The Validity of Commonly Used Adipose Tissue Body Composition Equations Relative to Dual Energy X-ray Absorptiometry (DXA) in Gaelic Games Players

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Key words
- gaelic football
- anthropometry
- DXA
- adipose tissue
- regression analysis
- hurling

Abstract

Dual-energy X-ray absorptiometry (DXA) and adipose tissue percentage estimates (AT%) derived from regression based skinfold equations were compared. 35 Gaelic games players [20.9 ± 1.7 years; 78.1 ± 8.6 kg; 179.5 ± 5.7 cm] underwent whole body fan beam DXA scans following a standardised protocol and assessment of skinfold thickness at 8 sites. Adipose tissue% from the sum of skinfolds and/or via body density were calculated for general and athlete specific equations (SKf-AT %). The relationship, i.e., proportional bias, fixed bias and random error (SEE) between DXA-AT% and AT% derived from the 6 skinfold equations were determined using least squares regression analysis. Skinfold AT% estimates were underestimated relative to DXA-AT% across all skinfold equations except that of Durnin and Wormersley [9] ($D\&W-\sum_{4AT\%}$) (16.7 ± 3.4 vs. 16.6 ± 4.0%). All equations demonstrated 95% prediction intervals ranges exceeding ~10%. Each equation failed to predict AT% relative to DXA within an accepted ± 3.5% anthropometric error rate. It is recommended that the conversion of absolute skinfold thickness to an AT% is avoided and that the skinfold equations assessed herein are not utilised in Gaelic games players. Alternate 'sum of skinfold' approaches should be considered.

Introduction

Gaelic games (hurling and Gaelic football) are the pre-eminent participation and spectator sports in Ireland [27]. Both sports may be characterised as intermittent, high intensity invasion field games. Work rate analysis indicates that players in both codes cover distances of approximately 8–10 km per match, with the exercise intensity approximating ~85% of maximal heart rates [28]. The work rate patterns and skill mix impose physiological challenges as a result of habitual training and match play which ultimately impact upon and influence the body habitus expressed by Gaelic games participants [28, 30]. Excess adiposity i.e., adipose tissue percentage (s) (AT%) exceeding 15% are undesirable and may compromise performance in Gaelic games where repeated acceleration of body mass, maintenance of sprint speed as well as contesting frequent aerial challenges where mass must be lifted against gravity occurs [8, 27, 28].

Assessment of body composition, particularly 'Body fat %' or more correctly 'adipose tissue %' [25] is often used as a default performance-profiling marker of Gaelic games players [27, 28]. In the research and applied Gaelic games settings adiposity has been solely estimated from skinfold thicknesses using generic equations to derive expressions of AT%; criterion assessment by DXA has not previously been published [27]. In particular the general equation of Durnin and Womersley [9] has been extensively used [8, 26, 37]. Wide variances in AT% estimates from this equation are reported despite players being drawn from notionally similar performance, training status and racial populations [27, 28]. To allow for the evaluation of training regimen, nutritional intervention and the comparisons across the playing population it is imperative that these skinfold equations provide representative estimates of the player's body composition.

Several issues regarding the application of Durnin and Womersley [9] and other generalised skinfold thickness equation in Gaelic games players arise. Firstly, no assessment of how well this equation and other equations characterize adiposity in Gaelic games players exists as validation with criterion models has not been undertaken. Second, skinfold equations that were developed via hydro-

accepted after revision
December 12, 2012

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DOI http://dx.doi.org/10.1055/s-0033-1333693
Published online:
July 30, 2013
Int J Sports Med 2014; 35: 95–100
© Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

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Table 1 Anthropometric characteristics of the Gaelic games players combined and by code of play. Data are Mean ± SD. DXA = Dual Energy X-ray Absorptiometry; DXA-AT % = DXA-Adipose Tissue %; DXA-BMC = DXA-Bone Mineral Content; DXA-BMD = DXA-Bone Mineral Density.

Variable	Gaelic games (n = 35)		Gaelic football (n = 20)		Hurling (n = 15)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
age (years)	20.9 ± 1.7	18.0–26.0	20.8 ± 1.2	19.0–23.0	21.2 ± 2.3	18.0–26.0
height (cm)	179.5 ± 5.7	167–194.2	179.4 ± 4.6	172–186.1	179.8 ± 7.0	167–194.2
body Mass (kg)	78.1 ± 8.6	62.4–96.9	76.9 ± 7.9	62.4–94.1	79.8 ± 9.57	65.8–96.9
DXA-Lean mass (kg)	58.7 ± 6.1	47.0–70.3	58.5 ± 5.4	47.0–66.9	59.0 ± 7.1	48.0–70.3
DXA-Fat mass (kg)	12.45 ± 4.0	6.3–24.6	11.6 ± 3.7	6.6–21.2	13.6 ± 4.2	6.3–24.6
DXA- AT %	16.6 ± 4.0	10.0–26.4	15.7 ± 3.8	10.1–23.4	17.9 ± 4.18	10.0– 26.4
DXA-BMC (kg)	2.54 ± 0.3	1.8–3.3	2.5 ± 0.3	1.8–3.1	2.58 ± 0.3	2.2–3.3
DXA-BMD ($g \cdot cm^{-2}$)	1.298 ± 0.070	1.135–1.497	1.284 ± 0.076	1.135–1.497	1.318 ± 0.061	1.24–1.441

densiometry assume the densities of tissue is constant, an argument that is no longer empirically supported [5,6,29,33,36]. Variations in gender, ethnicity, sport participation and level of performance may also act to compromise inherent assumptions about the 2-compartment model [6,38]. Subcutaneous adipose tissue distribution and debate regarding the selection of population appropriate skinfold measurement sites may also contribute to the imprecision associated with generalised prediction equations, particularly where athletic populations are assessed [11,36].

Further to these issues, consideration of the most appropriate analysis strategies to implement with regard to ‘method comparison or validation’ of these skinfold equations to criterion standard arises. Debate over validation approaches has centered upon whether it is more appropriate to adopt a regression based approach for validity assessment rather than the Bland and Altman [2] limits of agreement approach. Establishing the efficacy of a skinfold equation(s) relative to a ‘criterion standard’ has frequently being examined using the Bland and Altman 95 % limits of agreement approach [11,14,25,29]. Recently, O’Connor et al. [24] has criticised the application of the Bland and Altman [2] limits of agreement with regard to regression validation studies. This criticism proceeds on the basis that Bland and Altman [2] may indicate the presence of bias when such bias is not present. Similarly, others have highlighted such concerns [1,16,15]. The notion is expressed by O’Connor et al. [25] and others [1,16,15,24] that in validation studies where a perceived ‘gold standard’ and ‘field method’ are compared the implementation of the Bland and Altman [2] approach could lead to erroneous conclusions as to the presence of bias. Indeed, Bland and Altman [2,3] have restated this caveat several times.

Dual energy X-ray absorptiometry (DXA) represents a rapid non-invasive methodology which may eliminate such issues associated with skinfold derived estimates of body composition [33]. DXA utilises a 3 compartmental model resolving body composition components into ‘DXA defined’ fat mass, lean mass, bone mineral content and density. DXA is accepted as a current laboratory standard and has been validated against multi-compartment models for assessment of fat mass and fat free mass in athletes [35]. It has been extensively utilized as a ‘referent’ or comparison measure [25] to evaluate the efficacy of other indirect methodologies [10,11,29,32,39,40]. The aims of the present study were firstly to compare the accuracy of AT% derived from the several commonly utilised skinfold prediction equations relative to DXA and second to establish DXA derived reference values of body composition in Gaelic games players.

Methods

Participants

35 Caucasian Gaelic games players drawn from Gaelic football (n = 20) and hurling (n = 15) participated in this study (▶ **Table 1**). Participants represented a heterogeneous population drawn from club and university teams. Several (elite level) county players (n = 4) were also sampled. All players at the time of assessment were in mid-competitive season. Participants were provided with both verbal and written explanation of the study purpose and design, written informed consent was obtained. Institutional ethical approval was obtained in line with local procedures. The authors have read and understood IJSM’s ethical standards document and confirm the work conforms to these ethical standards [12].

Research design

Participants underwent an anthropometric assessment following the recommendations of the International Society for the Advancement of Kinanthropometry (ISAK) [20]. Subsequently, a DXA scan was performed in the same afternoon to minimise the impact of diurnal, environmental or training factors on within-subject variability. Participants were requested to eat and drink minimally for 2 h prior to the testing procedures [22]. All participants were asked to refrain from exercise for the period 24 h prior to assessment; compliance was confirmed verbally by each participant.

Anthropometry

Height was measured to the nearest 0.1 cm using a free standing stadiometer and body mass was determined to the nearest 0.01 kg on digital scales (Seca 702, Seca GmbH, Hamburg, Germany). Skinfold thicknesses were determined utilising standard techniques agreed by ISAK [20]. Briefly, anthropometric landmarks were identified and skinfold sites marked prior to the commencement of measurement. Skinfold thickness was determined at 8 sites (bicep, triceps, subscapular, supraspinale, iliac crest, abdominal, anterior thigh and medial calf) using Harpenden skinfold callipers (Cranlea, Birmingham, UK). Each skinfold site was measured sequentially and then repeated. Where the duplicate measure deviated from the first measurement by > 5 % the site was re-measured for a third time and the closest of the measures utilised. Adipose tissue % and body density was calculated according to the following formula: Durnin and Wormersley [9] ($D\&W-\sum_{4AT\%}$), Eston et al. [11] ($Eston-\sum_{2SKf}$ $_{\&}$ $Eston-\sum_{6SKf}$)$_{,}$ Lohman, [19], Reilly et al. [31], Withers et al. [41], Reilly et al. [29]; where appropriate the AT % was derived using Siri’s 2-compartmental model [34] (SKf-AT%). Absolute

Table 2 Least Squares regression analysis (r) of the slopes, intercepts, standard error of estimate (SEE) and the mean of the 95 % prediction interval (95 % PI) of DXA adipose tissue % vs. skinfold equations (SKf-AT %) in Gaelic games players.

Equation	Mean ± SD	Slope	Intercept	SEE	r	Mean 95 % PI $^{\#}$
DXA	16.6 ± 4.0	–	–	–	–	
D&W – $\sum_{4AT\%}$ (1974)	16.7 ± 3.4	0.90 (0.61–1.18)	1.61 (− 3.24–6.45)	2.76	0.74$^{¥}$ (0.54–0.86)	5.78 (11.56)
Lohman (1981)	11.6 ± 2.8	1.15 (0.84–1.47)	3.27 (− 0.51–7.05)	2.54	0.79$^{¥}$ (0.62–0.88)	5.32 (10.64)
Withers et al. (1998)	12.2 ± 3.1	1.03 (0.75–1.31)	4.10 (0.58–7.62)	2.52	0.79$^{¥}$ (0.62–0.89)	5.28 (10.56)
Eston et al. (2005) – $\sum_{2SKf}$	15.4 ± 3.5	0.91 (0.66–1.17)	2.62 (− 1.14–6.64)	2.57	0.78$^{¥}$ (0.61–0.88)	5.38 (10.76)
Eston et al. (2005) – $\sum_{6SKf}$	14.4 ± 3.5	0.96 (0.74–1.18)	2.84 (− 0.41–6.09)	2.25	0.84$^{¥}$ (0.70–0.91)	4.71 (9.42)
Reilly et al.(2009)	11.7 ± 1.7	1.86 (1.37–2.36)	− 5.21 (− 11.05–0.62)	2.48	0.80$^{¥}$ (0.63–0.89)	5.19 (10.38)

¥ significantly correlated with DXA. # PI ranges may be calculated by multiplying the 95 % PI interval by 2 (Ranges are in parentheses).

skinfold thickness (mm) was calculated for the sum of 4, 5 and 8 sites respectively; ($\sum_{4\ SKf:}$ biceps, triceps, subscapular, iliac crest), ($\sum_{5\ SKf:}$ biceps, triceps, subscapular, iliac crest, anterior thigh) and ($\sum_{8\ SKf:}$ bicep, triceps, subscapular, supraspinale, iliac crest, abdominal, anterior thigh and medial calf).

Dual energy X-ray absorptiometry (DXA)

All participants underwent whole body fan beam measurement of body composition by DXA using standardised in-house protocols (Hologic QDR, Discovery A, Bedford, MA, USA. software version 12:4:3). Prior to each set of data acquisitions. DXA system calibration was carried out using an anthropometric spine and step phantom with a subsequent radiographic uniformity scan. Briefly, prior to the DXA scan participants were questioned about recent exposure to ionizing radiation and the presence of orthopaedic or other medical implants; where present participants were required to remove all jewellery and piercings. Participants then lay supine on the DXA scanner bed and were positioned within the scanning area with the arms by the side of the body, with the palmar surface of the hand orientated toward the lateral aspect of the thigh, fingers and toes were pointed to ensure standard positioning. A foam spacer was placed between the hand and lateral aspect of the thigh to ensure even spacing. Once positioned, participants were instructed to remain still for the duration of the scan; total scan time was ~180 s. All scans were administered and analysed by the same experienced operator. In the present study we report the sub-total percentage adipose tissue i. e., whole body minus the head (DXA-AT %) on the recommendation of Wallace et al. [40] who indicate that this component measure of DXA represents stronger associations and reduced measurement error than with DXA defined total (whole body) adiposity.

Statistical analysis

Descriptive statistics for the data under consideration are presented as mean ± SD. Data were explored using boxplots and Q-Q plots. Differences in age, height, body mass and DXA defined AT %, Bone Mineral Content (BMC) Bone Mineral Density (BMD), fat mass and lean mass between playing codes were determined using paired t-tests. The strength of association between individual skinfold sites and DXA estimates of AT% was assessed using Pearson (r) correlation analysis. A least squares regression approach was used to assess the validity of the 6 AT% equations, where the DXA estimates of adiposity (DXA-AT %) were regressed against each skinfold AT % equation separately [16, 15]. The potential for any fixed bias was assessed by determining whether the intercept for the regression was different from zero. Similarly, to identify if proportional bias was present the slope of the regression line was assessed to determine if it was different from 1. The random error was quantified using the standard error of the estimate from the regression. Visual inspection of the residual plots (standardised residual on standardised predicted) was carried out to determine if the random error was uniform along the range of measures taken. To evaluate the predictive accuracy of each equation for individuals, the 95 % prediction interval (95 % PI) for each regression equation was also calculated. As these vary in size along the range of measurements, means of each predictive interval were calculated. Additionally, we adopted an a priori definition of acceptable anthropometric error rate i. e., ± 3.5 % in line with previous suggestions from both an applied [18] and statistical perspective. Statistical significance was established at an alpha level of $P \le 0.05$. Statistical analyses were carried out using SPSS for windows version 17 (PASW, Chicago, IL).

Results

▼

Descriptive characteristics of the combined Gaelic games population and by respective playing code are presented in ▶ **Table 1**. No significant difference in age, height, and body mass between codes was apparent.

Correlation analysis

All SKf-AT % estimates derived from each equation correlated with DXA-AT % values presenting a diverse range of correlations (*r*) and overlapping 95 % confidence intervals ($P < 0.05$; ▶ **Table 2**). Strong associations, between DXA-AT % and skinfold thickness (mm) were apparent for the sum of $\sum_{8SKf}$ ($r = 0.77$, $P < 0.05$; 95 % CI: 0.59–0.87), [29], $\sum_{5SKf}$ ($r = 0.78$, $P < 0.05$; 95 % CI: 0.60–0.88) [31], and $\sum_{4SKf}$ ($r = 0.71$, $P < 0.05$; 95 % CI 0.50–0.84) [9]. Each individual skinfold site's association with DXA-AT % was also determined; all sites were positively correlated with DXA-AT % ($P < 0.05$). Correlations (*r*) and 95 % confidence intervals between each skinfold site and DXA-AT % varied considerably. The highest correlations were identified between DXA-AT % and anterior thigh, triceps and medial calf respectively (▶ **Table 3**).

Regression analysis

The relationship between DXA-AT % and AT % derived from the 6 skinfold equations was explored using least squares regression analysis in order to identify if any bias (proportional or fixed) was present and to quantify the random error. The slopes, intercepts and the standard error of estimates (SEE) together with 95 % prediction intervals are presented (▶ **Table 2**). The random error associated with each predictor equation was relatively similar across the prediction equations with the smallest value being 2.48 (Reilly et al. [29]) with the largest being 2.76 (Durnin and Wormersley [9]). The 95 % PI for each equation were also similar in magnitude with the highest being 5.78 (Durnin and Wormersley [9]) and lowest 4.71 (Eston – $\sum_{6SKf}$ [11]). The potential for any bias was assessed by visual inspection of the regression line (▸ **Fig. 1**). Estimates of AT% using D&W – $\sum_{4AT\%}$ showed the least amount of bias with the regression line being close to the line of unity. The slopes and positions of the regression lines for Lohman [19] and Withers et al. [41] provide strong evidence for the presence of fixed bias that results in underestimation of AT%. There was less fixed bias for Eston – $\sum_{2SKf}$ [11] and Eston – $\sum_{6SKf}$ [11] and the influence of this within the range of current measurements was reduced by both equations having a slope less than one (see ▸ **Table 2**). Adipose tissue % derived from the equation of Reilly et al. [29] demonstrated a strong negative fixed bias (see intercept column of ▸ **Table 2**). However, the slope of the line was considerably higher than one, which resulted in values that underestimated AT% compared to those gained from DXA.

Table 3 The relationship (r) and 95% Confidence Intervals (CI) between individual skinfold sites and DXA-adipose tissue % (DXA–AT %) in Gaelic games players (n = 35).

Skinfold Site	DXA (r)	95% CI.
Biceps	0.38	0.06–0.63
Triceps	0.73	0.53–0.85
Sub-Scapular	0.65	0.41–0.81
Supra-Spinale	0.65	0.41–0.81
Iliac-Crest	0.60	0.33–0.77
Abdominal	0.45	0.14–0.68
Anterior Thigh	0.77	0.59–0.88
Medial Calf	0.66	0.42–0.81

Discussion

Several commonly utilised skinfold prediction equations were examined using a least squares regression approach to determine their efficacy in estimating AT% relative to DXA which acted as a 'criterion comparison measure'. Present findings indicate that of the 6 skinfold equations evaluated 5 i.e., Eston – $\sum_{2SKf}$, Eston – $\sum_{6SKf}$ [11], Lohman, [19], Reilly et al. [29] and Withers et al. [41] underestimated SKf-AT% relative to the DXA-AT% and provided 95% prediction intervals which are unacceptable relative to a priori 'practical' criteria [18]. The relative magnitude of underestimation across equations ranged from negligible to considerable (▸ **Table 2**). The athlete specific equation of Withers et al. [41] has been consistently reported in this laboratory as effective in assessing body composition in athletic populations (soccer players) relative to the 3 compartment DXA model [29, 39]. The inability of this and the other equations [11, 29] to quantify AT% accurately in Gaelic games players may reflect a phenotypical divergence from the athletic populations upon which the Withers et al. [41] equation and the others were generated. It may also explain why in other elite groups the Withers et al. [41] equation maintains its efficacy [29, 39]. Although recent reports suggest that confluence between the population characteristics upon on which an equation was generated and that on which it is applied does not necessarily predispose towards accuracy in the derived predictions of AT% [25].

In contrast to the other equations, the general equation of D&W – $\sum_{4AT\%}$ [9] provided AT% estimates which although demonstrating coincidence with DXA-AT% expressed a clear lack of precession i.e. the prediction intervals in which 95% of the estimates would be expected to lie between the methods was very

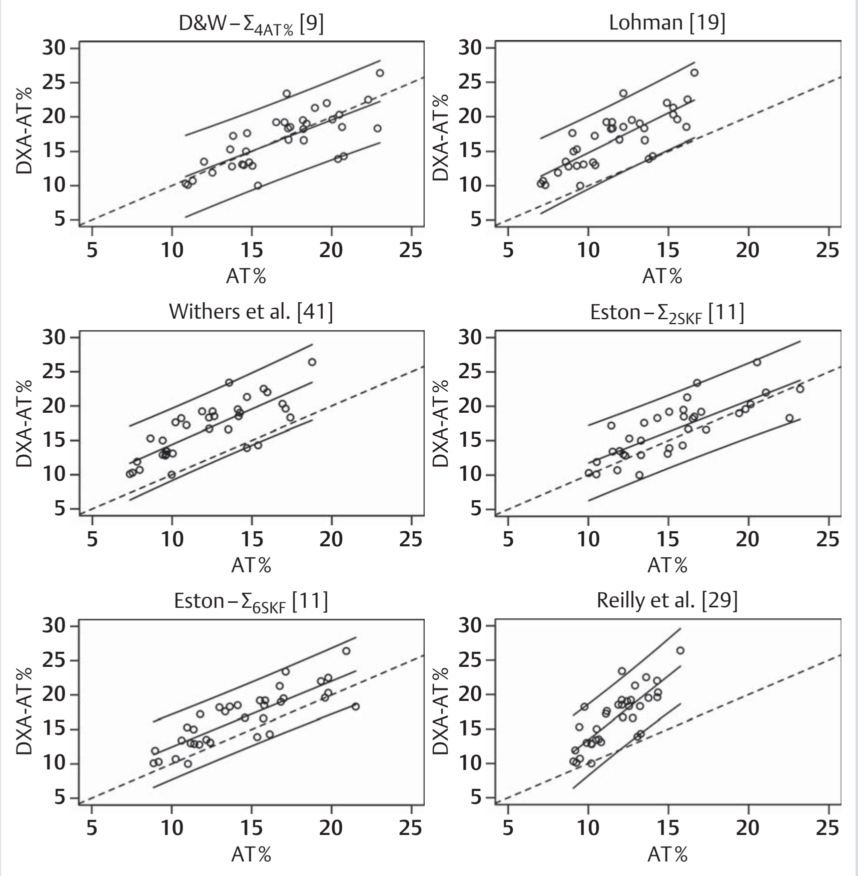

Fig. 1 Least squares regression plots of DXA adipose tissue % (DXA-AT%) versus skinfold equations adipose tissue % (AT %) for Gaelic games players. Plots indicate line of Unity [broken line], line of regression and 95% Prediction Intervals [solid lines]. D&W – $\sum_{4AT\%}$ = Durnin & Wormersley [9]; Eston – $\sum_{2SKf}$, = Eston et al. (11) sum of 2 skinfolds; Eston – $\sum_{6SKf}$ = Eston et al. (11) sum of 6 skinfolds.

wide ~12%. This level of divergence is not only expressed in the $D\&W-\sum_{4AT\%}$ [9] equations but in all 6 equations. The standard error of the estimate or typical error [16] which represents difference between the prediction and criterion measure was compared to those presented when the equations were developed. In the present study the typical error was lower ($D\&W-\sum_{4AT\%}$ [9]; Lohman [19]), similar (Withers et al. [41]), or greater (Eston et al. [11]; Reilly et al. [29].) than original SEE estimates. These variances in typical error relative to the original equations may reflect methodological and population difference used in their derivation.

Importantly, these typical and 95% PI errors indicate anthropometrically important discrepancies between the skinfolds equations estimates of AT% and DXA, which must negate their effective application in these Gaelic games players. This is consistent with Heyward et al. [14] who has indicated that whilst skinfold equations may provide an accurate estimate of mean body composition, e.g. AT% at the group level, it may not reflect that accuracy when applied on an individual basis. Practically, if we assume a player has an estimated 'adipose tissue %' of 16.0%, based on the equation of $D\&W-\sum_{4AT\%}$ [9] the 'DXA value' could lie within a region as low as 10% or as high as 22%. Therefore, the 95% PI indicates each equation provides unacceptable estimates of error relative to a priori 'practical' criteria [18], despite each equation correlating significantly with DXA-AT%.

This regression based approach with prediction intervals emphasises that it is critical for practitioners to be cognisant of the potential error inherent in these approaches and consider whether the estimates derived from them can effectively be applied to the context in which they are working, i.e., is the potential imprecision in the estimates acceptable for the task they are being applied to. Lohman, [18] has outlined a hierarchy of anthropometric error values for indirect body composition assessment methods defining practical thresholds for acceptable and unacceptable error values equivalent to <3.5% and >5% AT%, respectively. In implementing this taxonomy a priori we sought to establish a clear decision threshold as to whether or not to accept AT% estimates derived from the prediction equations under consideration. The application of such criteria with regard to the acceptance of a typical error or prediction interval estimates 'upfront' is not unusual [14].We concur with the sentiment of others who have indicated that $D\&W-\sum_{4AT\%}$ may provide unacceptable individual estimates of AT% in athletic populations although such concordance is approached via different methodological strategies, i.e., Bland and Altman 95% limits of agreement [11,40].

The imprecision, i.e., wide prediction intervals associated with the application of these equations is well documented and, may reside with a number of issues; including violations of generic assumptions upon which many skinfold equations are predicated. Such factors include the uniformity of tissue density, subcutaneous adipose tissue distribution and adaptive responses in tissue density as a result of habitual training [11,25,38]. Present estimates of body density exceed estimates ascribed to these standardised assumptions [5,6]. Whilst such factors must be considered important and contributory to the imprecision noted (▶ **Table 2**), the anthropometrist skills and technical error of measurement are equally critical. The provision of field-based anthropometric support is frequently delivered by non-ISAK accredited personnel. In such circumstances the potential for measurement error exists and may further obfuscate the utility of the skinfold equation(s) utilised [17,25].

Given the lack of coincidence between SKf-AT% and DXA-AT% estimates in the present Gaelic games players consideration must be directed toward the veracity of AT% reported in the Gaelic games literature. In particular, the formula of $D\&W-\sum_{4AT\%}$ has been extensively applied in elite and club level players to derive AT% estimates which range from 11.5–18% [4,7,8, 28,30,37]. Given the wide 95% PI associated with the $D\&W-\sum_{4AT\%}$ equation presented herein, it may be problematic to accept these literature derived estimates as representative. It will be necessary to revisit AT% ratings in Gaelic games populations at all levels of participation with other models of body composition. The present DXA-AT% estimates of ~16% for Gaelic football and 18% for the hurlers initiates that process and places the players in the current study along the upper end of values reported in the literature. In accepting a DXA defined rating of adiposity as a 'comparison value', it must be remembered that DXA represents an indirect body composition method which is subject to measurement error particularly in light of several recent papers on the importance of scanning protocol [23,22]. As such DXA itself contributes to the imprecision in assessing agreement between body compositional methods despite its generally held attribution as 'a gold standard' [13]. Recent caveats regarding the viability of DXA as a 'comparison method' must be considered [5,33].

In light of this uncertainly it may be more effective, particularly in the 'field setting' to use an alternate approach. Reilly et al. [31] and others [21] have recommended using the absolute skinfold thickness measurement expressed in their original units (mm) as a surrogate of adiposity, tissue distribution and as a means of tracking changes in subcutaneous adiposity. Eston et al. [11] also support such a view indicating that where poor agreement exists, a strong rationale for the abandonment of prediction equations in favour of an absolute skinfold measure may be preferable. Critical to the efficacy of the absolute skinfold approach is the selection of appropriate skinfold measurement sites relative to the population under consideration. In Gaelic games the equation of Durnin and Wormersley [9] uses skinfold measurement sites drawn exclusively from the upper body. This regional partitioning may be unrepresentative of the adipose tissue distribution seen in Gaelic footballers and hurlers where both the upper and lower limbs contribute to skill execution and performance. In athletic populations the selection of both upper and lower body skinfold sites may provide a more representative picture of whole body adiposity [11,31]. In support of this view the $\sum_{5-SKf}$ expressed in absolute terms (mm) provides a much stronger correlation with DXA-AT% than with the $\sum_{4SKf}$ alone in the current population. The inclusion of the anterior thigh i.e. $\sum_{5SKf}$ would seem to proffer an advantage in adiposity assessment over simply reporting the $\sum_{4SKf}$ upper body skinfold sites [29]. The addition of several other skinfold sites i.e., $\sum_{8SKf}$ does not improve this association which is consistent with previous reports [29].

Conclusions

The skinfold equations evaluated herein provided unacceptable error estimates of SKf-AT% relative to DXA-AT% values and cannot be regarded as appropriate to implement when estimating adiposity in Gaelic games players. This recommendation is predicated on the imprecision of AT% estimates and the wide 95% PI ranges which fail to conform to accepted error terms for anthropometric assessment. The application of these equations in this population should be avoided. As an alternate, we recommend the adoption of absolute skinfold thickness across a variety of upper and lower body measurement sites i. e., $\sum_{5-\mathrm{SKf}}$ expressed in their original units (mm) to provide a marker of adiposity as previously suggested by Reilly et al. [31].

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