the adipose deposits directly under the skin, i.e. the subcutaneous tissue (McArdle et al., 2016).

Through this study, it was observed that segmental prediction models can be created that use skinfolds thickness and circumferences to determine fat mass. However, it is not possible to propose an equation using such variables, since for prediction, it is recommended to have 10 to 20 participants per predictive variable (Pedhazur, 1997), which would necessitate a sample of 30 to 60 subjects.

The main limitation of this study is the small sample size, which may have a negative impact on the statistical analysis. However, it is worth mentioning the innovative character of this study, which is the first to analyze the body composition of athletes with spinal cord injury segmentally.

Conclusion

In summary, segmental analysis of body composition through circumferences and skinfold thickness may be appropriate for the accurate determination of segmental body composition in athletes with spinal cord injury, especially the sum of segmental skinfolds that strongly and significantly expressed fat mass predicted by DXA.

Further studies with larger representative samples and segmental analyses that include evaluations of the largest number of measurements (circumferences, skinfolds, lengths, and bone diameters) in each body segment for the creation of subsequent predictive models may provide more expressive results.

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