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Original Research

Estimation of Body Fat Percentage in Jockeys: Implications for a Weight Category Sport

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ABSTRACT

International Journal of Exercise Science 13(4): 511-525, 2020. The assessment of body composition in horse racing, a unique weight-restricted sport, provides an important health and performance indicator. The accuracy of skinfold prediction equations at estimating % body fat (% BF) was compared with dual-energy X-ray absorptiometry (DXA) data in a group of professional Irish jockeys (age 27.5 ± 7.7 years). Body composition was assessed in seventy-two male professional jockeys (flat n=35 and national hunt n=37) using standardised guidelines for skinfold thickness at 8 sites and DXA body fat assessment. Hydration status was assessed using urine specific gravity (Usg) to determine if participants were euhydrated and male specific prediction equations (Durnin and Womersley, Evans, Lohman, Reilly, Withers and Zemski) were selected to estimate % BF. Jockey-group specific equations were developed using the collected dataset. The selected equations underestimated % BF with variability between equations ranging from 7% to 10% compared to the DXA % BF of 15%. Flat jockeys were significantly lighter and shorter ($p < 0.05$) compared to national hunt jockeys resulting in the need for individual jockey-specific equations. The Flat and National Hunt Jockey specific equations demonstrated overall agreement accounting for 84% and 83% variance, respectively. Caution must be taken when using existing prediction equations due to the variability of % BF relative to DXA. Jockey-specific equations offer an alternative method for interpreting estimated body fat %.

KEY WORDS: Body composition, DXA, horse racing, skinfold equations, anthropometry

INTRODUCTION

Body composition profiling is an important health and performance practice which is used in clinical and athletic populations to guide dietary interventions and monitor training regimes (1,24). Assessment of body composition and its precision has advanced in recent times as high performance athletes in weight class, gravitational and aesthetic sports use these measurements of body proportion and composition to monitor growth and the effectiveness of training and nutritional manipulation (1,19). In the case of weight-sensitive sports, athletes seek an advantage for competition qualification, performance and adjudication by maintaining a low body mass sometimes using unhealthy methods such as severe dehydration and disordered eating to achieve and sustain the desired weight (19,24). For this specific athletic population, accurately quantifying fat mass and fat free mass is a priority as the effects of extremely low body fat may increase the risk of injury and severe medical problems such as low bone density and cardiovascular and gastrointestinal complications (1,37).

In horse racing, achieving a low body fat plays an essential role in the unique challenge faced by jockeys to align their body mass with the stipulated weight of the horse they ride in each race (41). As a weight-category athlete, a low body mass is also necessary for racing eligibility. Jockeys can compete at amateur and professional level with weight classifications in Ireland ranging from 52.7 to 64 kg and 62 to 76 kg for flat and national hunt jockeys respectively (40). Previous research has shown that jockeys have to typically reduce their body mass on average by 4% in the 48 hours before racing (10) or in some cases as much as 6.7% (4.5 kg) in less than 24 hours before racing (42). Such rapid weight loss before racing typically by severe dehydration can lead to suboptimal performance including reduced plasma volume and decreased muscle strength (10,39). Furthermore, jockeys are also required to weigh-in immediately before and after every race that they ride therefore restricting the opportunity to replenish energy and fluid stores depleted in making weight. In comparison, the weigh-in for other weight category sports such as boxing, wrestling and lightweight rowing take places 24 hours beforehand and is only required prior to competition thereby allowing time for the athlete to re-hydrate and re-fuel (40). Other weight classification sports also have a set number of competitions across a designated season, in horse racing there is no defined offseason (40). This often leads to jockeys competing 10 – 12 months of the year, sometimes 7 days a week with typically several races each day (8,41). Consequently, jockeys are placed in a situation of compromised health and performance as the weight allocations, largely variable and unpredictable, result in extreme methods of dieting and dehydration (40). The long-term implications are largely unknown as conflicting research has shown an increased prevalence of osteoporosis and high blood pressure in retired jockeys from the UK not Ireland (7,22).

Estimating body fat in athletic populations is commonly assessed using field-based methods such as skinfold thickness and bioelectrical impedance and laboratory based equipment like air displacement plesmography (BodPod) and Dual energy X-ray absorptiometry (DXA)(2,3). The laboratory based methods can be invasive, costly, time-consuming and require technical expertise and therefore may be impractical and inaccessible. Despite this, DXA is becoming an increasingly popular method for assessing body composition particularly amongst elite athletic populations (25). Furthermore, DXA is recognised by the International Olympic Committee as the preferred method for measuring absolute body composition and is now widely accepted as a practical criterion method for assessing fat mass and fat-free mass in athletes (3,12). This is supported in clinical sport science and medicine research as it provides excellent reproducibility and is often used as the criterion method from which other body composition measurements are validated (15,38). However, the feasibility of DXA remains a barrier for some athletes while the cumulative exposure to radiation as a result of diagnostic procedures (X-ray and CT-scan) for injury diagnosis limits the frequency it can be used (1,6). Alternatively, field-based methods are an accessible and practical means for monitoring change in body fat, as they are cost effective, simple to use and time efficient. In particular, the assessment of skinfold thickness has no limit to usage allowing for repeated measurements throughout the season. However, estimating percentage body fat (% body fat) requires prediction equations, which can introduce huge variability in results (36).

A large number of prediction equations have been developed (examples including Durnin and Womersley, Evans, Lohman, Reilly, Withers and Zemski) to estimate % body fat using skinfolds. The accuracy of each equation is affected by a number of factors including the group of athletes or range of sports included in the equations design, the skinfold callipers used and the location of assessment sites (24). As a result, large variability has been reported in estimating % body fat when using prediction equations due to the diversity of body types across various sports and the use of unstandardised assessment methods (36). Previous studies estimating % body fat in jockeys have used DXA and a variety of equations including Withers et al. (1987) and Durnin & Womersley (1974)(10,30,40). However, using different equations for the same cohort could introduce measurement error and can limit comparisons between the same cohorts. As weight-making athletes, jockeys require a specific-equation to estimate % body fat as their unique body type differs, particularly to other sport-specific equations like soccer (31) and rugby (44). A standardised prediction equation for jockeys would also provide accurate body fat reference ranges thus protecting jockeys against the adverse effects of chronic weight-cycling and severe dehydration such as impaired reproductive health and heat stroke (23,39).

The aim of this study therefore was to 1) compare the accuracy and variability of available prediction equations at estimating % body fat in a group of professional jockeys relative to DXA and 2) develop and assess the validity of a jockey-specific prediction equation using anthropometric variables.

METHODS

Participants

Professional jockeys with a current racing licence were invited to attend a one off testing session to assess body composition via DXA and skinfold thickness. The testing session also included an assessment of body mass, height and hydration status. Given the extensive commitments of the jockeys recruited, it was not possible to standardise the time of day of testing. However participants were advised to avoid exhaustive exercise in the previous 24 hours, be euhydrated, have voided and fasted or have eaten only lightly (<500 g)(18) before attending the testing session. Written informed consent was provided by each participant. Since a racing licence is permitted at 16 years of age, minors were also included in this study. For these participants, they provided participant assent and parental consent prior to participation in the study. The study was approved by the university ethics committee and the research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (29).

Seventy-two professional male jockeys (flat n=35 and national hunt (also known as jump) n=37) participated in the study. Participants were recruited through racecourse advertising, medical officer referral and word of mouth. Participants were injury free with an average of 10.1±8.1 years (flat 10.6±10.1 years and national hunt 9.7±5.7 years) of competitive riding experience.

Protocol

Hydration Status: Hydration status was estimated from urine samples provided at the start of the testing session. Urine specific gravity (Usg) was measured with a handheld refractometer (Atago, USA). As classified in previous research euhydration was defined by a Usg of ≤ 1.020 (32).

Anthropometrics: Body mass was assessed with participants in minimal clothing using electronic scales (SECA, Vogel & Halke GmbH, Hamburg, Germany) measured to the nearest 0.1 kg. Height was measured with a stadiometer incorporated in the scale to the nearest 1 cm. An International Society for the Advancement of Kinanthropometry (ISAK) level 2 accredited anthropometrist (technical error of measurement (TEM) of 2.5% for skinfolds) performed all skinfold measurements in line with standardised ISAK procedures (34) using Harpenden calipers (British Indicators, Hertfordshire, UK) to 0.1 mm accuracy. Skinfold measurements included the following eight skinfold sites; triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, mid-thigh, and medial calf. All measures were taken twice in a cyclical fashion. If the difference between duplicate measures exceeded 5% for skinfolds, a third measurement was taken. The mean of duplicate or median of triplicate measurements was used for all subsequent analysis.

Six prediction equations were selected: Durnin and Womersley (11); Evans (14); Lohman (20); Reilly (31); Withers (43) and Zemski (44). Selection was based on common use in the assessment of % body fat in athletic populations, male specific and use of some or all of the specified ISAK sites.

Dual X-ray absorptiometry: A total body scan was performed on all participants using DXA (Lunar Prodigy, GE Healthcare, Madison, WI, software version 16). Scanning protocols were implemented using the techniques previously described to maximise technical reliability and minimise error (28). Briefly, participants were positioned supine, hands mid-prone with feet inverted using velcro positioning aid. One trained technician performed and interpreted all examinations to ensure consistency.

Statistical Analysis

Data analyses were carried out using SPSS 25 (SPSS Inc., Chicago, Illinois, USA). Descriptive statistics were calculated and presented as mean ± standard deviation (SD) [range: minimum to maximum]. The Kolmogorov – Smirnov test was used to assess normality. An independent t-test was performed to explore the differences of descriptive statistics between jockey groups.
Multiple regression analysis using the enter method was conducted to obtain the best model for a jockey-specific prediction equation. The enter method was chosen as it ensured complete

representation of total body fat in both jockey groups. DXA % body fat was used as the dependent variable and predictor variables included the 8 skinfold sites and age. Body mass was not included as a variable in the equation due to the acute influence of weight change in this athletic population and also the logistical issues with standardisation (18). The R square was used to explain the variance between the developed equation and the DXA derived body fat %. A p-value of < 0.05 indicated statistical significance for this study.

Paired t-test and Pearson correlations were used in establishing the difference and relationship of % body fat between DXA and the 6 different skinfold prediction equation. Correlation coefficients were ranked by magnitude as; negligible, $0.0 < r < 0.30$; low, $0.30 < r < 0.50$; moderate, $0.50 < r < 0.70$; high, $0.70 < r < 0.90$; very high, $0.90 < r < 1$ (16).

A Bland-Altman plot was used to assess bias and possible trends between the % body fat of DXA and each individual prediction equation including a jockey-specific equation. The Bland-Altman method provided a subjective assessment with the difference between DXA and each prediction equation plotted against the mean of the two measurements within 95% limits of agreement (4). The variability and precision of each plot were visually inspected assessing for proportional bias, trends and distance between limits of agreement.

RESULTS

Descriptive characteristics: Physical characteristics and descriptive values of hydration and sum of 8 skinfolds are reported in Table 1. Flat jockeys were significantly lighter (mean = 56.1 kg, p = 0.001) and smaller (mean = 167.2 cm, p = 0.001) compared to national hunt (mean = 65.5 kg, mean = 174.6 cm) jockeys. Based on the mean data for Usg the group were classified as hydrated (1.018 ± 0.007) with a 95% confidence interval between 1.017 and 1.020.

Table 1. Physical characteristics for all jockeys.

	All (n = 72) Mean±SD (range: min to max)	Flat (n = 35) Mean±SD (range: min to max)	National hunt (n = 37) Mean±SD (range: min to max)
Age (yrs)	27.5 ± 7.7 (17.0 – 51.0)	27.5 ± 9.6 (17.0 – 51.0)	27.5 ± 5.4 (20.0 – 39.0)
Body mass (kg)	60.9 ± 5.7 (49.6 – 77.0)	56.1 ± 3.2* (49.6 – 63.0)	65.5 ± 3.4 (58.9 – 77.0)
Height (cm)	171.0 ± 6.2 (154.9 – 184.0)	167.2 ± 5.5* (154.9 – 178.6)	174.6 ± 4.5 (166.3 – 184.0)
Sum 8 skinfolds (mm)	46.0 ± 10.3 (26.6 – 78.7)	44.1 ± 10.2 (26.6 – 78.7)	47.7 ± 10.5 (29.3 – 74.1)
Hydration (Usg)	1.018 ± 0.007 (1.004 – 1.033)	1.018 ± 0.007 (1.004 – 1.028)	1.018 ± 0.007 (1.005 – 1.033)

***** p <0.05 significant difference flat and national hunt

Agreement between estimated body fat percentage from DXA and prediction equations: Body fat % ranged from 6.9% to 14.8% depending on the body composition method and prediction equation used. The DXA-derived % body fat was greater than that of the selected prediction equations (Table 2). The prediction equations showed a significant moderate to high positive correlation (r from 0.63 to 0.77) with DXA (Table 2). The Lohman (r=0.77) followed by Reilly and Evans (r=0.76) equations reported the highest correlation values amongst the prediction equations.

Table 2. Mean percentage body fat, correlations, bias and limits of agreement between DXA and prediction equations.

Equation	Mean % Body fat [95% CI]	Correlation [95% CI]	*p* - value	Difference	
				Bias ± SD	**LoA**
DXA	14.8 [14.2 – 15.2]	-	-	-	-
Zemski	10.1 [10.0– 10.4]	0.63 [0.5 – 0.8]	<.001	-4.7 ± 2.0*	-0.7 to -8.7
Reilly	9.2 [9.0 – 9.4]	0.76 [0.6 – 0.8]	<.001	-5.6 ± 1.9*	-2.0 to -9.3
Evans	8.0 [7.8 – 8.4]	0.76 [0.6 – 0.8]	<.001	-6.8 ± 1.7*	-3.5 to -10.1
Lohman	8.9 [8.5 – 9.5]	0.77 [0.7 – 0.9]	<.001	-5.9 ± 1.7*	-2.6 to -9.3
Withers	6.9 [6.7 – 7.3]	0.74 [0.6 – 0.8]	<.001	-7.9 ± 1.7*	-4.5 to -11.3
D&W	7.1 [6.8 – 7.8]	0.66 [0.5 – 0.8]	<.001	-7.7 ± 2.0*	-3.9 to -11.6

*p < 0.001, significant difference DXA and skinfold prediction equations. Data presented as mean [95% Confidence Interval (CI)], Pearson correlation coefficient (r), p – value, Bias ± SD and LoA = Limits of Agreement. D&W= Durnin and Womersley skinfold prediction equation

Bland-Altman plots are presented in Figure 1. The equations of Lohman and Durnin & Womersley indicate no bias however both presented wide limits of agreement (-2.6 to -9.3 and -3.9 to -11.6, respectively) across the range of body fat scores (Table 2). Contrary, the Evans, Reilly, Withers and Zemski equations all displayed a poor level of agreement with features of proportional bias.

Development of Jockey Specific Equations: Different physical characteristics between jockey groups indicated the need for separate % body fat prediction equations to be developed for flat jockeys and national hunt jockeys. The enter method was used to predict the variance for both jockey groups. The total variance explained by the Flat Jockey model was 84%, $F(9, 25) = 14.9$, $p = 0.001$. The National Hunt Jockey model explained a total variance of 83%, $F(9, 27) = 14.2$, $p = 0.001$.

Equation 1. Flat Jockey

% body fat = 5.561 + (0.035 x Age) + (0.394 x Tricep) + (-0.121 x Subscapular) + (0.184 x Bicep) + (0.413 x Iliac crest) + (0.257 x Supraspinale) + (0.285 x Abdominal) + (0.168 x Mid-thigh) + (-0.265 x Medial calf)

Equation 2. National hunt Jockey

% body fat = 8.012 + (0.26 x Age) + (-0.497 x Tricep) + (-0.103 x Subscapular) + (0.083 x Bicep) + (0.376 x Iliac crest) + (-1.073 x Supraspinale) + (0.647 x Abdominal) + (0.318 x Mid-thigh) + (0.967 x Medial calf)

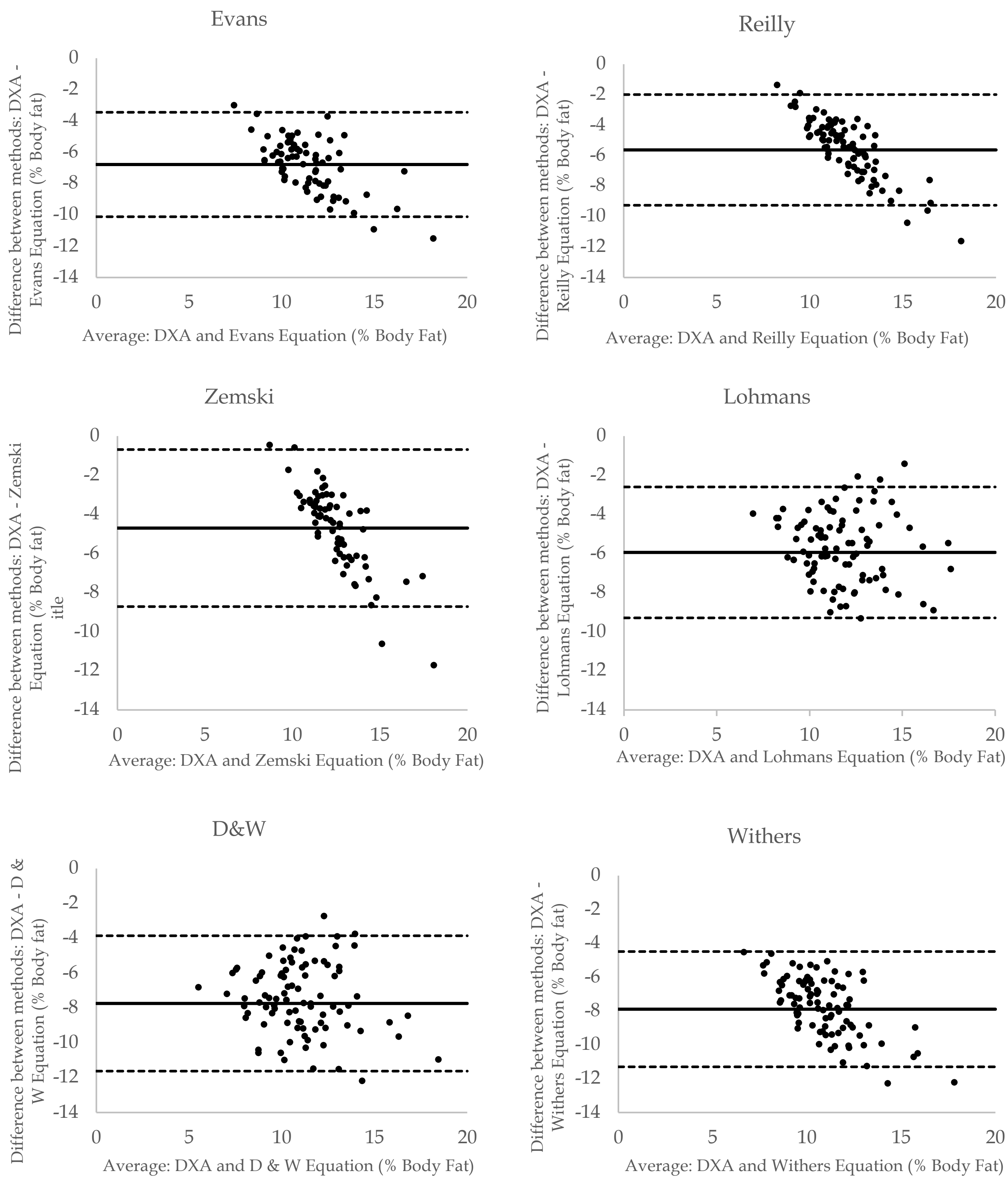

Figure 1. Bland-Altman plots comparing the % body fat between DXA and the selected prediction equations. The centre line represents the mean difference between methods and broken lines represent 95% upper and lower limits of agreement (bias ± 1.96 × standard deviation). D&W= Durnin and Womersley skinfold prediction equation.

Agreement of Jockey Specific Equations: Data from the flat and national hunt jockeys are presented in Table 3. Both jockey specific equations, 'Flat Jockey' and 'National hunt Jockey', reported the highest correlations compared to the selected prediction equations, r = 0.92 and 0.91 respectively.

Table 3. Relationship between % body fat derived from DXA and prediction equations

Groups	Equation	Mean % Body fat [95% CI]	Correlation [95% CI]	p - value
Flat Jockeys	DXA	15.0 [14.0 – 16.0]	-	-
	Zemski	10.0 [9.7 – 10.4]	0.69 [0.5 – 0.8]	.001
	Reilly	9.0 [8.7 – 9.4]	0.84 [0.7 – 0.9]	.001
	Evans	7.8 [7.3 – 8.2]	0.86 [0.7 – 0.9]	.001
	Lohman	8.4 [7.6 – 9.3]	0.87 [0.8 – 0.9]	.001
	Withers	6.6 [6.2 – 7.1]	0.85 [0.7 – 0.9]	.001
	D&W	6.6 [5.8 – 7.3]	0.82 [0.7 – 0.9]	.001
	Flat Jockey	15.0 [14.1 – 15.9]	0.92 [0.8 – 1.0]	.001
National hunt Jockeys	DXA	14.6 [13.9 – 15.3]	-	-
	Zemski	10.2 [9.9 – 10.5]	0.58 [0.3 – 0.8]	.001
	Reilly	9.3 [9.0 – 9.7]	0.75 [0.6 – 0.9]	.001
	Evans	8.3 [7.7 – 8.8]	0.74 [0.6 – 0.9]	.001
	Lohman	9.3 [8.5 – 10.0]	0.70 [0.5 – 0.8]	.001
	Withers	7.2 [6.7 – 7.7]	0.70 [0.4 – 0.8]	.001
	D&W	7.5 [6.8 – 8.2]	0.54 [0.3 – 0.7]	.001
	NH Jockey	14.6 [14.0 -15.0]	0.91 [0.8 – 1.0]	.001

Data presented as mean [95% Confidence interval (CI)], Pearson correlation coefficient (r) [95% CI] and p - value in a group of flat jockeys and national hunt and jockeys. D&W = Durnin and Womersley skinfold prediction equation

The Bland-Altman plots between DXA and the jockey specific equations (Figure 2) showed overall agreement with no bias for the Flat Jockey (bias±SD (± limits of agreement) = 0.0±1.2 (-2.2 to 2.3)) and National Hunt Jockey (bias±SD (95% limits of agreement) = 0.0±0.9 (-1.7 to 1.7)) equations.

DISCUSSION

The study aimed to compare the accuracy and variability of prediction equations at estimating % body fat relative to DXA in a group of professional jockeys. Findings from this study suggest that commonly used prediction equations display considerable variability in the assessment of % body fat and underestimate % body fat relative to DXA in a group of professional jockeys. The equations of Lohman and Durnin and Womersley appear to consistently underestimate % body fat without bias in jockeys relative to DXA. In contrast, the Zemski, Reilly, Evans and Withers equations demonstrated proportional bias whereby % body fat was underestimated to a greater extent in jockeys with higher levels of body fat compared to those with lower levels of body fat. This highlights the need for caution when interpreting % body fat in jockeys from previous research as different equations have been used as well as DXA.

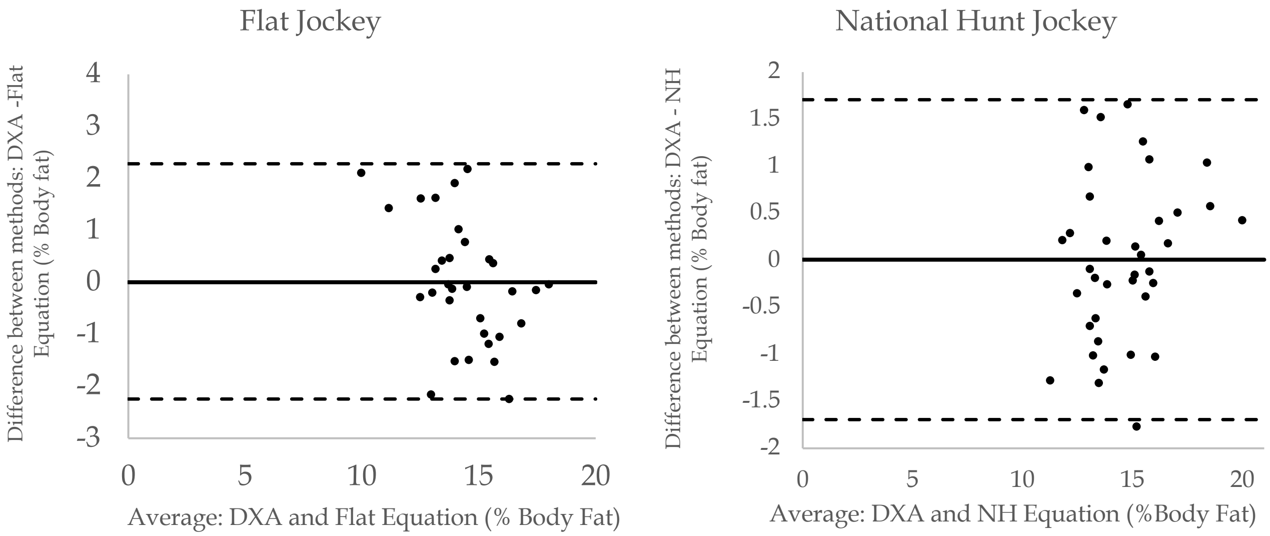

Figure 2. Bland-Altman plots comparing the % body fat between DXA and the specific prediction equations for Flat Jockey and National Hunt Jockey. The centre line represents the mean difference between methods and broken lines represent 95% upper and lower limits of agreement (bias ± 1.96 × standard deviation).

The prediction equations showed modest variability in % body fat values (6.9-10.1%) in the jockey cohort which is supported by previous findings using various prediction equations in adolescent swimmers (15% to 23% body fat) (21) and elite football players (7% to 18% body fat)(36). The authors suggested the variation between equations may in part be explained by the sites selected for the equation and the different sample populations (sport-specific vs non-athlete or competitive vs recreational level) used in each design (21, 36). The selection of appropriate sites is a key element in the accuracy of a prediction equation (35). The lack of similarity between equations is possibly the result of some equations using only three sites (Evans, Lohman and Zemski) compared to others using four sites (Durnin & Womersley and Reilly) or seven sites (Withers). In spite of this, it has been reported the Evans three site skinfold model showed similar accuracy to a seven site model also developed by Evans in top-level judoists (33). Authors concluded that skinfold equations 3- and 7-site did not accurately track body composition to detect adiposity changes (33). It may then be suggested that using a combination of specific sites will provide a more valid estimate of % body fat where upper and lower limb skinfold sites are included (13). However, despite only using upper body sites the equations of Lohman and Durnin and Womersley showed consistent agreement, without bias, when underestimating % body fat in the group of jockeys relative to DXA. The selection of sites in each equation may be due to the differences in reference methods, the choice of regression procedure or the pursuit of an efficient field based assessment tool (36). In any case, the current study supports the difficulty of making comparisons using data obtained from different equations.

The inconsistency of each equation compared to DXA may be the result of regional differences in fat distribution between sample populations (35). The equations of Lohman and Durnin & Womersley which were derived across a wide sample population including mixed body types, sedentary and athletic, is likely to have improved the accuracy between the predicted and actual % body fat as it accommodates diverse fat patterning suggesting a generalised equation can be employed for athletic populations. This however may inherently lack precision when applied to a specific sporting population like jockeys, who have a unique body type, resulting in the underestimation of % body fat (44). Nonetheless, separate studies of elite rock climbers and elite youth soccer players have reported least bias and high accuracy when using the Durnin and Womersley equation to estimate % body fat relative DXA (12,27). It was suggested that the characteristics of the study participants may be represented by the sample studied in the Durnin and Womersley equation (12). The athlete specific equations of Withers and Evans were based on subjects from multidiscipline and multi-ethnic backgrounds. These equations showed an irregular pattern of data distribution by underestimating % body fat far greater in jockeys with higher levels of body fat compared to jockeys with lower levels of body fat. This was similar to that of the single sport equations of Reilly and Zemski suggesting the diversity of fat distribution from these sample populations are different to that of a jockey cohort leading to poor levels of accuracy when estimating % body fat (33). An inaccurate estimate of % body fat could result in unnecessary clinical resources and interventions.

The use of different reference methods to validate each equation may also provide a reason for the variability in % body fat values. Only one of the examined equations, Evans, used a 4-compartment model by measuring total body water, bone density and body density. The Zemski and Reilly equations both used DXA, a three-compartment model which is accepted as a method for validation studies (35). While the more established equations of Lohman, Withers and Durnin and Womersley used hydrodensitometry as the reference method. This two compartment model partitions the body assuming a constant density in fat-free mass which is likely to be violated in athletic populations (13). As a limiting factor it makes comparisons between the present research of jockeys difficult with estimates of % body fat from prediction equations likely to be method dependent (36) suggesting an alternative jockey-specific equation is necessary.

The weight-sensitive nature of horse racing places increasing pressure on jockeys to maintain a low body mass therefore warranting the use of assessment methods which can accurately and reliably track changes in body composition across a racing season (10). Furthermore, the accurate assessment of body composition assists the health and performance guidelines such as setting the minimum riding weight and monitoring the possible risk of relative energy deficiency in sport (RED-S)(26).Currently DXA is used to assess body composition however due to regulations governing radiation exposure, a comparable method is necessary to allow regular assessments. The results of the DXA derived % body fat in this study showed slight differences compared to previous literature (9,40,41). Average height and weight calculated from the previous research was similar for flat jockeys (164.0 cm and 54.6 kg, respectively) and national hunt jockeys (173.3 cm and 65.3 kg, respectively). However, flat (15%) and national hunt jockeys (14.5%) body fat was higher than previously reported (8.3-13% and 10.4-13.8% respectively)(9,40,41). The higher levels of body fat compared to previous literature may be related to different DXA models, the broader age profile in the current study or variance in jockey conditioning and dietary intake. It is also worth highlighting the potential measurement error when assessing fat mass in small lean athletes (1,3).

Various prediction equations have also been used in the past when assessing body composition in jockeys with most utilising the Withers equation in professional jockeys (8,10,40). The % body fat estimated from previous research was between 7.4% and 9.0% which is slightly higher than that of the current findings (7%). The reported studies recruited smaller sample sizes with a younger cohort on average and, this may have caused the variation in estimated % body fat. Similarly, O'Reilly, Cheng & Poon (30) applied the Durnin and Womersley equation in a group of twenty flat jockeys from Asia including 9 Caucasian jockeys reporting a % body fat of 5.8%. This is only slightly lower than what was found in flat jockeys from the present study (6.6%) which maybe the result of the technical error between studies or the expected variation between different cohorts (17). Caution must be taken when providing feedback on % body fat as each method is likely to cause discrepancy between values (36).

A secondary aim of this study was to develop and asses the validity of a jockey-specific prediction equation at estimating % body fat using data collected from the skinfold and DXA measurements. The novel equations developed from the two jockey cohorts are the first of their kind to estimate % body fat. Results from the paired t-test found flat jockeys to be significantly lighter and shorter than national hunt jockeys, suggesting the need for specific equations to be designed as the race demands differ for both jockey populations. Using the enter method a jockey-specific equation for Flat Jockeys and National Hunt Jockeys was developed explaining 84% and 75% variance, respectively. The enter procedure for regression analysis was selected as this guaranteed both equations included sites from the upper and lower limbs in addition to trunk, thus accounting for biological variability in the regional distribution of body fat (13). Additionally, by using the maximum number of variables the jockey-specific equations provide a comprehensive profile of the whole body as suggested by ISAK therefore accounting for the extreme lean individuals who may be misrepresented in equations using a reduced number of sites derived by DXA (35). To guarantee a high level of accuracy using the jockey-specific equation it is important the anthropometrist is well trained and follows a standardised protocol by using techniques and equipment recommended by ISAK (1).

The Flat Jockey and National Hunt Jockey equations explained a moderate to high level of variance (84% and 83%, respectively), suggesting a good predictive power if the equation were used in a separate jockey population. Previous studies creating sport-specific equations have reported mixed findings of variability (73-90%) from DXA derived equations (5,31,36,44). The location and number of sites, body type and sample size have all been factors to affect the reported variance (36,44). The inclusion of all 8 skinfold sites in the present study may help to improve accuracy when applied to this specific population. Both equations showed a high level of agreement with DXA whereby the predicted % body fat is consistent across the jockey cohort with the actual body fat % derived from DXA. This is supported by the narrow limits of agreement for the Flat Jockey (-2.2 to 2.3) and National Hunt Jockey (-0.3 to 0.3) equations. Thus implying both jockey equations are unlikely to over – or underestimate % body fat, suggesting skinfold prediction equations and DXA could be used interchangeable as there is high level of precision between methods. The Evans equation reported wider limits of agreement compared to the present study, - 6.9% to 6.9%, which may be the result of using a reduced number of sites in a multidisciplinary sample population. Based on the findings of the present study both equations provide an accurate field based method to estimate % body fat relative to DXA in flat and national hunt jockeys. With no limit to the number of times anthropometric testing can be carried out, these novel equations could be used as a cost effective and non-invasive alternative for estimating % body fat in professional jockeys. A cross-validation study in a different sample of jockeys is necessary to assess whether the equations could be used interchangeable with DXA.

The jockey equations are the first of their kind for the horse racing industry, providing a practical method for assessing and tracking % body fat in jockeys internationally. By using standardised ISAK procedures, practitioners within the racing industry can use the jockey-specific equations to make consistent comparisons between jockey cohorts. Therefore, implement and monitor similar safety guidelines such as minimum riding weights and RED-S. The study was not without a number of limitations. While jockeys were advised to attend the testing sessions hydrated, and most complied, 29 jockeys presented to testing while dehydrated which may have negatively affected the accuracy of results. Due to the lifestyle and weight-sensitive nature of horse racing it is challenging to control the hydration status of jockeys suggesting future research should systematically examine changes in hydration status and the effect on results (28). The sample of jockeys which participated in the study is representative (flat 53% and national hunt 39% of current licenced jockey population) of a professional Irish male jockey population. However further studies should include amateur jockeys as typically they are a much more varied cohort living a different lifestyle and some racing less regularly compared to professional jockeys which is likely to affect body composition. Due to limited numbers of female jockeys in the overall jockey population, they were excluded from the study, therefore appropriate guidelines for estimating % body fat are required for the female cohort. Lastly, longitudinal body composition data is required for this population as there is a lack of normative values in lean athletes which could be a factor affecting the accuracy of fat mass assessment (3).

The selected prediction equations showed low levels of accuracy and high variability by underestimating % body fat compared to DXA in a group of professional jockeys. Poor overall agreement and proportional bias between the DXA derived body fat % and the prediction equations suggests caution must be taken when providing feedback to jockeys or if making comparisons with data obtained from equation estimates. This study indicates jockey specific equations are necessary for the accurate assessment of % body fat in a jockey population, thus novel equations for flat jockeys and national hunt jockeys were developed from the collected data. The Flat Jockey and National Hunt Jockey equations demonstrated narrow limits of agreements without bias. To be used interchangeable with DXA further research is required to cross-validate the equations in a separate jockey population. These sport-specific equations are practical and non-invasive thus providing an alternative method to assess and track changes in body fat % for the health and performance of jockeys.

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