Validation of a skinfold based index for tracking proportional changes in lean mass

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Running title: LMI for monitoring change in muscle mass

Keywords: anthropometry, elite athlete, LMI, rugby union, skinfolds, testing

Abstract

The lean mass index (LMI) is a new empirical measure that tracks within-subject proportional changes in body mass adjusted for changes in skinfold thickness. **Objective:** To compare the ability of the LMI and other skinfold-derived measures of lean mass to monitor changes in lean mass. **Methods:** Twenty elite rugby union players undertook full anthropometric profiles on two occasions 10 weeks apart to calculate the LMI and five skinfold-based measures of lean mass. Hydrodensitometry, deuterium dilution and dual-energy X-ray absorptiometry provided a criterion four-compartment (4C) measure of lean mass for validation purposes. Regression-based measures of validity, derived for within-subject proportional changes via log transformation, included correlation coefficients and standard errors of the estimate. **Results:** The correlation between change scores for the LMI and 4C lean mass was moderate (0.37, 90% confidence limits -0.01 to 0.66) and similar to the correlations for the other practical measures of lean mass (range 0.26 – 0.42). Standard errors of the estimate for the practical measures were in the range of 2.8 to 2.9%. The LMI correctly identified the direction of change in 4C lean mass for 14 of the 20 athletes, compared with 11 to 13 for the other practical measures of lean mass. **Conclusion:** The LMI is probably as good as other skinfold-based measures for tracking lean mass and is theoretically more appropriate. Given the impracticality of the 4C criterion measure for routine field use, the LMI may offer a convenient alternative for monitoring physique changes, provided its utility is established under various conditions.

Introduction

Physique traits are known to influence competitive success in many individual and team sports. Among adult athletic populations much of the focus on assessment of physique traits has centred on routine monitoring of body fat levels on the basis of the negative implications of excess body fat on frontal body surface area, power to weight ratio and thermoregulation [1]. However in sports demanding high strength and power, absolute levels of lean or muscle mass may be more closely associated with competitive success than body fat. Data collected during the 1999 Rugby Union World Cup revealed correlations between final ranking and body size [2], with teams consisting of the larger forwards being more successful. In rowing, performance is correlated with absolute levels of fat-free mass [3]. While between-subject experimental data is of interest, coaches and athletes at the elite level are more interested in monitoring within-subject longitudinal changes as they prepare for major competitions.

Several techniques are available for measurement of fat free mass (FFM) and muscle mass, including radiographic (computer tomography, magnetic resonance imaging, dual x-ray absorptiometry), metabolic (creatinine, 3-methylhistidine), nuclear (total body potassium, total body nitrogen) and bioelectrical impedance [4]. Selection of the appropriate technique is based on accuracy, reliability, expense, safety, portability, invasiveness and technical expertise necessary to conduct the procedures. For reasons of timeliness and practicality the routine monitoring of body composition among athletic populations is often undertaken using anthropometric traits such as body mass and subcutaneous skinfold thicknesses. Estimates of body density, fat mass and/or FFM are then derived using one of many regression equations. However, these equations are based on a single-measurement between-subject cross-sectional comparison of anthropometric parameters and laboratory-based techniques such as hydrodensitometry [5]. To our knowledge only one previous investigation [6] detailed the ability of practical anthropometry measures to track changes in body composition when assessed

using a criterion measure. Furthermore most equations were derived from non-athletic populations [7]. A major issue is the ability of these equations to track changes in physique traits of athletes in response to training and/or dietary interventions [5, 8]. In particular, the ability of skinfold-based prediction equations to track changes in the lean mass of elite athletes needs to be established.

A novel approach of assessing lean mass changes in elite athletes using a simple field test of basic anthropometric measures has been proposed (SEE COMPANION PAPER). The Lean Mass Index (LMI) is an empirical measure that tracks within-subject proportional changes in body mass adjusted for changes in skinfold thickness. As such, the LMI tracks changes in body mass not associated with changes in skinfolds. The LMI could be a simple and practical measure for estimating changes in lean mass of trained athletes. The primary objective of this study was therefore to establish the reliability and validity of the LMI against the criterion four compartment (4C) model and other skinfold-based measures of fat-free mass or muscle mass.

Methods

Subjects

Twenty Super 12 rugby players (9 forwards, 11 backs) of Caucasian, Polynesian or Melanesian ethnicity volunteered for this study. The players age (mean ± SD) was 23.2 ± 2.0 years, with a body mass of 96.0 ± 10.3 kg, a sum of seven skinfolds of 80.9 ± 23.2 mm, and a LMI of 53.1 ± 5.3 $mm.kg^{-0.14}$.

Experimental Design

Volunteers undertook assessment of physique traits, including both anthropometrically derived indexes (including the LMI) and criterion two (2C), three (3C) and 4C measures, before and after 10 weeks of intensive pre-season strength and conditioning training. To

assess the utility of the LMI and other anthropometrically derived indexes against the criterion measures we established the mean change over the 10 weeks, the precision of the estimate, and the degree of individual response around the mean change.

To minimize within-subject biological variability, all assessments, excluding the dual energy x-ray absorptiometry (DXA) scan, were conducted on the same morning (0500 - 0900 h) when volunteers were at least 8 h post-prandial and in a euhydrated state. DXA measurements were undertaken within 6 h of the other tests (1200 - 1400 h). To standardize hydration status, volunteers were provided with guidelines on maximizing hydration status in the 24 h prior to each assessment. Volunteers were provided with 1.0 L of a commercially available oral rehydration solution (Gastrolyte®) following their final training session on the day prior to assessments. To confirm hydration status, the specific gravity of the first void urine sample was assessed immediately using an automated refractometer (UG-1, Atago Ltd, Tokyo, Japan).

Body Composition

Practical Measures - Anthropometry

Full anthropometric profiles, including body mass, stretch stature, sitting height, skinfolds at nine sites, eleven girths, nine lengths and six breadths were landmarked and measured by an International Society for the Advancement of Kinanthropometry (ISAK) accredited level III anthropometrist with technical errors of measurement of 1.7% for skinfolds and <1% for all other measures. Sitting height and stretch stature were measured using a Harpenden wall-mounted stadiometer (Holtain Ltd, Crosswell, United Kingdom) with a precision of ± 1mm. Skinfolds were assessed using Harpenden calipers (British Indicators Ltd, Hertfordshire, United Kingdom). Girth measurements were made with a flexible steel tape (Lufkin W 606 PM, Cooper Industries, Lexington, SC). Lengths were assessed using a large sliding caliper

(British Indicators Ltd, Hertfordshire, United Kingdom). The majority of breadths were also measured with the large sliding caliper; biepicondylar breadths were measured with vernier calipers (Holtain Ltd, Crosswell, United Kingdom). All anthropometric equipment was calibrated prior to each assessment period, with additional checks against National Association of Testing Authorities (NATA) certified calibration weights and rods.

All measurements were made on the right side of the body using techniques previously described [9]. The full anthropometric profile was undertaken in duplicate to establish within-day retest reliability. If the difference between duplicate measures exceeded 4% for skinfolds or 1% for all other parameters, a third measurement was taken but only after the full profile had been completed in duplicate. The mean of duplicate or median of triplicate anthropometric measurements were used for all subsequent analysis.

Lean Mass Index

Detailed methods for the calculation of the LMI are provided elsewhere (SEE COMPANION PAPER). Briefly, we analyzed the relationship between changes in log-transformed mass and sum of skinfolds using repeated-measures multiple linear regression. Back-transformation yielded a function of mass and sum of skinfolds. The function tracked changes in mass controlled for changes in skinfolds. The LMI is a supplementary estimate of body composition and allows the quantification of proportional changes in lean mass.

Prediction Equations

Anthropometric data were used to derive estimates of muscle mass via fractionation [10] or body density [11-13]. The Siri equation [14] was used to convert body density to body fat (%). Fat free mass was then calculated according to the formula: FFM = Body mass – (body mass * fat (%)/100). Specific anthropometric data used in each estimate are specified in Table 1.

Criterion Measures

The 4C body composition model involves the measurement of body density (BD), total body water (TBW) and bone mineral content (BMC) by hydrodensitometry, isotopic (deuterium) dilution and DXA respectively. Derivation of the 4C model is described elsewhere [13]. The 4C model served as the gold standard from which changes in anthropometrically derived data were compared. The 2C model is derived from BD alone while the 3C model also incorporates TBW in the calculation of FFM.

Total Body Water

Total body water was measured using the stable isotope of hydrogen, deuterium, in the form of water (^2H_2O). Volunteers presented at the laboratory at 0500 h on the day of assessment, voided their bladder and provided a small urine sample (~20-30 ml). Body mass was measured on a calibrated digital scale with a precision of ± 0.02 kg (A & D Co., Tokyo, Japan). Thereafter athletes drank a 10% solution of ^2H_2O (diluted with tap water) based on their body mass (0.5 $g.kg^{-1}$). The dose consumed was recorded to one-hundredth of a gram. An equilibrium period of approximately 4 h without eating, drinking or exercising was enforced between administration of the tracer and collection of the post-dose urine sample. Enrichment of the pre-dose urine sample, the post-dose urine sample, local tap water and the dose given were measured in duplicate via isotope ratio mass spectrometry (Hydra, Europa Scientific, Crewe, UK) using procedures described previously [15]. The mean of duplicate measures was used in subsequent analysis. Total body water was calculated in accordance with the recommendations of Schoeller et al. [16], who advocate a 3% correction factor for the exchange of ^2H_2O with labile hydrogen of protein and other body constituents.

Hydrodensitometry

Body density was determined by underwater weighing at approximately functional residual capacity, with measurement of associated respiratory gas volume by oxygen dilution immediately following each trial (while the subject remained immersed to neck level) using procedures described previously [17]. A minimum of three and a maximum of eight trials were performed, with the median of three trials showing the least variability used in all subsequent calculations.

Dual-energy X-ray Absorptiometry

Total BMC was determined using a Norland XR-36 series DXA (Norland Corp., Fort Atkinson, WI), with Norland Body Composition software (v. 2.5.0) in the medium mode [18]. As the BMC reported from DXA represents ashed bone, results were multiplied by a correction factor (1.0426) to obtain bone mineral mass [19]. Quality control calibration procedures were undertaken according to the manufacturer's specifications at the beginning of each testing session using calibration standards provided with the scanner. Volunteers were scanned while wearing minimal clothing, with all metallic objects removed prior to assessment.

Statistical Analysis

The LMI is intended to track proportional or percent changes in lean mass [20]. The LMI and the other measures in this study were therefore log transformed for all analyses [21], because this approach converts uniform proportionality into uniform additively (an implicit assumption for the linear modelling in the validity analyses). The Pearson correlation coefficient was calculated for the straight line fit between the criterion and each practical measure of FFM in the pre-test, the post-test, and the 10-week post-pre change scores. For change scores, the line was forced through the origin; the slope of the resulting line thereby

represented the scaling factor for predicting percent changes in the criterion measure from percent changes in the practical measure, and the standard error of the estimate was the prediction error. Magnitudes of correlations were interpreted qualitatively using Cohen's scale: $r < 0.1$, trivial; 0.1–0.3, small; 0.3–0.5, moderate, >0.5, large. Confidence limits for correlations and for the difference between correlations were derived by re-sampling 3000 times from the original data (bootstrapping). Measures of centrality and spread are shown as mean ± between-subject standard deviation (SD). The magnitude of change is expressed as percentage of the baseline score ± SD. Uncertainty in population values of statistics was expressed as 90% confidence limits (90%CL). The typical (standard) error of measurement was calculated as the measure of within-day retest reliability [21]. Analyses were performed using the Statistical Analysis System (Version 8.02, SAS Institute, Cary, NC).

Results

The baseline values in anthropometric measures and proportional changes in height, sum of seven skinfolds, and anthropometric measures of muscle mass and FFM are provided in Table 2. All mean changes in body composition over the 10 weeks were trivial, with the exception of a small increase in FFM calculated using the Forsyth and Sinning [11] equation, and a small decrease in the sum of seven skinfolds. Individual variation in the changes (the SD of the change scores) was either trivial or small for all measures of lean mass, with the 4C criterion measure showing the largest variation. Variation in the sum of skinfolds was of similar small magnitude, but the variation in total body water was moderate-large.

Figure 1 shows graphically the relationships of the baseline, post and change scores of the 4C criterion measure with those of the LMI, and Table 3 lists statistics for the relationships of the 4C model with all measures. The 3C measure and body water had very high correlations for baseline, post and change scores. Correlations for baseline and post values of the practical

measures of lean mass and of body mass were also very high (0.85-0.98), whereas the correlations with skinfold thickness were small. The change scores for the LMI and the other practical measures of lean mass had only small-moderate correlations with the criterion, although uncertainty in the correlations (confidence limits, ~±0.30) allowed for the true correlations to be trivial to strong. There was less uncertainty for the comparison of the LMI correlation (0.37) with that of some of the other measures, in particular the Withers et al equation (0.41; difference -0.04, confidence limits ±0.17) and the Drinkwater and Ross equation (0.28; difference 0.09, confidence limits ±0.21). The change scores for the LMI also had stronger correlations with those of the Withers et al (0.89) and Drinkwater and Ross (0.75) than with the other practical measures of lean mass (Thorland et al, 0.59; 2C FFM, 0.57; and Forsyth and Sinning, 0.31).

The standard errors of the estimate (SEE) for the prediction of change in 4C FFM by all practical measures were within the range of 2.8 to 2.9%, whereas the SEE for the predictions by changes in 3C and body water were much smaller (0.3% and 0.8% respectively). The LMI correctly identified the direction of change in 4C FFM (increased or decreased) in 70% of cases. The TBW and 3C methods were 95% and 100% accurate respectively in identifying the direction of change, while the other skinfold-based measures were within 55% to 65% accurate.

The within-day errors of measurement were all small in comparison with the 10-week variation. The error was greatest for 2C FFM (0.4%, or about one-third of the 10-week variation). Errors for the 4C, the other measures of FFM, body mass, and sum of skinfolds were less than one-fifth of their respective 10-week variations.

Discussion

This investigation was prompted by the need to establish a fast, convenient, and valid measure of changes in lean mass in highly trained athletes. For this purpose we compared relationships between change scores for a criterion measure of lean mass with a new practical measure of lean mass (the LMI), and an array of existing anthropometrically derived estimates of lean mass. Professional rugby union athletes were monitored during 10 weeks of pre-season training, a period in which both changes in fat mass and fat free mass were a priority for the players. The primary finding of this investigation is that the LMI is probably as good as other skinfold-derived measures for tracking within-subject lean mass changes. Moreover, the practical measures evaluated in this study were as effective as the conventional 2C model of hydrodensitometry alone in tracking changes in lean mass. Thus, the LMI can be used to routinely monitor changes in FFM.

A number of cross-sectional between-subject validation studies have been undertaken on anthropometric methods of assessing physique traits primarily using the 2C hydrodensitometry model as the gold standard, or more recently the 4C model. As has been observed previously [6], cross-sectional validity assessments between criterion and anthropometric measures often identify strong relationships in heterogeneous populations. This was also the case in the present investigation; most likely because of the influence of body mass, which itself showed a strong correlation with the criterion measure. However, single time point assessments do not address the ability of a specific technique to track changes in physique traits over time. As we were most interested in monitoring changes in physique traits of the athletes during a period of pre-season training, we validated commonly used physique assessment tools in tracking changes in lean mass. These correlations between within-subject percent change scores can not be confounded by body mass.

Few studies have been undertaken to validate the ability of various techniques to track change in physique traits. Van Marken Lichtenbelt and associates [6] observed a strong relationship (r = 0.88) between the gold standard 4C model and skinfold derived estimates of FFM change. Because of the relatively large method error, the authors suggested skinfold estimates be employed to monitor group responses rather than that of individual athletes. Others have reported that anthropometrically derived equations may not be accurate predictors of changes in body composition [5, 8]. Prediction equations currently available have not been formulated to monitor within-subject changes in physique traits. Rather they were created to offer an estimate of between-subject physique traits at a single time point. Consequently, it is not surprising that estimates from these equations correlated only moderately with the criterion measure when monitoring an individual longitudinally.

The short-term test-retest measurement error of the 4C criterion measure and the other measures of FFM were all much less than the variation in the change scores over the 10 weeks of the present investigation. The change scores therefore represented real changes within each subject rather than measurement error. Further, error of measurement arising from physique assessment did not account for the relatively modest correlations between change scores. We must conclude that there were substantial changes in criterion lean mass that were not tracked by the practical measures of lean mass.

When changes in the LMI or other practical measures are calibrated to the criterion using the slopes of the lines of best fit (Table 3), the error in the estimate is ~3%. It follows that the calibrated practical measures are suitable only for tracking changes somewhat greater than 3%. It is important to recognize that the slopes of the change in criterion measure/change in practical measure relationship have considerable uncertainty. Furthermore, the slopes may also be different for moderate to large changes. With this in mind, it would be sensible to

regard this investigation as providing reasonable evidence that the LMI is comparable with the other practical measures of lean mass, and that the LMI is theoretically at least more appropriate for tracking changes in individuals. We acknowledge the LMI provides a proportional rather than an absolute measure of change in FFM. Despite this, the LMI tracked changes in FFM as well as other anthropometry derived measures and predicted the correct direction of change better than other practical tools. The improved ability to predict the direction of change may be attributable to greater specificity of the equation to the population under investigation and/or that the LMI has been derived from the longitudinal assessment of within-subject changes in mass and skinfolds.

In summary, given that the 4C criterion measure will never be an option for routine field use, the LMI and other practical, anthropometrically derived tools may offer a convenient, fast and economical option for monitoring physique changes. However, the LMI remains a proportionality index that tracks changes in mass not accounted for by changes in skinfolds and further investigation is required to establish its utility under all conditions.

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Volunteers were fully informed of the nature and possible risks of the investigation before giving their written informed consent. The investigation was approved by the Human Research Ethics Committee of the Australian Institute of Sport (Approval Number 20031013).

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Figures

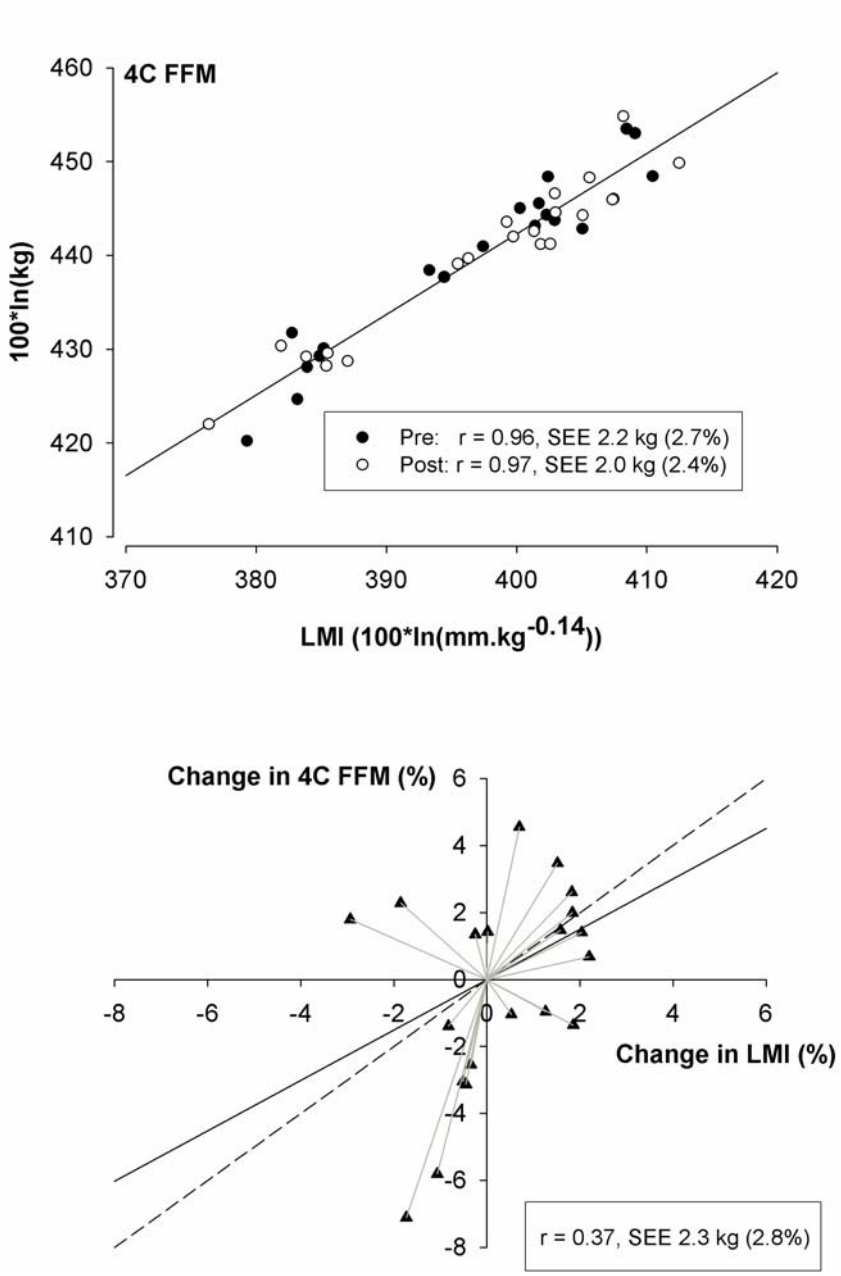

Figure 1: The first panel is a two-dimension plot showing a nearly perfect relationship between the 4 compartment estimate of FFM and the LMI before and after 10 weeks of pre-season training for 20 individual subjects. The second panel shows a moderate relationship between change scores for the 4 compartment estimate of FFM and the LMI after 10 weeks of pre-season training for 20 individual subjects. Solid line represents the mean correlation for the change scores from baseline. The dashed line represents the line of identity.

Tables

Table 1: Estimates of muscle mass and body density and the anthropometric measurements they are derived from.

Reference	Estimate	Anthropometric Measures
Drinkwater and Ross 1980 [10]	Muscle mass	Skinfold corrected[a] relaxed arm, chest, mid thigh and calf girths plus forearm girth
Forsyth and Sinning 1973 [11]	Body density	Subscapula, abdominal, tricep and mid-axilla skinfolds
Thorland et al., 1984 [12]	Body density	Tricep, subscapula, mid-axilla, iliac crest, abdominal, thigh and calf skinfolds
Withers et al., 1996 [13]	Body density	Tricep, subscapula, bicep, supraspinale, abdominal, thigh and calf skinfolds

[a] Corrected girths are raw girths corrected for skinfolds by subtracting the appropriate skinfold thickness (cm) multiplied by π

Table 2: Baseline values (mean ± SD) in anthropometric measures for 20 rugby union players and proportional changes (mean ± SD) after 10 weeks of intensive training.

	Baseline	Change (%)
Body Mass (kg)	96.0 ± 10.3	-1.0 ± 2.1
Height (cm)	184.1 ± 6.8	0.1 ± 0.3
Sum of seven skinfolds (mm)	80.9 ± 23.2	-9.2 ± 9.6
Lean Mass Index ($mm.kg^{-0.14}$) [20]	53.1 ± 5.3	0.3 ± 1.5
Drinkwater and Ross 1980 [10]	47.5 ± 4.7	-0.1 ± 1.2
FFM Prediction Equations (kg)		
Forsyth and Sinning 1973 [11]	75.8 ± 7.6	2.8 ± 2.9
Thorland et al., 1984 [12]	81.0 ± 6.7	1.3 ± 2.1
Withers et al., 1996 [13]	82.1 ± 7.2	0.4 ± 1.5
Hydrodensitometry FFM (kg)		
2C	83.6 ± 6.9	0.5 ± 1.4
3C	81.7 ± 7.6	-0.1 ± 3.1
4C	81.6 ± 7.5	-0.2 ± 3.0
Body Water	82.1 ± 8.6	-0.6 ± 5.3

Table 3: Relationships between criterion (4C) fat-free mass and other estimates of body composition for baseline, post-test and change scores. Change score correlations were forced through the origin and the slope of the relationship represents the scaling to convert percent changes in the anthropometric measure to that of the criterion 4C FFM.

	Correlations (r)			Slope
	Baseline	Post	Change	(%/%, ±90%CL)
Body mass	0.90	0.88	0.07	0.12, ±0.52
Sum of seven skinfolds	0.28	0.18	0.19	-0.04, ±0.09
LMI [20]	0.96	0.97	0.37	0.76, ±0.74
Drinkwater and Ross, 1980 [10]	0.91	0.89	0.28	0.66, ±0.90
FFM Prediction Equations				
Forsyth and Sinning, 1973 [11]	0.72	0.84	0.26	0.20, ±0.29
Thorland et al., 1984 [12]	0.91	0.95	0.42	0.53, ±0.45
Withers et al., 1996 [13]	0.94	0.97	0.41	0.82, ±0.72
Hydrodensitometry FFM (kg)				
2C	0.97	0.98	0.31	0.65, ±0.79
3C	1.00	1.00	0.99	0.97, ±0.04
Body Water	0.98	0.98	0.97	0.55, ±0.06