Title

Assessing Fat Mass of Adolescent Swimmers Using Anthropometric Equations: A DXA Validation Study

Running head

Body fat assessment in adolescent swimmers

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Abstract

Purpose: The aim of the present study was to determine which of the published anthropometric equations is the most appropriate to estimate body-fat percentage ($BF_{\%}$) in adolescent swimmers. **Methods:** Eighty-eight swimmers (45 boys / 43 girls) participated in this study. Following the recommendations of the International Society of the Advancement of Kinanthropometry (ISAK), biceps, triceps, sub-scapular, iliac-crest, supraspinale, front-thigh and medial calf skinfold thickness were measured. Waist, hip, mid-thigh, calf, relaxed arm and arm flexed and tensed girths were also registered. $BF_{\%}$ was measured with DXA to obtain the reference value. Existing anthropometric-equations were applied and $BF_{\%}$ results obtained from anthropometric-equations were compared to DXA $BF_{\%}$ results with modified Bland-Altman. **Results**: The Flavel, Durnin-Rahaman-Siri and Durnin-Rahaman-Brozek were the only equations that did not demonstrate statistically significant differences when compared to DXA. **Conclusion**: The present study showed that the best anthropometric equation from existing literature to estimate $BF_{\%}$ in SWI is that proposed by Durnin-Rahaman (independently of applying the Siri or Brozek equation).

Keywords: Swimming; Body composition; Teenagers; Water.

Assessing Fat Mass of Adolescent Swimmers Using Anthropometric Equations: A DXA Validation Study

It is widely known that increases in fat mass are related to several cardiovascular and metabolic pathologies (Cordova, Villa, Sureda, Rodriguez-Marroyo, & Sanchez-Collado, 2012), and that active people show lower body-fat percentages ($BF_{\%}$) and better general health (Thompson, Karpe, Lafontan, & Frayn, 2012) than sedentary people. Moreover, body composition in athletes is directly related with performance in many sport modalities (Avlonitou, Georgiou, Douskas, & Louizi, 1997), and assessing body composition during adolescence allows scientists and coaches to obtain useful information regarding nutritional status, health and performance related variables.

There are several methods to assess body composition and estimate $BF_{\%}$; hydrostatic weighting and air displacement plethysmography (ADP) are the current reference methods for adults. However, these methods are based on a two-compartment model, which assumes that fat mass and fat free mass are 0.9 g/cc and 1.1 g/cc for adults. Nevertheless, Lohman et al. (1986) proposed an alternative solution and established age and sex specific constant values for children to calculate $BF_{\%}$. It has been recently stated that the reference method for children should involve a four-compartment model (Silva, Fields, & Sardinha, 2013), which is impractical for most researches because of its cost, time involvement and poor compliance in children (Silva et al., 2013). Therefore, dual-energy X-ray absorptiometry (DXA) has been used by several researches as a reference method to develop specific anthropometric equations (Silva et al., 2013), as it is an accurate and reliable device to evaluate body composition (Crook, Armbya, Cleves, Badger, & Andres, 2012). However, DXA is expensive and needs a specific body composition laboratory to be performed. Nevertheless, there are other simpler and more accessible techniques such as anthropometric measurements for the evaluation of body composition and the estimation of $BF_{\%}$.

In order to be accurate, anthropometric equations should be as specific as possible and prove themselves to be accurate and reliable for the specific group they were designed for. Several anthropometric equations designed for youth (Carter, 1982; Deurenberg, Weststrate, & Seidell, 1991; Faulkner, 1968; Slaughter et al., 1988) have been compared to $BF_{\%}$ estimated with DXA in order to examine their validity in children (Eisenmann, Heelan, & Welk, 2004), and adolescents (Rodriguez et al., 2005). Specific anthropometric equations have been designed for different populations in order to estimate $BF_{\%}$, as each population might present different anthropometric characteristics. However, to our knowledge, no studies have focused in determining an accurate anthropometric equation for adolescent swimmers who present lower $BF_{\%}$ than sedentary controls (personal findings).

Therefore, the aim of this study was to determine which of the published anthropometric equations is the most adequate to estimate $BF_{\%}$ in adolescent swimmers.

Methods

Participants

A total of 88 Caucasian adolescent swimmers participated (45 boys / 43 girls) in the study from different swimming clubs of Spain.

Possible benefits and risks derived from the participation in the study were explained to adolescents and their parents. Written informed consent was obtained from parents and assent was obtained from adolescents. The study was performed following the ethical guidelines of the Declaration of Helsinki 1961 (revision of Fortaleza 2013). The protocol study was approved by the Ethics Committee of Clinical Research from the Government of Aragón (ref.CP08/2012, CEICA; Spain), and is explained in detail elsewhere (Gomez-Bruton, Gonzalez-Aguero, Casajus, & Vicente-Rodriguez, 2014).

Inclusion criteria

In order to be included in the present study, participants had to be between 11-18 years old, currently swimming for more than 6 hours per week and for a period of at least 3 years.

Exclusion criteria

Participants older than 18 years, taking drugs that could affect body composition or non-Caucasian were excluded. Ethnicity, that was self-reported, was considered as an exclusion criteria due to the known effects that ethnicity has on body composition (Ortiz et al., 1992) and therefore on skinfold equations. One participant was non-Caucasian and thus excluded from the final sample.

Anthropometric measurements and anthropometric equations

Height was measured with a stadiometer without shoes and the minimum clothes to the nearest 0.1 cm (SECA 225, SECA, Hamburg, Germany) and weighted to the nearest 0.1 kg (SECA 861, SECA, Hamburg, Germany). Body mass index (BMI) was calculated as the division between weight (kg) and squared height (m^2). Following the recommendations of the International Society of the Advancement of Kinanthropometry (ISAK) (Marfell-Jones, Stewart, & Marfell-Jones, 2006) biceps, triceps, sub-scapular, iliac-crest, supraspinale, front thigh and medial calf skinfolds were measured by a level 2 ISAK anthropometrist. Waist, hip, mid-thigh, calf, relaxed arm and arm flexed and tensed girths were also registered.

Total body density was estimated via Durnin and Rahaman equation (1967) and then inserted in Siri (1993) and Brozek (1963) equations to estimate $BF_{\%}$. In addition, $BF_{\%}$ was directly estimated via Slaughter et al. (1988), Flavel et al. (2012), Faulkner et al. (1968) and Deurenberg et al. (1991), all described in Table 1.

Body fat measurement with DXA

Whole body $BF_{\%}$ was calculated with a DXA QDR-Explorer (Hologic Corp. Software version 12.4, Waltham, MA). DXA scans were completed with the same device and software and performed by the same technician who had been fully trained in the operation of the scanner, the positioning of participants, and the analysis of results, according to the manufacturer´s guidelines. The coefficients of variation of the BMC, BMD and bone area at whole body in our laboratory were 2.3%, 1.3% and 2.6% respectively (Gracia-Marco et al., 2012).

Statistical analysis

Results are presented as mean ± standard deviation (SD). The studied variables showed normal distribution tested with the Kolmogorov-Smirnov test.

Differences between methods (DXA vs. each equation) were analyzed by paired t-test. Bonferroni corrections were applied to control for the potential inflation of multiple comparisons, and therefore, the p value 0.05 was divided by six (number of comparisons that were done). Consequently, only those equations that presented differences with DXA $BF_{\%}$ at a level of $p<0.008$ were considered to present statistically significant differences. The 95% limits of agreement (1.96*SD of the inter-methods differences) and confidence intervals (inter-methods difference ± 95% limits of agreement) were calculated for each equation. In addition, agreement between DXA and each equation was determined according to modified Bland-Altman plots (Krouwer, 2008). Inter-method differences were plotted against the reference method (in this case $BF_{\%}$ measured with DXA) instead of the mean value because the reference method was expected to be closer to the "true value" than the mean (Krouwer, 2008). Heteroscedasticity was examined with the Koenker test (Koenker, 1981) to determine whether the inter-methods difference was associated with a change in the estimation variance. When p value was lower than 0.05, the equation compared to DXA demonstrated heteroscedasticity.

Effect size statistics using Cohen´s d (G*Power version 3.1.9.2 for Mac OS X) were calculated for paired t-test. Taking into account the cut-off established by Cohen, the effect size d can be small (0.2 – 0.5), medium (0.5 – 0.8) or large (>0.8) (Cohen, 1992). Statistical significance was set at $p < 0.05$. All the statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS) version 19.0 for Windows (SPSS Inc., Chicago, IL, USA).

Results

Descriptive results are summarized in Table 2. Boys presented higher age, height, weight and body mass index (BMI) than girls. All participants presented a BMI between 15 and 28.

Estimated $BF_{\%}$ with different equations, inter-method differences and 95% limits of agreement and heteroscedasticity of each prediction equation against DXA are summarized in Table 3. Slaughter, Flavel, Faulkner and Deurenberg equations underestimated $BF_{\%}$ between 1.07 and 6.81 points compared to DXA values (Table 3; Cohen´s d ranged from 0.28 to 2.18). The Flavel and Durnin-Rahaman (either using Siri or Brozek) were the only equations that did not show statistically significant differences when compared to DXA. The equations showed 95% limits of agreement between 5.35 and 8.88, being the Durnin and Rahaman-Siri equation the one with lowest 95% limits of agreement. Moreover, the Durnin and Rahaman (either using Siri or Brozek) equation presented the lowest effect size (Cohen´s d = 0.17 and 0.03 for Siri and Brozek respectively), suggesting that the differences found between $BF_{\%}$ from DXA and the equations were very small. None of the equations presented heteroscedasticity (Table 3).

Figure 1 represents the modified Bland–Altman plots for the different equations. All the plots present a positive slope when ideally they should present a horizontal linear slope. Consequently, for higher values of DXA $BF_{\%}$ the existing equations will underestimate $BF_{\%}$.

Discussion

The main finding of the present study was that from the existing anthropometric equations the Durnin and Rahaman (independently of applying the Siri or Brozek equation) (Brozek et al., 1963; Durnin & Rahaman, 1967; Siri, 1993) and Flavel equations (2012) showed no statistically significant differences in the estimation of $BF_{\%}$ when compared to DXA. Nonetheless, the Durnin and Rahaman equations presented the lowest 95% limits of agreement and lowest mean differences and we would therefore recommend the use of these equations to assess BF% in adolescent swimmers.

The chosen equations are the most used equations to calculate $BF_{\%}$ in children and adolescents (Deurenberg et al., 1991; Durnin & Rahaman, 1967; Faulkner, 1968; Flavel et al., 2012; Slaughter et al., 1988). In fact, to date many studies have used the previously mentioned equations to estimate $BF_{\%}$ in swimmers (Richardson, Beerman, Heiss, & Shultz, 2000; Zuniga et al., 2011), without a clear definition on which one better fits their body shape and morphological characteristics. Thus, due to the fact that a specific equation for adolescent swimmers has not been developed yet, it seemed timely to determine which equation was the most appropriate to estimate $BF_{\%}$ in this population.

A review performed by Silva et al. (2013) reported that Slaughter et al. (1988) was the most adequate equation to estimate $BF_{\%}$ in children and adolescents; however, in this study, Durnin and Rahaman (1967) equation has demonstrated higher accuracy than Slaughter et al. (1988) equation to estimate $BF_{\%}$ in adolescent swimmers. Both Slaughter et al. (1988) and Durnin and Rahaman (1967) equations were developed among general population (non-athletic populations). Thus, the use of 4 skinfolds for estimating $BF_{\%}$ in the Durnin and Rahaman (1967) equation compared to the use of 2 skinfolds by the Slaughter et al. (1988) equation could favour the accuracy of the estimation of $BF_{\%}$ by the Durnin and Rahaman et al. (1967) equation.

Although the Durnin and Rahaman and Flavel were the only equations that did not show statistically significant differences when compared to DXA, the Bland-Altman plots showed that the Durnin and Rahaman equations demonstrated the lowest data dispersion. The Bland-Altman plot regression lines suggest that all equations are underestimating $BF_{\%}$ in participants with higher $BF_{\%}$, as when DXA $BF_{\%}$ is higher, the difference between methods (DXA – equation) also becomes higher, and ideally the difference should always be near zero. On the other hand, for participants with lower $BF_{\%}$, it seems like anthropometric equations will overestimate $BF_{\%}$ as when DXA $BF_{\%}$ is low, the difference between methods (DXA – equation) is negative (for most equations), suggesting that the predicted $BF_{\%}$ is higher than the measured $BF_{\%}$ with DXA.

Due to the common characteristics of sports practiced in water, all involving a high amount of training hours and demanding both the lower and upper limbs to move with a high energy expenditure (vigorous swimming and water polo have been both rated with 10 METs) (Ortiz et al., 1992), it is possible that these populations present similar body composition and thus it would be interesting to validate the present findings in other water athletes.

This study presents a methodological main limitation, as the reference method, DXA, uses a three-compartment model while the gold standard model for measuring $BF_{\%}$ in children and adolescents is the four-compartment model (Silva et al., 2013). However, some studies have evaluated the validity of DXA to assess $BF_{\%}$ in adolescents. Crook et al. (2012) found DXA to be a better tool than ADP to evaluate $BF_{\%}$ when they were both compared to deuterium oxide dilution in preschoolers. In addition, Maddalozzo et al. (2002) found that DXA was a valid tool to measure $BF_{\%}$ in young adults when it was compared to ADP. Nevertheless, DXA is known to underestimate $BF_{\%}$ in children and adolescents (Silva et al., 2013). A subsample of the present study was measured with ADP, bioelectrical impedance analysis, anthropometry and DXA, finding different $BF_{\%}$ with each technique.

Nonetheless, in a healthy population like a group of swimmers, the $BF_{\%}$ number might not be as important as the change in that number. If non-specific equations are used, it is possible that the $BF_{\%}$ we get is under- or overestimating real $BF_{\%}$, but more importantly, it is possible that changes in $BF_{\%}$ are not well tracked.

The study also presents several strengths. Firstly, the sample size, being bigger than other comparable studies of similar characteristics (88 vs. 45 (Reilly et al., 2009) or 26 (De Lorenzo et al., 1998)). And secondly, this is the first study aiming to evaluate which previously anthropometric equation for children and adolescent is the most appropriate to estimate $BF_{\%}$ in adolescent swimmers.

In conclusion, the results of this study demonstrated that the equation of Durnin and Rahaman (either Siri and Brozek equations) (Brozek et al., 1963; Durnin & Rahaman, 1967; Siri, 1993) is the most appropriate equation to use in adolescent swimmers from existing anthropometric equations in literature. On the other hand, future studies that develop and validate specific anthropometric equations for adolescent swimmers are recommended.

What does this study add?

The present study has found that the Durnin and Rahaman (with Siri or Brozek equation) is the best equation to assess $BF_{\%}$ in adolescent swimmers. Therefore, the present study can guide coaches towards which anthropometric equation is the best one to use in adolescent swimmers.

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