Application of a Sub-set of Skinfold Sites for Ultrasound Measurement of Subcutaneous Adiposity and Percentage Body Fat Estimation in Athletes


Abstract

Body composition assessment is an integral feature of elite sport as optimization facilitates successful performance. This study aims to refine the use of B-mode ultrasound in the assessment of athlete body composition by determining suitable sites for measurement. 67 elite athletes recruited from the Human Performance Laboratory, University College Cork, Ireland, underwent dual measurement of body composition. Subcutaneous adipose tissue thickness at 7 anatomical sites were measured using ultrasound and compared to percentage body fat values determined using Dual-Energy X-ray Absorptiometry. Multiple linear regressions were performed and an equation to predict percentage body fat was derived. The present study found subcutaneous adipose tissue depths at the triceps, biceps, anterior thigh and supraspinale sites correlated significantly with percentage body fat by X-ray absorptiometry (all p<0.05). Summation of the depths at these locations correlated strongly with percentage body fat by Dual-Energy X-ray Absorptiometry ($R^2=0.879$). The triceps, biceps, anterior thigh and supraspinale sites are suitable anatomical landmarks for the estimation of %BF using B-mode ultrasound. Use of B-mode ultrasound in the assessment of athlete body composition confers many benefits including lack of ionising radiation and its potential to be used as a portable field tool.

Introduction

Success in elite sport is determined by many inherent variables including ability, skill, technique and physical attributes. To gain a potential competitive edge, attention focuses on modifiable physical traits, of which body composition is universally targeted with considerable success [4, 8, 12]. In the modern sporting arena, elite athletes are accustomed to regular body composition assessment as a metric of both health and fitness status. Many athletes strive to reduce percentage body fat (%BF) values as part of their training goals. Current modalities used in the assessment of %BF are considered cumbersome, time-consuming, expensive and inaccurate [11, 16]. All %BF assessment techniques are subject to some degree of methodological error and there is significant variability between tests. Skinfold thickness measurement using callipers is the most commonly used %BF assessment technique [16]. However, its use may be prone to tester bias and poor inter-tester reliability [5, 6]. Multi-compartment models are suitable for use as a validation criterion against which to compare other %BF estimation methods [1]. Unfortunately, these techniques are time-consuming and often impractical when measuring large numbers of athletes. Likewise, 3-compartment model evaluation of athlete %BF with Dual Energy X-ray Absorptiometry (DXA) has its limitations. Of particular relevance is the significant degree of error in %BF estimation of leaner individuals [24–26]. The radiation dose administered with DXA is comparatively low to other imaging modalities. However, professional athletes may accumulate substantial radiation doses within their playing careers if several assessments are required over consecutive playing seasons. Furthermore, DXA availability is largely restricted to the hospital setting and to the campuses of national sporting organizations [16]. Recently, the application of B-mode (brightness mode) ultrasound has emerged as an accurate and efficient modality for %BF measurement with potential for field use at local training facili-
ties [19]. The use of ultrasound for %BF measurement has so far been largely confined to Europe, used by only 4% of medical and scientific groups studied worldwide [16]. Ultrasound can be used for the measurement of adipose tissue layer depth [13] and studies have trialled ultrasound to extrapolate total %BF [21]. In comparison to skinfold measurement using callipers, ultrasound has the potential to reduce inter- and intra-operator variability through the use of pre-programmed algorithms. In addition, ultrasound measurement of subcutaneous adipose tissue thickness has previously demonstrated high levels of concordance between operators [17]. However, this works on the premise that the ultrasound probe is placed correctly onto the subject. Currently, there is no consensus as to the most accurate and reliable ultrasound sites to measure and how best to relate subcutaneous adipose tissue thickness values at these sites to total %BF [18,21]. The aim of this study was to determine distinct anatomical sites that are accurate for ultrasound assessment of subcutaneous adipose tissue thickness in the estimation of total %BF in athletes. In addition, using a combination of these anatomical sites we aim to derive a simple equation to allow accurate prediction of %BF using ultrasound-measured subcutaneous adipose tissue thickness.

Materials and Methods

Participants

Athletes were recruited from the Human Performance Laboratory of the Mardyke Arena in University College Cork (UCC), Ireland. These high-level athletes comprise elite collegiate sports scholarship recipients and previous external attendees of the laboratory. Both male and female athletes aged greater than 18 years were included. To attain a sufficient diversity of body compositions, no athletes were excluded based on the type of sport engaged. For inclusion, all athletes were required to be active in their sport at the time of the study. Athletes were invited by email to voluntarily enrol in the study. Those willing to participate were provided with pre-measurement preparation details, including instructions to avoid prolonged or intense exercise for 24-h prior to measurement and to avoid consumption of large meals before their visit [20,23]. Ethical approval was obtained from the Clinical Research Ethics Committee of the Cork teaching hospitals and all athletes provided informed consent prior to participation in accordance with principles outlined in the declaration of Helsinki. Likewise, the study methods met the ethical standards of the International Journal of Sports Medicine [10].

67 athletes (50 male, 17 female) responded to the study invitation. All athletes fulfilled the inclusion criteria. The most common sport was triathlon with 13 participants, followed closely by athletics (Table 1). Sporting disciplines ranged from professional race-walkers to members of national team squads (e.g., rugby union and field hockey). The mean %BF by DXA was 16.9% (5.5) (Table 2).

Body composition assessment by DXA

Both DXA and B-mode ultrasound assessments were performed during a 60-min assessment in Cork University Hospital in Spring 2014. A 3-compartment DXA model was used as the criterion measure of %BF in this study [9]. At each measurement session, the same investigator (OC) performed total body scans of the athletes using the same calibrated apparatus: a GE Healthc Care Lunar iDXA (Madison, Wisconsin, USA). The enCORE software (version 13.4, 2010) was used for scan analysis and region %BF values were calculated (Region %BF=Fat mass/(Fat + Lean + Bone mass)).

Body composition assessment using B-mode ultrasound

Subcutaneous adipose tissue thickness was measured to 0.1 mm at 7 ISAK (International Society for the Advancement of Kinanthropometry) recognized sites: triceps, biceps, subscapular, supraspinale, abdominal, anterior thigh and medial calf [15]. These sites were chosen due to their ease of accessibility, widespread use, and because they span both upper and lower limbs in addition to the trunk. At each session, the same investigator (DON) identified and marked these sites on the right-hand side of the body with a felt tip pen. A different investigator (SON), a specialist registrar in radiology, blind to the athletes’ DXA results, subsequently measured subcutaneous adipose tissue thickness at the 7 sites using a GE Logiq E9 ultrasound machine (GE medical systems, Milwaukee, Wisconsin, USA). A thick layer of gel was applied to the skin overlaying the previously marked sites and a lightweight ‘hockey-stick’ probe (GE L8-18i-SC) was used to assess subcutaneous adipose tissue depth. The ultrasound was switched to the musculoskeletal application, to measure at a frequency of 15 MHz, with a gain of 53 dB to a depth of 3 cm. The probe was rested on the thick gel layer avoiding compression of the underlying skin and subcutaneous adipose tissue, a technique previously described by Muller et al. [18]. Dissipation of the gel layer from the ultrasound image on screen was indicative of excessive compression. For consistency and to ensure operator ease and access during scanning, biceps, triceps and subscapular sites were imaged with the athlete seated while supraspinale, abdominal, anterior thigh and medial calf sites were assessed while supine. Upper limb sites were measured with the elbow fully extended and lower limb sites measured with the knee flexed to 90 degrees.

Table 1

<table>
<thead>
<tr>
<th>Number of participants by sport, divided by category</th>
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<tbody>
<tr>
<td><strong>Athletics</strong></td>
</tr>
<tr>
<td>Middle distance running: 9</td>
</tr>
<tr>
<td>Long distance running: 8</td>
</tr>
<tr>
<td>Race walking: 4</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Baseline Characteristics of Participants (n=67)</th>
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</thead>
<tbody>
<tr>
<td><strong>BMI (kg/m²)</strong></td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>23.2</td>
</tr>
</tbody>
</table>

* %BF (DXA) = Percentage body fat by the reference standard, Dual-energy x-ray absorptiometry; b BMI = Body mass index; c Std. Dev = Standard deviation.
To determine the ultrasound sites that best predict %BF as compared to the criterion measure, DXA. Multiple regression models were evaluated. The most accurate model, which incorporated a summation of subcutaneous adipose tissue depths at 4 anatomical sites, was used to derive a %BF prediction equation. The accuracy of this equation in the prediction of %BF was evaluated from the determination coefficient $R^2$ between true and estimated values of %BF and the standard error of the estimate (SEE) as described by Lohman [14]. Agreement between body composition estimates were examined by calculating the 95% limits of agreement as described by Bland and Altman [3]. The student’s paired t-test was used to compare mean %BF estimation using the ultrasound-derived equation to mean %BF estimates by DXA. For all analysis $p < 0.05$ was considered statistically significant.

### Results

Multiple linear regression analyses were conducted using the ultrasound measurement of subcutaneous adipose tissue depth at the 7 ISAK sites. This analysis found strong individual associations between 4 of the assessed sites and %BF as measured by DXA. The 4 sites identified as having the strongest associations were: biceps, triceps, supraspinale and anterior thigh. Regression coefficients are shown in Table 3. The summation of subcutaneous adipose tissue depths (mm) at these 4 identified anatomical sites correlated strongly with %BF by DXA; $p < 0.001$ and $R^2 = 0.879$. In contrast, summation of measurements at all 7 ultrasound sites ($R^2 = 0.749$) was not as significant as the 4-site model. Multiple linear regression analyses were performed using a backward elimination approach to develop a model for predicting %BF from ultrasound-derived subcutaneous adipose tissue depths at the 4 identified sites. Several models were evaluated and the equation to best predict %BF was: Percentage body fat = (0.476 × the sum of subcutaneous adipose tissue depths at triceps, biceps, supraspinale and anterior thigh sites) + 1.846

The equation was applied to the summation of subcutaneous adipose tissue at the 4-sites measured in the athletes. The resulting mean %BF = 16.9% with a standard error of the estimate of 1.9% and limits of agreement of 3.7.

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**Table 3** Multiple linear regression coefficients of the 7 selected ultrasound sites.

<table>
<thead>
<tr>
<th>Ultrasound site (Variable)</th>
<th>Unstandardized B</th>
<th>Standardized error</th>
<th>Standardized Beta</th>
<th>Level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triceps **</td>
<td>0.329</td>
<td>0.102</td>
<td>0.242</td>
<td>0.002</td>
</tr>
<tr>
<td>Biceps *</td>
<td>0.374</td>
<td>0.169</td>
<td>0.163</td>
<td>0.031</td>
</tr>
<tr>
<td>Subscapular</td>
<td>0.040</td>
<td>0.083</td>
<td>0.028</td>
<td>0.634</td>
</tr>
<tr>
<td>Supraspinale ***</td>
<td>0.534</td>
<td>0.093</td>
<td>0.380</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Abdominal **</td>
<td>−0.004</td>
<td>0.042</td>
<td>−0.005</td>
<td>0.919</td>
</tr>
<tr>
<td>Anterior thigh **</td>
<td>0.590</td>
<td>0.181</td>
<td>0.300</td>
<td>0.002</td>
</tr>
<tr>
<td>Medial calf</td>
<td>0.100</td>
<td>0.180</td>
<td>0.051</td>
<td>0.580</td>
</tr>
</tbody>
</table>

Asterisks denote level of significance. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$
Discussion

Our data identified 4 anatomical sites that are suitable for the measurement of subcutaneous adipose tissue thickness and subsequently for the estimation of athlete %BF using ultrasound: biceps, triceps, supraspinale and anterior thigh. Sports physicians, athletic trainers and exercise physiologists commonly use these well-defined ISAK sites in the estimation of %BF by measuring skinfold thickness with callipers. These sites are easily accessible by ultrasound with minimal technical difficulty in assessing adiposity depth.

Selection of anatomical sites for ultrasound measurement

From the linear regression analysis the 4 sites selected for the final model span the upper and lower limbs in addition to the trunk, facilitating derivation of an equation applicable to athletes with contrasting body morphologies and participating in a diverse range of sports (i.e., upper body vs. lower body predominant). The inclusion of 3 limb sites in our 4-site ultrasound-derived equation is an advantage as these sites have previously been found to have low rates of non-evaluable images when measured by non-experienced ultrasound users [17, 18]. Error in the measurement of subcutaneous adipose tissue thickness, from the dermal-adipose border to the adipose-muscle fascia border, is attenuated by the presence of distinctly visible layers at the 4 selected sites (Fig. 1).

We found in this group of athletes that subcutaneous adipose tissue depth at the other measured ISAK sites did not show a significant correlation to %BF. The subcapsular site proved technically difficult to assess due to difficulty in interpreting the presence of additional structures and adiposity depth, a difficulty noted elsewhere [17, 18]. Furthermore, exclusion of the abdominal site eliminates the need for recognition and interpretation of Camper’s fascia, which has previously been identified as an obstacle to accurate measurement of adiposity [17, 18].

Prediction of athlete body fat using ultrasound equation

The novel ultrasound-derived equation compared favourably to the criterion measure used in this study, 3-compartment DXA evaluation. Summation of the depth of subcutaneous adipose tissue at the 4 selected sites showed a very strong correlation with %BF by DXA. This ensures that the novel ultrasound-derived equation is highly similar to the widely used and standardized laboratory measure of %BF, the 3-compartment DXA model. We have sampled a cohort of elite and sub-elite athletes with a variety of baseline clinical characteristics. The diversity within the sample group is demonstrated by the range of body fat values, absolute weights and athlete ages recorded (Table 2), in addition to the large number of sports played (Table 1). This suggests that the described ultrasound technique is applicable to athletes participating in a range of sports and of a variety of body composition profiles. As none of the athletes recruited in this study were found to have %BF values greater than 30%, the applicability of the 4-site ultrasound equation to these populations should not be assumed. Likewise, caution should be exerted when extrapolating %BF estimations using the ultrasound technique in individuals with a body fat of between 25% and 30% as only 2 athletes in our study are within this range. Lower degrees of variation from the criterion measure were found when the ultrasound technique was applied to those athletes with %BF values of 15% or less (Fig. 3). This suggests that the degree of error is greater as absolute %BF increases. This is likely due in part to the increased risk of compression error in individuals with greater quantities of subcutaneous fat. Avoiding subcutaneous tissue compression is an important consideration in insuring the accuracy of the proposed %BF assessment method.

Limitations and directions for future research

This current study has a number of limitations. Choice of a 3-compartment DXA model as the reference criterion may have been improved by the use of a 4-component model or other established modalities such as bioelectrical impedance analysis or air displacement plethysmography. The use of a 4-component model has the advantage of not assuming constant hydration of athletes’ fat free mass unlike DXA measurement, thus reducing another potential source of error. Likewise, the accuracy of this ultrasound method to detect fluctuations in %BF reliably over time is unknown. Before the use of ultrasound to estimate %BF is widely practiced and recommended, this is an important feature that requires investigation. Furthermore, this study does not examine the accuracy of this ultrasound technique when performed by non-radiology trained practitioners. However, recent work has indicated that the use of B-mode ultrasound by non-radiologists in the measurement of subcutaneous adipose tissue is consistent and accurate [17, 18]. Unlike assessment of body composition by DXA, the described ultrasound technique does not provide information regarding lean tissue or muscle mass, a critical component in the monitoring of improved fitness and body composition profiles. Ultrasound does have the potential to do so via the measurement of muscle thickness, muscle cross sectional area and fascicle length [22]. The practice of ultrasound assessment of body composition is in its infancy and will undoubtedly require modification and refinement before it is established as a widespread field tool. Future work should aim to improve inter- and intra-observer reliability using the B-mode ultrasound technique as well as addressing the other limitations outlined above.
In contrast to laboratory-based assessments such as DXA, bio-electrical impedance, air displacement plethysmography or hydrostatic weighing, ultrasound has a number of advantages: a shorter measurement time; its potential as a portable tool; and no ionising radiation is applied. Additionally, ultrasound assessment of body composition is unlikely to be affected by intake of large carbohydrate meals prior to measurement. This appears to be the case with DXA [23]. While the expense of acquiring an appropriate machine may deter practitioners, ultrasound usage among sports medicine physicians for purposes beyond musculoskeletal injury evaluation is also increasing [2,7]. Refinement of the B-mode ultrasound technique may lead to the inclusion of body composition assessment as a core competency for future trainees in sports ultrasound.

Conclusion

This study has identified 4 suitable sites for the measurement of subcutaneous adipose tissue depth using ultrasound and an equation to estimate %BF in athletes. By summing the subcutaneous adipose tissue depths at specific, well-defined anatomical landmarks, we have described a favourable and alternative field technique for the assessment of %BF in athletes. To the best of our knowledge this is the first published study to do so in an exclusively athletic population, across a range of absolute weights and BMI values. Ultrasound can be applied with a degree of accuracy similar to DXA for body composition assessment in athletes. Future work should refine and standardize this technique further and examine its role and applicability when used by non-radiology trained professionals.

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Conflict of interest: The authors have no conflict of interest to declare.

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