ORIGINAL ARTICLE

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

G J Slater, G M Duthie, D B Pyne, W G Hopkins

Br J Sports Med 2006;40:208–213. doi: 10.1136/bjsm.2005.019794

See end of article for authors' affiliations

Correspondence to:
G M Duthie, Australian
Institute of Sport,
Belconnen, ACT2616,
Australia; gduthie@
nswrugby.com.auAccepted
27 September 2005**Background:** 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:** 20 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 choice, four compartment (4C) measure of lean mass for validation purposes. Regression based measures of validity, derived for within-subject proportional changes through 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 interval –0.01 to 0.66) and similar to the correlations for the other practical measures of lean mass (range 0.26 to 0.42). Standard errors of the estimate for the practical measures were in the range of 2.8–2.9%. 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.**Conclusions:** 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.

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 are 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 (computed 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 thickness measurements. Estimates of body density, fat mass, FFM, or combinations of these 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 variables and laboratory based techniques such as hydrodensitometry.⁵ To our knowledge only one previous investigation⁶ 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 or dietary interventions, or both.^{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. The lean mass index (LMI) is an empirical measure that tracks within-subject proportional changes in body mass adjusted for changes in skinfold thickness. The LMI is calculated as M/S^x , where M is the subject's body mass in kilograms, S is the sum of seven skinfolds in millimetres, and x is an exponent (0.13 for forwards and 0.14 for backs). 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 choice, four compartment (4C) model and other skinfold based measures of fat-free mass or muscle mass.

Abbreviations: BMC, bone mineral content; DXA, dual energy x ray absorptiometry; FFM, fat-free mass; LMI, lean mass index; TBW, total body water

METHODS

Subjects

Twenty Super 12 rugby players (nine forwards, 11 backs) of white, 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 an 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 four (4C) component measures, before and after 10 weeks of intensive preseason strength and conditioning training. To assess the utility of the LMI and other anthropometrically derived indices 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 minimise 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 eight hours post-prandial and in a euhydrated state. DXA measurements were undertaken within six hours of the other tests (1200–1400 h). To standardise hydration status, volunteers were provided with guidelines on maximising hydration status in the 24 hours before each assessment. Volunteers were provided with 1.0 litre of a commercially available oral rehydration solution (Gastrolyte®) following their final training session on the day before the assessments. To confirm hydration status, the specific gravity of the first void urine sample was assessed immediately, using an automated refractometer (UG-1, Atago, Tokyo, Japan).

Body composition

Anthropometry

Full anthropometric profiles, including body mass, stretch stature, sitting height, skinfolds at nine sites, 11 girths, nine lengths, and six breadths were landmarked and measured by an International Society for the Advancement of Kinanthropometry (ISAK) accredited level 3 anthropometrist (GS) with technical errors of measurement of 1.7% for sum of seven skinfolds and <1% for all other measures. Sitting height and stretch stature were measured using a Harpenden wall mounted stadiometer (Holtain, Crosswell, UK) with a precision of ± 1 mm. Skinfolds were assessed using Harpenden calipers (British Indicators, Hertfordshire, UK). Girth measurements were made with a flexible steel tape (Lufkin W606 PM, Cooper Industries, Lexington, South Carolina, USA). Lengths were assessed using a large sliding caliper (British Indicators). The majority of breadths were also measured with the large sliding caliper; biepicondylar breadths were measured with vernier calipers (Holtain). All anthropometric equipment was calibrated before 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 variables, 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 was used for all subsequent analysis.

Lean mass index

We analysed the relation 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. With certain assumptions it is possible to show that the LMI is indeed such an index and to assign a meaning to the constant x .

The first assumption is that fractional changes in skinfold thickness represent fractional changes in body fat mass. Thus, if S is skinfold thickness, F is fat mass, and Δ is a small change in a variable, we assume $\Delta S/S = \Delta F/F$. Next, we replace F/F with an expression involving small changes in total mass M and lean mass L that can be integrated. We have $M = F + L$, or $F = M - L$, therefore $F = M - L$, so:

$$\Delta S/S = \Delta F/F = (M - L)/F = M/F - L/F.$$

Now, if x is fat mass as a fraction of total mass, then $F = xM$, so $M/F = (1/x)M/M$. Also $F = xM = x(L + F)$, so $F = xL/(1 - x)$, and $L/F = L/(xL/(1 - x)) = (L/L)(1 - x)/x$.

$$\text{Therefore } \Delta S/S = [1/x]M/M - [(1 - x)/x](L/L).$$

$$\text{Rearranging, } x\Delta S/S = M/M - (1 - x)L/L.$$

Integrating, under the assumption that the small changes in S and L are insufficient to produce substantial changes in x , $x \log S = \log M - (1 - x) \log L + \log C$, where C is a constant.

$$\text{Therefore, } \log L^{(1-x)} = \log(CM/S^x), \text{ so } L^{(1-x)} = CM/S^x.$$

Thus fractional or per cent changes in M/S^x will represent fractional or per cent changes in $L^{(1-x)}$ or simply in L , for small x . Therefore M/S^x is an index for tracking small proportional changes in lean mass of individuals.

Prediction equations

Anthropometric data were used to derive estimates of muscle mass through fractionation¹⁰ or body density.^{11–13} Fractionation uses the unisex reference human or phantom to create a four way fractionation of body mass, partitioning total body mass into fat mass, muscle mass, bone, and residual mass based in individual anthropometric traits including girths, skinfold thickness measurements, and breadths. In brief, individual anthropometric data were geometrically adjusted to the height of the phantom (with known anthropometric traits, including fractionated masses) and estimates of fractionated masses were made. Thereafter, fractionated masses were scaled back to the original height of the individual. The Siri equation¹⁴ was used to convert body density to body fat (%). Fat free mass was then calculated according to the formula:

$$\text{FFM} = \text{body mass} - (\text{body mass} * \text{fat} (\%)/100).$$

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 criterion choice from which changes in anthropometrically derived data were compared, as it controls for biological variability in fat-free mass, hydration, and BMC. The 2C model is derived from body density 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 (²H₂O).

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* relaxed arm, chest, mid-thigh, and calf girths plus forearm girth
Forsyth and Sinning 1973 ¹¹	Body density	Subscapular, abdominal, triceps, and mid-axillary skinfolds
Thorland <i>et al.</i> 1984 ¹²	Body density	Triceps, subscapular, mid-axillary, iliac crest, abdominal, thigh, and calf skinfolds
Withers <i>et al.</i> 1996 ¹³	Body density	Triceps, subscapular, biceps, supraspinale, abdominal, thigh, and calf skinfolds

*Corrected girths are raw girths corrected for skinfolds by subtracting the appropriate skinfold thickness (cm) multiplied by π .

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 $^2\text{H}_2\text{O}$ (diluted with tap water) based on their body mass ($0.5 \text{ g} \cdot \text{kg}^{-1}$). The dose consumed was recorded to 0.01 g. An equilibrium period of approximately four hours 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 by 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 $^2\text{H}_2\text{O}$ 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 carried out, 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 Corporation, Fort Atkinson, Wisconsin, USA), 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 before assessment.

Statistical analysis

The LMI is intended to track proportional or per cent changes in lean mass (Duthie G M *et al.*, unpublished data). The LMI and the other measures in this study were therefore log transformed for all analyses,²⁰ because this approach converts uniform proportionality into uniform additivity (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 per cent 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 resampling 3000 times from the original data (bootstrapping). Measures of centrality and spread are shown as mean and between-subject standard deviation (SD). The magnitude of change is expressed as percentage of the baseline score with SD. Uncertainty in population values of statistics was expressed as the 90% confidence interval (CI). The typical (standard) error of measurement was calculated as the measure of within-day retest reliability.²¹ Analyses were carried out using the Statistical Analysis System (version 8.02, SAS Institute, Cary, North Carolina, USA).

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

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

	Baseline	Post scores	Change (%)
Body mass (kg)	96.0 (10.3)	95.0 (10.0)	–1.0 (2.1)
Height (cm)	184.1 (6.8)	184.2 (6.8)	0.1 (0.3)
Sum of seven skinfolds (mm)	80.9 (23.2)	73.9 (22.4)	–9.2 (9.6)
Lean mass index ($\text{mm} \cdot \text{kg}^{-0.14}$) ²⁰	53.1 (5.3)	53.3 (5.3)	0.3 (1.5)
Drinkwater and Ross 1980 (muscle mass) ¹⁰	47.5 (4.7)	47.4 (4.7)	–0.1 (1.2)
FFM prediction equations (kg)			
Forsyth and Sinning 1973 ¹¹	75.8 (7.6)	78.0 (7.9)	2.8 (2.9)
Thorland <i>et al.</i> , 1984 ¹²	81.0 (6.7)	82.0 (6.9)	1.3 (2.1)
Withers <i>et al.</i> , 1996 ¹³	82.1 (7.2)	82.4 (7.3)	0.4 (1.5)
Hydrodensitometry FFM (kg)			
2C	83.6 (6.9)	84.0 (7.0)	0.5 (1.4)
3C	81.7 (7.6)	81.5 (7.0)	–0.1 (3.1)
4C	81.6 (7.5)	81.4 (7.0)	–0.2 (3.0)
Body water	82.1 (8.6)	81.5 (7.4)	–0.6 (5.3)

Values are mean (SD).
FFM, fat-free mass.

Figure 1 (A) Two dimensional plot showing a nearly perfect relation between the four compartment (4C) estimate of fat-free mass (FFM) and lean mass index (LMI) before and after 10 weeks of pre-season training in 20 individual subjects. (B) Moderate relation between change scores for the 4C estimate of FFM and the LMI after 10 weeks of pre-season training in 20 individual subjects. Each symbol represents an individual player's change in LMI and change in 4C FFM over the 10 weeks of pre-season training. The solid line represents the mean correlation for the change scores from baseline. The dashes line is the line of identity.

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 Sinning¹¹ 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 to large.

Figure 1 shows graphically the relations of the baseline, post, and change scores of the 4C criterion measure with those of the LMI, and table 3 lists statistics for the relations 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 to 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 to moderate correlations with the criterion, although uncertainty in the correlations (confidence limits $\sim \pm 0.30$) 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 interval ± 0.17) and the Drinkwater and Ross equation (0.28; difference 0.09, confidence interval ± 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 2.8–2.9%, 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 55–65% 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

Table 3 Relations between criterion (4C) fat-free mass and other estimates of body composition for baseline, post-test, and change scores

	Correlations (r)			Slope (%/%) $\pm 90\%$ CI
	Baseline	Post	Change	
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 <i>et al.</i> , 1984 ¹²	0.91	0.95	0.42	0.53 ± 0.45
Withers <i>et al.</i> , 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

Change score correlations were forced through the origin and the slope of the relation represents the scaling to convert per cent changes in the anthropometric measure to that of the criterion 4C FFM.
CI, confidence interval; FFM, fat-free mass; LMI, lean mass index.

What is already known on this topic

- Body composition assessment of athletes is typically undertaken by measurement of body mass and subcutaneous skinfolds. Estimates of fat-free mass are then calculated using prediction equations derived from cross-sectional studies.
- These estimates may not be adequate for tracking changes in fat-free mass in individual athletes.

What this study adds

- We have developed a "lean mass index" that represents changes in body mass controlled for changes in skinfold thickness.
- The index appears to be valid for monitoring moderate to large changes in the lean mass of athletes.

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 relations 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 changes in both 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 for routine monitoring of changes in FFM.

Various 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 relations in heterogeneous populations. This was also the case in the present investigation, most probably 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 per cent change scores cannot be confounded by body mass.

In the only other validity study of changes in lean mass, van Marken Lichtenbelt *et al*⁶ observed a strong relation ($r = 0.88$) between changes in the criterion 4C model and skinfold derived estimates of FFM following eight weeks of steroid enhanced strength training. This comparatively high correlation is probably a result of large variation in the change in body composition arising from their intervention, which produced a mean change in FFM of around 5% and probably produced individual variation of a similar magnitude. In contrast, the mean change in lean mass in our athletes was only 0.1%, and the standard deviation was only 1.5%. Others have suggested 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. It also follows that error of measurement arising from physique assessment did not account for the relatively modest correlations between change scores, and therefore that a substantial component of the variation in criterion lean mass was not tracked by the practical measures of lean mass. Whether this component is related more to changes in hydration status than to muscle mass needs to be clarified with more research.

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 recognise that the slopes of the change in criterion measure/change in practical measure relation 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 that 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, or that the LMI has been derived from the longitudinal assessment of within-subject changes in mass and skinfolds, or both of these.

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.

ACKNOWLEDGEMENTS

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.

We would like to acknowledge the Australian Sports Commission, NSW Rugby Union, Royal North Shore Hospital (Sydney), and the University of Sydney.

Authors' affiliations

G J Slater, G M Duthie, D B Pyne, Australian Institute of Sport, Belconnen, ACT, Australia

W G Hopkins, Auckland University of Technology, Auckland, New Zealand

Competing interests: none declared

REFERENCES

- 1 Norton K, Olds T, Olive S, *et al.* Anthropometry and sports performance. In: Norton K, Olds T, editors. *Anthropometrika*. Sydney: University of New South Wales Press, 1996:287–364.
- 2 Olds T. The evolution of physique in male rugby union players in the twentieth century. *J Sports Sci* 2001;**19**:253–62.
- 3 Yoshiga C, Kawakami Y, Fukunaga T, *et al.* Anthropometric and physiological factors predicting 2000 m rowing ergometer performance time. *Adv Exerc Sports Physiol* 2000;**6**:51–7.
- 4 Lukaski HC. Estimation of muscle mass. In: Roche AF, Heymsfield SB, Lohman TG, editors. *Human body composition*. Champaign, IL: Human Kinetics, 1996:109–28.
- 5 Cisar CJ, Housh TJ, Johnson GO, *et al.* Validity of anthropometric equations for determination of changes in body composition in adult males during training. *J Sports Med Phys Fitness* 1989;**29**:141–8.
- 6 van Marken Lichtenbelt WD, Hartgens F, Vollaard NB, *et al.* Body composition changes in bodybuilders: a method comparison. *Med Sci Sports Exerc* 2004;**36**:490–7.
- 7 Lee RC, Wang Z-M, Heo M, *et al.* Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. *Am J Clin Nutr* 2000;**72**:796–803.
- 8 Wilmore JH, Girandola RN, Moody DL. Validity of skinfold and girth assessment for predicting alterations in body composition. *J Appl Physiol* 1970;**29**:313–17.
- 9 Norton K, Whittingham N, Carter L, *et al.* Measurement techniques in anthropometry. In: Norton K, Olds T, editors. *Anthropometrika*. Marrickville, NSW: Southwood Press, 1996:25–75.
- 10 Drinkwater DT, Ross WD. Anthropometric fractionation of body mass. In: Osiyn MD, Beunen G, Simons J, editors. *Kinanthropometry II*. Baltimore: University Park Press, 1980:178–89.
- 11 Forsyth HL, Sinning WE. The anthropometric estimation of body density and lean body weight of male athletes. *Medicine and Science in Sports and Exercise* 1973;**5**(3):174–180.
- 12 Thorland WG, Johnson GO, Tharp GD, *et al.* Estimation of body density in adolescent athletes. *Hum Biol* 1984;**56**:439–48.
- 13 Withers B, LaForgia J, Heymsfield S, *et al.* Two, three and four-compartment models of body composition analysis. In: Norton K, Olds T, editors. *Anthropometrika*. Sydney: University of New South Wales Press, 1996:199–234.
- 14 Siri WE. Body volume measurement by gas dilution. In: Brozek J, Henschel A, editors. *Techniques for measuring body composition*. Washington, DC: National Academy of Sciences, 1961:108–17.
- 15 Bell NA, McClure PD, Hill RJ, *et al.* Assessment of foot-to-foot bioelectrical impedance analysis for the prediction of total body water. *Eur J Clin Nutr* 1998;**52**:856–9.
- 16 Schoeller DA, Ravussin E, Schutz Y, *et al.* Energy expenditure by doubly labeled water: validation in humans and proposed calculation. *Am J Physiol* 1986;**250**:R823–30.
- 17 Van Der Ploeg GE, Gunn SM, Withers RT, *et al.* Comparison of two hydrodensitometric methods for estimating percent body fat. *J Appl Physiol* 2000;**88**:1175–80.
- 18 Gottfredsen A, Baeksgaard L, Hilsted J. Body composition analysis by DEXA by using dynamically changing samarium filtration. *J Appl Physiol* 1997;**82**:1200–9.
- 19 Heymsfield SB, Lichtman S, Baumgartner RN, *et al.* Body composition of humans: comparison of two improved four-compartment models that differ in expense, technical complexity, and radiation exposure. *Am J Clin Nutr* 1990;**52**:52–8.
- 20 Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med* 2000;**30**:1–15.

ELECTRONIC PAGES**Online case reports**

The following electronic only articles are published in conjunction with this issue of *BJSM* (see also page 271).

C34T mutation of the AMPD1 gene in an elite white runner

A Lucia, M A Martin, J Esteve-Lanao, *et al*

The case is reported of an elite, male, white endurance runner (28 years of age), who is one of the best non-African runners in the world despite carrying the C34T mutation in the gene (*AMPD1*) that encodes the skeletal muscle specific isoform of AMP deaminase, an enzyme that plays an important role in muscle metabolism. The frequency of the mutant allele in sedentary white people is 8–11%. Previous research has shown that this mutation, at least in homozygotes, can impair the exercise capacity of untrained people and their trainability. The maximum oxygen uptake of the study subject was exceptionally high (83.6 ml/kg/min), whereas his ammonia and lactate concentrations at high submaximal running speeds were lower than those of other world class runners who are not carriers of the mutation. The partial metabolic deficiency of the study subject is possibly

compensated for by his exceptionally favourable anthropometric characteristics (body mass index 18.2 kg/m²).

(*Br J Sports Med* 2006;**40**:e7) <http://bjsm.bmjournals.com/cgi/content/full/40/3/e7>

Rapid recovery from acute transverse myelitis in an elite female swimmer

G Dubnov, N W Constantini

Rubella is now an uncommon disease, and neurological complications are rarely encountered. One complication, acute transverse myelitis, has been described in a few case reports and usually has an unfavourable outcome. The case is presented of an elite swimmer who developed transverse myelitis after rubella, which was treated with methylprednisolone.

The recovery was so rapid and complete that two months after the acute event she broke a national swimming record.

(*Br J Sports Med* 2006;**40**:e8) <http://bjsm.bmjournals.com/cgi/content/full/40/3/e8>