Tracking within-athlete changes in whole body fat percentage in wheelchair athletes

Abstract

Purpose: To evaluate tracking of within-athlete changes in criterion measures of whole-body fat percentage (dual energy X-ray absorptiometry; DXA) with skinfold thickness measures (Σ 4, 6, or 8) in wheelchair basketball players. **Methods:** This longitudinal study tracked body composition of sixteen international wheelchair basketball players at 5 time points over a 15-month training/competition period. The primary outcome was DXA-derived whole-body fat percentage (BF%), with Σ 4, 6, or 8 skinfolds (mm) as the predictor variable. Data were analysed using a linear mixed model with restricted maximum likelihood (random intercept, with identity covariance structure) to derive the within-athlete prediction error for predicting criterion BF% from Σ skinfolds. This prediction error allowed us evaluate how well a simple measure of the Σ skinfolds could track criterion changes in BF%; that is, we derived the change in Σ skinfolds that would have to be observed in an individual athlete to conclude that a substantial change in criterion BF% had occurred. All data were log-transformed prior to analysis. **Results**: Σ 8 skinfolds were the most precise practical measure for tracking changes in BF%. For the monitoring of an individual male wheelchair basketball player, a change in Σ 8 skinfolds by a factor of greater than 1.28 (multiply or divide by 1.28) is associated with a practically meaningful change in BF% ($\geq$1 percentage point). **Conclusions:** Σ 8 skinfolds can track changes in BF% within individual wheelchair athletes with reasonable precision, providing a useful field monitoring tool in the absence of often impractical criterion measures.

Key Words: DUAL ENERGY X-RAY ABSORPTIOMETRY, SPINAL CORD INJURY, SUM OF SKINFOLD THICKNESS, WHEELCHAIR BASKETBALL, PARALYMPIC

INTRODUCTION

Physical impairment causes substantial changes in body composition which in turn affects the functional and physical performance potential of disability games players.[1,2] Knowledge of body composition can play a key role in optimising athletic performance and is often used in talent identification initiatives and routine monitoring of adaptations to training and diet.[3] Determination of body composition in wheelchair games players is not only important for appropriate design and fit of sports wheelchairs,[4] but since the combined wheelchair-user interface can have a great influence on propulsion effort,[5] it is critical that we understand the physique of the wheelchair athlete.

Training within wheelchair team sports generally follows a periodized program in an attempt to optimize performance for the competitive season; however, relatively few studies have examined the anthropometric changes occurring in wheelchair athletes over the course of an athletic season.[6,7,8,9] Body composition in these few studies was typically assessed using sum of skinfold thicknesses (Σ skinfolds), a field-based technique that is readily available and time and cost effective. Rather than converting the data to body fat percentage (BF%) using prediction equations [a practice that is not well supported due to the error associated with lack of wheelchair athlete population specific equations][10,11], these studies reported site-specific or Σ3 and Σ4 skinfold values. More recently, it has been suggested that Σ6 and Σ8 skinfold values are associated with BF% measured by dual energy x-ray absorptiometry (DXA) in wheelchair games players with a spinal cord injury (SCI) and those with an amputation, with standard errors of estimate within 5% in both groups.[12] The suitability and sensitivity of using Σ skinfold thickness to assess changes in adiposity in persons who participate in wheelchair sports across a competitive season is not well understood (e.g. individuals with a SCI, polio, amputation or with a neurological disorder).

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DXA offers the advantage of quantifying soft tissue composition providing more accurate measures of lean and fat tissue mass.[13] More importantly, in an athletic setting following best practice protocol of DXA, small changes in body composition can be confidently detected over time.[13] With standardized positioning supported using Velcro/foam wedges as needed to account for the type of impairment, work from our laboratory has shown DXA to have similar reproducibility among wheelchair athletes as previously reported in the able-bodied populations.[14] It has also been noted that DXA offers greater validity for characterizing whole body and regional body composition in people with SCI.[2] However, DXA may not always be available or feasible due to its high cost and requirement for specialized trained personnel. Therefore, the purpose of the present study was to evaluate the tracking of within-athlete changes in criterion measures of whole body BF% (DXA) with Σ skinfold thickness over a 15-month training and competition period of international wheelchair basketball players.

METHODS

Participants

Sixteen men were recruited from Great Britain's Wheelchair Basketball World Class Performance Programme 2008-2010. Diagnoses of physical disabilities met the eligibility criteria to participate in wheelchair basketball: SCI from trauma at the 6th thoracic to lumbar region (n=4; 3 suffered a complete SCI), spina bifida (n=3), polio (n=1), club foot/ neurological condition (n=3), single-leg amputation (n=4) and double-leg amputation (n=1). Nine participants were dependent upon a wheelchair for daily ambulation. All participants were trained to an elite level (>10 to <15 hours per week, excluding the off-season) and consisted of two 1.0, one 1.5, three 2.0, two 2.5, one 3.0, two 3.5, two 4.0 and three 4.5 International Wheelchair Basketball Federation (IWBF) classified players. Data collection took place at Loughborough University in Loughborough, England, UK. The study procedures were

approved by the University Research Ethics Committee and the National Research Ethics Service, and all participants gave written informed consent.

Design

Participants attended the laboratory for body composition assessment five times throughout a 15-month period that included both Club level and National (GB) competitive seasons (Figure 1). Not all participants were assessed at all time-points due to overseas Club commitments or illness. Body composition assessment included anthropometrics (body mass, body length, BMI), DXA, and skinfold thickness measures at eight sites.

Insert Figure 1 near here

Participants were asked to refrain from exercise and consuming alcohol and caffeine for ≥ 12 hours, eating or drinking for at least 2 hours, and to be euhydrated before each testing session. Urine osmolality was assessed using an Osmocheck (Vitech Scientific Ltd, West Sussex, UK) to determine hydration status. Prior to the first visit, each participant completed a 24-hour dietary recall, to standardise food and fluid intake on the day of the repeat measurements.

Body composition measurements

Anthropometrics

Body mass was measured in minimal clothing, to the nearest 0.1 kg using a wheelchair double beam scale (300 series, Marsden, London, UK). Body length was measured in the supine position to the nearest 0.1 cm with a steel Lufkin measuring tape. For the participant who had a double amputation, length was measured using the same methodology, but was taken from the head to the point of amputation. For participants who were unable to lie straight, body length was calculated from the sum of body segments. BMI was calculated by dividing body mass by length squared (kg/m^2) and was not reported for the participant with the double amputation.

Dual Energy X-Ray Absorptiometry

Body composition was assessed using a Lunar Prodigy Advance DXA scanner (GE Lunar, Madison, WI, USA) running version 12.20, Encore 2006 software. The scanner was calibrated daily using standard protocols, and an aluminium spine phantom also scanned daily to ensure there was no drift. Protocols for whole body scan acquisition have been described previously.[14] Participants wore loose fitting, lightweight clothing with no metal or reflective material, and all jewellery and prostheses were removed where possible. After voiding the bladder, each individual was aligned supine on the bed and appropriately positioned as closely as possible to the standard protocols and according to previous visits. Velcro restraints/foam wedges were applied around participants' knees and ankles to minimise movement during the scan, unless this was not possible because of the physical impairment; these were noted for subsequent visits. Two trained investigators undertook the scans, with one investigator analysing all DXA scans. Total body scans analysis estimated whole body fat mass (FM, % and kg) and lean soft tissue mass excluding bone mineral mass (LTM, kg). Coefficient of Variation (CV) values for all whole-body measurements were <2.0%, and the least significant change values were calculated as 0.2kg, 1.1kg, and 1.0kg for whole body mass, whole body LTM, and whole body FM, respectively.[14]

Skinfold Thickness

An eight-site skinfold thickness profile was performed on all participants on the right side, unless access to a specific skinfold site was not possible due to the physical impairment or absence of lower limbs: biceps, triceps, subscapular, iliac crest, supraspinale, abdominal, anterior thigh and medial calf. In that instance the left side was used, or the site not reported. All measurements were made in accordance with protocols stated by the International Society for the Advancement of Kinathropometry (ISAK)[15] by the same trained accredited ISAK investigator, using a set of Harpenden Skinfold Callipers (Baty International, West Sussex, UK). For the wheelchair-bound individuals the skinfold thickness measures were taken in a

seated position in a standard seat without armrests to allow for better access to the iliac crest and supraspinale. For the ambulant individuals, skinfold measures were taken with the individual in the anatomical standing reference position. Each measurement was taken in duplicate and any two assessments varying by more than 10% of one another were repeated, and the closest measures were averaged to determine the representative value.

Skinfold thickness values were used to calculate the Σ of 4 (biceps, triceps, subscapular, and supra-iliac) 6 (biceps, triceps, subscapular, iliac crest, supraspinale, and abdominal), and 8 (biceps, triceps, subscapular, iliac crest, supraspinale, abdominal, thigh, and calf); raw values in millimetres were recorded. Precision of this technique following ISAK training from observations (n=10) by one trained investigator (Σ of 8) was ~3% of the mean.

Statistical analyses

All analyses were performed using Statistical Analysis System (SAS) software (Version 9.4, SAS Institute, Cary, NC, USA). Baseline participant characteristics and outcome measures are presented as mean ± SD. For the primary analysis, we applied a linear mixed model (Proc Mixed) with natural log-transformed DXA whole BF% as the outcome variable and natural log-transformed Σ of skinfold thickness (4, 6, or 8) as the predictor. The log-transformed Σ of skinfold thickness was first standardised to a mean of zero using each athlete's mean and standard deviation (SD) for the repeated measures (Proc Standard):

$$(SD_X(X_i-\overline{X}))/SD_X,$$

(Where SD_x is the SD for the repeated measures for a particular athlete, X_i is a single observation's value, and $\overline{X}$ is the mean value for the repeated measures for a particular athlete.) This procedure removes between-subject variability in the predictor and isolates the within-subject variability to properly track body fat percentage with sum of skinfolds within-athlete. The predictor was entered as a fixed effect (slope) with a random intercept for athlete, to derive the within-athlete typical prediction error for predicting DXA BF% from Σ of skinfolds. Note

that there were insufficient data to provide robust predictions with a model that also allowed for random slopes. We used a restricted maximum likelihood estimation method and a variance components (identity) covariance structure, with degrees of freedom given by the Satterthwaite method. The within-athlete prediction error allowed us evaluate how well a simple measure of the Σ of skinfolds could track criterion changes in BF%; that is, we derived the change in Σ of skinfolds that would have to be observed in an individual athlete to conclude that a meaningful change in criterion BF% had occurred.

The threshold for the minimum practically important change in BF% was elicited from the sample of athletes. The group consensus was that a change in criterion BF% of one percentage point (e.g. 22% fat to 23% fat) was a meaningful difference; that is, the smallest change considered to be of practical significance to athletes. Given the marked heterogeneity in body size and composition in this sample, we elected to express this threshold as a ratio (percentage) such that the absolute threshold for meaningful change was higher for an athlete with, for example, 30% fat, than one with 20% fat. The overall sample mean BF% across the study was 23.7%. A one-percentage point change in BF% (e.g. to 22.7%) gives a threshold for the minimum practically important change as a ratio of $\times/\div$ 1.044.

Using the observed slope for the predictor, the minimum practically important difference, and the within-athlete prediction error, we derived the magnitude of the change in predicted BF% such that there were at least 5 bits of information against the hypothesis of a true ratio change smaller than $\times/\div$ 1.044. This information is provided by the 'surprisal', or S-value.[16] The S-value is defined as $-\log_{base\,2}(p)$ and is equivalent to the number of consecutive heads in repeated tosses of a fair coin. The required threshold one-tailed p value to give at least 5 bits of information (5 consecutive heads) against the minimum practically important difference is 0.03, as $-\log2(0.03) = 5.06$ bits of information. Therefore, we derived the change in Σ of

skinfolds that gives a lower limit of a 2-sided 94% individual prediction interval for the change in predicted DXA BF% coincident with the minimum practically important difference.

The individual prediction error is given by the within-athlete typical error of the estimate together with the standard error for the fixed slope:

$$\text{Prediction error} = \sqrt{(2 \cdot \text{TEE}^2 + (\Delta \text{SF} \cdot \text{SE}_{\text{slope}})},$$

Where, TEE = the within-athlete typical error of the estimate (the square root of the model residual), ΔSF is the change in Σ skinfolds on the log scale, and SE_{slope} is the standard error for the fixed slope for Σ skinfolds. To derive a 94% prediction interval this prediction error was multiplied by the appropriate value from the t distribution with the model degrees of freedom.

RESULTS

All participants were euhydrated as determined via the osmolality of the waking urine sample that was analysed on arrival to the laboratory. For DXA, five participants were tested on all five occasions, seven on four occasions, two on three occasions and two on two occasions (Figure 1). Table 1 shows the participants' anthropometrics, DXA and skinfold thickness outcome measures at each of the five data collection time points.

Insert Table 1 near here

Tracking Body Composition Using Skinfolds vs. DXA

The within-athlete typical error of the estimate was 5.0% for Σ of 8 skinfolds, 5.3% for Σ of 6 skinfolds, and 5.9% for Σ of 4 skinfolds. Note that these values are not percentage points for body fat; they are typical errors expressed as a percent from the log-transformed model. Results are presented for the two best models: the Σ of 8 and Σ of 6 skinfolds.

Sum of 8 skinfolds

The observed slope for logSum8 skinfolds was 0.738 (95% CI, 0.600 to 0.875). The slope indicates that on average a 10% increase in Σ of skinfolds is associated with an 7.4% increase in BF%. (Note again that this is not an 7.4% increase in fat [e.g. 22.0% to 29.4% fat]; rather it

is 7.4% of the initial value, so approximately 23.6% vs. 22.0%, for example.) The within-athlete prediction error was 0.071 on the log scale, or 7.4% (back-transformed). The minimum change in Σ of skinfolds compatible with 5 bits of information against a change in predicted BF% below the minimum practically important difference was ×/÷ 1.28. That is, the initial Σ of skinfolds would have to increase or decrease by a factor of 1.28 for the coach to conclude that a meaningful change in body fat percentage had occurred for an individual athlete (e.g. 100 mm vs 128 mm).

Sum of 6 skinfolds

The observed slope for logSum6 skinfolds was 0.637 (95% CI, 0.513 to 0.762). The slope indicates that on average a 10% increase in Σ of skinfolds is associated with an 6.4% increase in BF%. The within-athlete prediction error was 0.075 on the log scale, or 7.9%. The smallest change in Σ of 6 skinfolds associated with a practically meaningful change in BF% was ×/÷ 1.35 (e.g. 80 mm versus 108 mm).

DISCUSSION

This is the first robust investigation of within-athlete changes in body composition over a competitive season among wheelchair basketball players using both a laboratory-based (DXA) and a field-based (skinfold thickness) measure. The main finding of the present study was that the Σ of 8 skinfolds was the most precise practical measure for tracking within-athlete changes in body composition over the 15-month period. The threshold chosen for the change in Σ of skinfolds for an individual associated with a meaningful change in whole BF% was that which provided 5 bits of information against a hypothesis of a change in criterion BF% smaller than ×/÷ 1.044 (one percentage point at the sample mean). In other words, when monitoring an individual wheelchair athlete, if the true (unknown) change in BF% was trivial, then it would be modestly surprising to observe a change in Σ of skinfolds of this magnitude, given the observed within-athlete relationship - equivalent to 5 heads in a row in consecutive tosses of

a fair coin. These results apply to a trained cohort of male wheelchair basketball players; other populations may differ, yet the statistical methods presented are generally applicable.

The mean DXA BF% at T1 (Table 1) was in line with previously reported data in the literature for male wheelchair athletes.[17,18,19,20,21] Our results demonstrate that the field-based technique (Σ of skinfolds) is appropriate for use in elite wheelchair games players, and that it is preferable to take as many skinfold sites as possible. Whilst we recommend using the Σ of 8 skinfolds, most previous studies involving athletic populations have reported Σ of 4 skinfolds.[6,7,8,9,22] Moreover, when DXA is not used in a clinical SCI rehabilitation setting, then clinicians have relied on predictive equations for both body density (e.g., Durnin-Womersley[23], Jackson-Pollock[24]) and subsequently BF% (e.g., Siri equation[25]) from sum of skinfolds.[26,27,28] We know that sports practitioners are being encouraged not to use these equations when working with athletes with a disability[3,4] because of the many assumptions about the distribution of fat and the constant relationship between skinfold thickness and body density. It is encouraging to see that studies have reported skinfold values of ≥ 8 sites,[20,28,29] yet practically it is important to note that this may be considered too invasive for the individual; for example, some may attach their urine collection bag to their leg, or feel uncomfortable with exposing their atrophied legs, making a thigh and/or calf measurement difficult to obtain. Moreover, in double amputees it is not physically possible. Skinfold assessment is a convenient method, and the uniqueness of this study is that a sport scientist can now determine whether a meaningful a change in whole body fat percentage has occurred across a competitive training season, utilizing either the Σ of 8 or 6 skinfolds as they feel appropriate. The novelty of the statistical analyses employed in the current study is that the findings are applicable at an individual athlete level.

Whilst a limitation of this study is the small sample size, the athletes tested were from the Great Britain wheelchair basketball team; therefore, this was a very select and unique population, making larger participant numbers extremely difficult to achieve. The repeated measures

within-athlete design, however, provides reasonable degrees of freedom for estimating the typical individual prediction error with adequate precision. With substantially more data, we would model a random slope as well as random intercept, with an unstructured covariance structure. This model would provide the standard deviation of the individual athlete slopes around the mean fixed slope, with this standard deviation then adding to the prediction error overall. We did not have enough data to estimate the variability in the within-athlete slopes robustly. Nevertheless, omitting a random slope term in the model leads to some of this variability being incorporated in the model residual, so we are confident in our primary results. Finally, questions remain regarding the suitability of Σ of 8 or 6 skinfolds based on the type and severity of impairment (e.g. ambulant and non-ambulant players)[30].

PRACTICAL APPLICATIONS

- This is the first robust within-athlete tracking study investigating within-athlete changes in body composition over a competitive season among wheelchair basketball players.

- Σ 8 skinfolds can track changes in BF% within individual wheelchair athletes with reasonable precision, providing a useful field monitoring tool for applied sport scientists in the absence of often impractical criterion measures.

- The model also has applications to other contexts/ outcomes where sports practitioners might want to track serial measurements within-subject.

- A major strength of this study is that the findings can be used by sports science practitioners in future longitudinal training preparations for athletes optimising their preparation for the Tokyo (2020) and Paris (2024) Paralympic Games.

CONCLUSIONS

In summary, we have shown it is possible to use the Σ of 8 or 6 skinfold thickness for tracking changes in body composition among elite wheelchair basketball athletes. Our findings suggest

that the field-based assessment of skinfold thickness can be used as a proxy measure when it is not possible to gain access to DXA. However, validation is needed for women, different ages and other impairment types across both men and women (e.g., those eligible for the sport of wheelchair rugby) to those reported in the present study.

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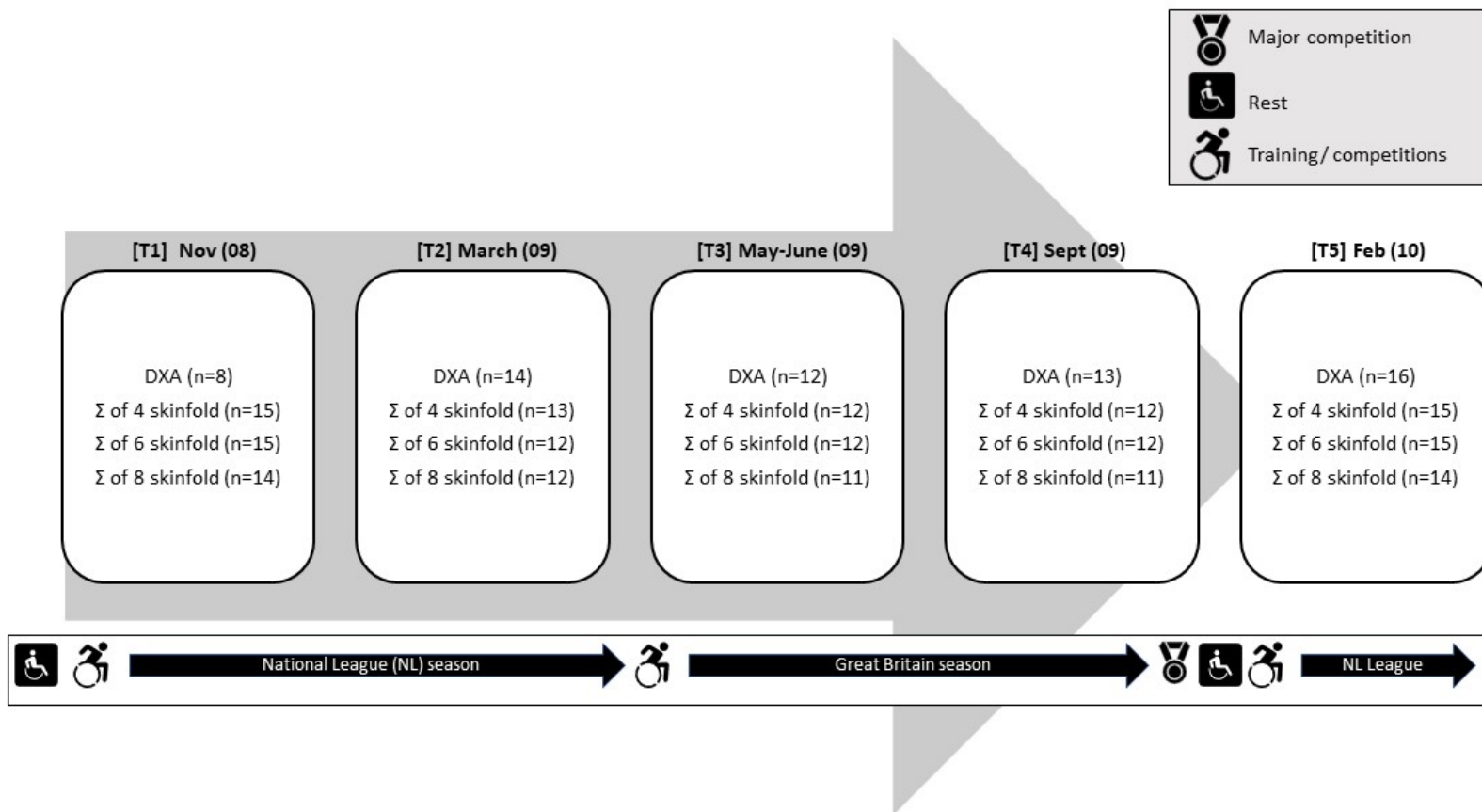
Figure 1: Study timeline.

Table 1: Anthropometrics, DXA and sum of skinfolds across five time points.

	T1	n	T2	n	T3	n	T4	n	T5	n
Body Mass (kg)	71.9 ±12.7	16	70.8 ±13.4	14	69.7 ±10.6	12	71.0 ±11.7	14	70.6 ±13.2	16
Body Length (m)	1.71 ±0.16	16	1.71 ±0.17	14	1.72 ±0.16	12	1.71 ±0.17	14	1.71 ±0.16	16
BMI*	24.5 ±4.2	15	24.7 ±4.0	14	23.9 ±3.9	12	24.4 ±4.1	14	24.4 ±3.7	15
Total body (DXA)										
Fat (%)	22.2 ±7.4	8	23.5 ±7.0	14	23.6 ±7.8	12	24.2 ±6.0	13	24.2 ±6.3	16
Fat (kg)	15.3 ±5.9	8	16.0 ±5.6	14	16.1 ±6.5	12	17.0 ±5.3	13	16.7 ±6.0	16
LTM (kg)	51.5 ±10.3	8	51.9 ±10.8	14	50.8 ±7.6	12	50.8 ±9.3	13	51.4 ±9.1	16
Sum of Skinfolds										
Sum of 4 (mm)	44 ±15	15	44 ±14	13	44 ±18	12	43 ±9	12	48 ±17	15
Sum of 6 (mm)	75 ±24	15	75 ±23	12	75 ±29	12	77 ±17	12	83 ±26	15
Sum of 8 (mm)	106 ±34	14	104 ±33	12	107 ±40	11	104 ±23	11	114 ±36	14

Footnote.

Values are mean ±SD
Abbreviations: BMI = body mass index (*excluding the double amputee); DXA = dual-energy x-ray absorptiometry; LTM = lean soft tissue mass (excluding bone mineral mass)
Note: time-points are consistent with Figure 1