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Body condition scoring as a predictor of body fat in horses and ponies

Alexandra H.A. Dugdale [a], Dai Grove-White [a], Gemma C. Curtis [a], Patricia A. Harris [b], Caroline McG. Argo [a,*]

[a] *University of Liverpool, School of Veterinary Science and Department of Obesity and Endocrinology, Faculty of Health and Life Sciences, Leahurst, Chester High Road, Neston, Wirral CH64 7TE, UK*

[b] *Equine Studies Group, Waltham Centre for Pet Nutrition, Freeby Lane, Waltham-on-the-Wolds, Melton Mowbray, Leicestershire LE14 4RT, UK*

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ABSTRACT

Body condition scoring systems were originally developed to quantify flesh cover in food animals and are commonly used to evaluate body fat in *Equidae*. The relationship between concurrent estimates of body fat content (eTBF%, deuterium oxide dilution; range, 2.7–35.6%) and subjective appraisals of body 'fatness' (body condition score, BCS; range, 1.25–9/9), was investigated in 77 mature horses and ponies. Univariate (UVM, $r^2 = 0.79$) and multivariable (MVM, $r^2 = 0.86$) linear regression models described the association, where BCS and eTBF% were explanatory and outcome variables, respectively. Other measures (age, sex, breed, body mass, ultrasound-generated subcutaneous and abdominal retroperitoneal fat depths, withers height, heart and belly circumferences) were considered as potential confounders but only height, belly circumference and retroperitoneal fat depth remained in the final MVM.

The association between BCS and eTBF% was logarithmic. Appraisal of the transformed regression (UVM), actual eTBF% values and 95%CIs of the model forecast, suggested that the power of log-transformed BCS as a predictor of eTBF% decreased as BCS increased. The receiver operating characteristic curve for the prediction of horses with an eTBF% of >20%, suggested that the UVM correctly classified 76% of horses using a 'cut-off' of BCS 6.83/9 (sensitivity, 82.5%; specificity, 70.8%). Negative values for eTBF% were obtained for two thin ponies which were excluded from analyses, and caution is advised in the application of deuterium dilution methodologies where perturbed tissue hydration could be predicted. The data suggest that BCS descriptors may warrant further consideration/refinement to establish more clinically-useful, sub-classifications for overweight/obese animals.

Introduction

With the current increase in companion animal obesity and its attendant requirement for weight management programmes (German, 2006; Sillence et al., 2006), body condition scoring (BCS) systems have been extensively accepted and applied as measures and monitors of body 'fatness' (Laflamme, 1997a,b). These simple monitoring tools were originally developed by the food animal industry to evaluate the superficial 'flesh' covering (soft tissue, largely muscle and fat) of livestock, to facilitate nutritional management and improve economic efficiency (Jeffries, 1961). The current trend to extrapolate BCS for the measurement of fat, as opposed to 'flesh', represents a marked deviation from initial purpose and lacks substantiating evidence. In practical terms, should BCS prove to be a reliable tool for the estimation of body fat content in horses and ponies, it would aid welfare by allowing the prompt identification and corrective management of under- and overweight animals and greatly facilitate clinical research.

Commonly used equine BCS systems are dependent on the subjective scoring of individual animals against a range of graded, anatomical descriptors. These systems have been developed by experienced observers to classify body condition in accordance with external appearance but without specific knowledge of the actual body fat content of the animals on which the systems were based (see, for example, Henneke et al., 1983; Kohnke, 1992). While the classification of external body condition is important, the fat content of 'flesh' is highly variable and the extent of internal fat depots cannot be visually assessed. Before BCS can be accepted as a predictor of body fat content, it is important that this association is clearly and quantitatively defined (Charette et al., 1996).

To date, the requirement for destructive and time consuming carcass dissection studies to quantify body fat, has meant that evidence for this association has been sparse (20 horses, Martin-Rosset et al., 2008; 7 ponies, Dugdale et al., 2011a). Despite limitations in animal numbers, these groups independently verified that the association between BCS and body fat is non-linear. This raised concerns with respect to the reliability of BCS-derived estimates of body fat content. For fatter animals, subjective and linear measures of BCS are associated with ever 'steepening' regions of the curve

* Corresponding author. Tel.: +44 151 7946094.
E-mail address: c.m.argo@liverpool.ac.uk (C.McG. Argo).

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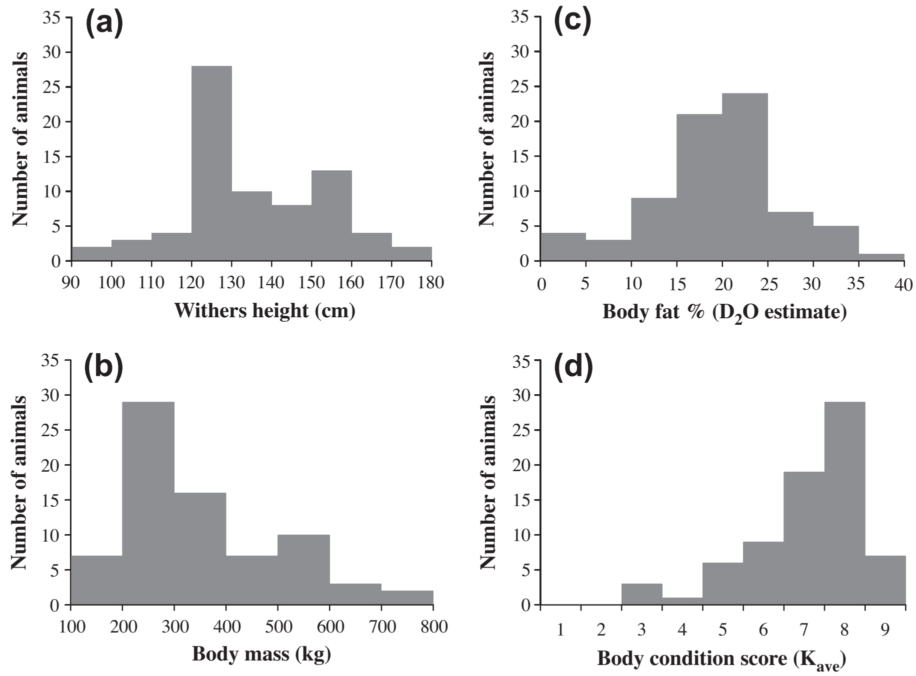

Fig. 1. Histograms representing the distributions of the 77 study animals across study ranges in (a) withers height (cm), (b) body mass (kg), (c) body fat percentage as estimated following deuterium oxide dilution, and (d) body condition score (K_{ave}).

Table 1
Linear regression models for (1) the univariable association between log transformed body condition score (BCS, K_{ave}) and the log transformed body fat percentage estimated following D_2O dilution for all animals; (2) the multivariable model describing the association between log transformed BCS (K_{ave}) and the log transformed body fat percentage (D_2O dilution), which included withers height, belly girth and ultrasound measurement of retroperitoneal fat as additional explanatory variables. The outcome variable in both models was log transformed body fat percentage, estimated by D_2O dilution.

Model	*n*	Variable	Coefficient	*P*	95% CI	r^2
1.	74	Log BCS	1.56	<0.001	1.37–1.74	0.79
		Constant	0.006	0.97	−0.34 to 0.36	
2.	74	Log BCS	1.22	<0.001	0.10–1.45	0.86
		Withers height	−0.006	0.024	−0.012 to 0.001	
		Belly girth	0.006	0.004	0.002–0.011	
		Retroperitoneal fat	0.006	0.012	0.001–0.01	

defining the relationship with body fat, where small errors in BCS would incur large and increasing errors in estimates of body fatness (Dugdale et al., 2011a).

The reliability and repeatability of BCS is dependent on the degree of variation in scoring both within and between observers, and these sources of systematic and random error have been subject to recent investigation (Mottet et al., 2009). The concerns are compounded by ambiguities of distinction between successive grade descriptors in the commonly used BCS systems, and the uncertainty often results in a range of relevant descriptors and the grade that is ultimately selected may be systematically influenced simply on the basis of the direction (up or down) in which the list is consulted.

A recent study used ponies to validate the deuterium oxide (D_2O) dilution method for the estimation of body fat content in vivo (Dugdale et al., 2011b). Application of this minimally-invasive but relatively expensive method has allowed the development of body composition studies to include previously unavailable data from living animals. In the current study, we investigated the performance of a commonly used BCS system and the influence of differences in its method of application as a predictor of body fat content, against simultaneous estimates of body fat content obtained following application of the D_2O dilution method in a mixed population of 77 mature horses and ponies, encompassing the expected range in BCS, throughout the year.

Materials and methods

Experimental design

Data from 77 horses and ponies were available for evaluation following the conduct of a series of studies at the University of Liverpool over the past 4 years (Dugdale et al., 2010, 2011a; Curtis et al., 2010, 2011). The population comprised; 5 Shetland, 1 Dartmoor, 41 Welsh Mountain, 2 Welsh section B and 2 Welsh section C ponies, 5 ponies of mixed breed, 17 cobs, 2 Warmblood horses and 2 Thoroughbred-cross animals. Twenty-two (22/77, 29%) of the animals were geldings and the remainder (55/77, 71%) were mares.

For each animal, age, sex, breed, withers height (to the nearest millimetre), body mass (BM, to the nearest 500 g), circumferential measurement of body girth at the heart and belly sites, and ultrasound-generated depth measurements of superficially accessible adipose depots at the subcutaneous rump and rib sites and at the retroperitoneal ventro-abdominal site (Dugdale et al., 2011c) were recorded. BCS was subjectively appraised by the same, experienced observer on each occasion using Kohnke's modification (1992) of the system originally described by Henneke et al. (1983) ranging from BCS 1 (very poor) to BCS 9 (extremely fat). On the same day, total body fat mass (TBFM), was calculated following the D_2O dilution-derived measurement of total body water (Dugdale et al., 2011b). Body fat percentage was calculated from TBFM and BM.

Recognition of the potential for systematic, observer error associated with the application of BCS systems warranted a considered approach to BCS recording to fulfil the objectives of the current study. The selected BCS system required that six anatomically distinct body regions (neck, withers, loin, tailhead, ribs, shoulder) were independently scored from region-specific lists of nine graded descriptors (Kohnke, 1992). Compliance with Kohnke's system required that overall BCS was designated as the mean of the six independent scores. In the current trial, BCS was determined for each animal only after initially highlighting all of the terms,

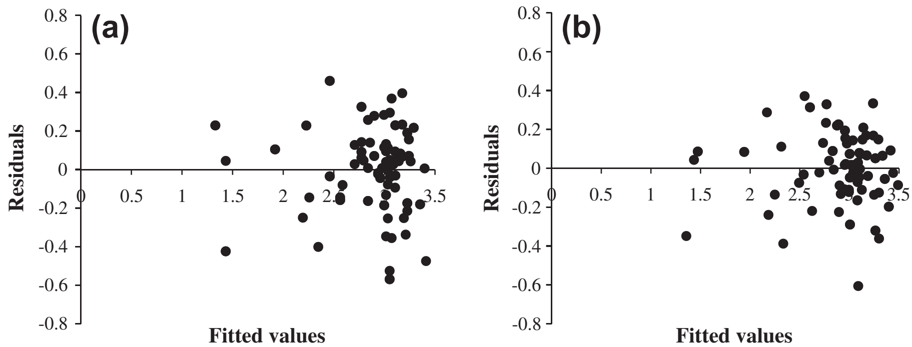

Fig. 2. Scatterplots representing the distribution of (a) the residuals against fitted values for the univariable regression model (Table 1, Model 1) of the association between body fat percentage as estimated following D_2O dilution and body condition score (K_{ave}) and (b) the residuals against fitted values for the multivariable regression model (Table 1, Model 2) which described the association between body fat percentage as estimated following D_2O dilution and body condition score (K_{ave}).

within each region-specific list of nine graded descriptors, which could justifiably be applied to that individual (Kohnke, 1992). Consequently, a range of scores was determined for each body region appraised which, when summed and averaged in accordance with Kohnke's instructions, provided overall minimum (K_{low}), maximum (K_{hi}), and mean (K_{ave}) scores for each individual.

Statistical analysis

Raw data for all explanatory variables (BM, age, breed, withers height, sex, ultrasound generated fat depths, body girths, body fat content estimated following D_2O dilution and three measures of BCS (K_{low}, K_{hi} and K_{ave}), were initially entered into a spreadsheet (Excel, Microsoft Office Professional Edition 2003) and subsequent statistical analysis was performed using STATA 11 (StataCorp).

The range and nature of the distribution of the three BCS readings (K_{low}, K_{hi} and K_{ave}), were assessed and the degree of association between them was evaluated using correlation. On this basis, all further analyses were performed using the average BCS (K_{ave}). Both univariable and multivariable linear regression models were fitted to describe the association between BCS and estimated total body fat percentage (eTBF%), as calculated following D_2O dilution, with the outcome variable being eTBF% and the explanatory variable being BCS, whilst other variables were considered as potential confounders. Best model fit was achieved in both cases by log-transforming both the outcome variable 'eTBF%' and the explanatory variable 'BCS'. In the case of the multivariable model, the following potential explanatory variables, log(K_{ave}), BM (kg), age (years), breed, withers height (cm), sex, ultrasound-generated fat measurements (mm) at the subcutaneous rib-eye and rump sites and ventro-abdominal retroperitoneal depot, heart and belly girths (cm) were initially included in the model and a backward stepwise modelling strategy was employed to determine which variables remained in the final model. The decision to eliminate a variable from the final model was made using a P-value >0.2 in likelihood ratio testing. Model fit was appraised by visual examination of residuals versus fitted values plots. In order to gauge the predictive ability of the univariable model for individual animals, confidence intervals based on the standard error of the forecast (as opposed to the standard error of the mean) were calculated.

In order to investigate further the ability of BCS measurement to predict the 'fat status' of an animal, a binary (yes/no) variable 'fat_horse' was generated whereby a horse was defined as being 'fat' if its estimated total body fat was >20%. This value was selected on the basis of data collected within our group but is not claimed to represent the adipose biology of the horse; rather it is taken to illustrate a principle. A receiver operating characteristic (ROC) curve was generated for the log transformed BCS score as a predictor of 'fat_ horse' (yes/no). This allowed investigation of the optimal cut-off score for log transformed BCS score and generated sensitivity and specificity parameters.

Results

The 77 animals within the study population ranged widely in withers height (mean, 119.9; median, 115.5; range, 85–169 cm, Fig. 1a), BM (mean, 305.0; median, 256.5; range, 159.5–764 kg, Fig. 1b), BCS (K_{ave}, 1.25–9/9, Fig. 1d) and age (mean, 12.2; median, 12.0; range, 5–39 years). Spurious results following D_2O dilution analyses were obtained for 3/77 animals (all Welsh Mountain pony mares) and data for these individuals were excluded from subsequent analyses. Of the three animals rejected from the study on the basis of 'biologically improbable' plasma deuterium enrichments, one was related to infusion error while the other two ponies were thin (BCS 1.25 and 2.67/9) and calculated estimates of total body fat content (eTBF) yielded negative results. TBF (%) estimates that were included in the analysis ranged from 2.74% to 35.6% (mean, 19.56%; median, 19.91%; Fig. 1c).

The best fitting simple univariate regression model (Table 1) was:

$$e^{\mathrm{TBF}} = 0.006 + e^{1.56*\mathrm{BCS}} \tag{1}$$

The final multivariable model (Table 1) included withers height, belly girth and ultrasound measurement of retroperitoneal fat as additional explanatory variables:

$$e^{\mathrm{TBF}} = 0.118 + e^{1.22*\mathrm{BCS}} + +0.006 * \mathrm{retroperitoneal\_fat}\ (\mathrm{mm}) + 0.007 * \mathrm{withers\_height} + 0.007 * \mathrm{belly\_girth} \tag{2}$$

Residual versus fitted plots for both models are shown in Figs. 2a and b, respectively. Visual examination suggested that model fit was relatively good and this conclusion was supported by the high r^2 values for both the univariable and multivariable models (79% and 86%, respectively). Comparison of the coefficients for the log transformed BCS (K_{ave}) as a predictor of log transformed eTBF in both the univariable and full model demonstrated that inclusion of the additional covariates (withers height, belly girth and ultrasound measurement of retroperitoneal fat) in the full model reduced the magnitude of the coefficient from 1.56 to 1.22 (Table 1). This represented a change in magnitude of almost 21% and suggested that these covariates, taken together are a significant confounder of the association between BCS (K_{ave}) and eTBF.

Visual inspection of the transformed regression line of the univariable model together with actual eTBF% values and the 95% limits of the confidence intervals of the forecast (Fig. 3) suggested that the predictive power of log transformed BCS (K_{ave}) as a predictor of eTBF becomes less accurate at higher BCS (K_{ave}) values, as demonstrated by the 'flaring' of the forecast confidence intervals.

Examination of the ROC curve for prediction of horses with an eTBF% > 20% (Fig. 4), suggested reasonable test performance with 76% of the horses in the study (n = 74) being correctly classified at a cut off of BCS 6.83/9. This equated to a test sensitivity of 82.5% and specificity of 70.8%.

Discussion

The current and alarming increase in companion animal obesity has highlighted the need for a simple method to quantify and monitor changes in body fat content. The BCS system used here was initially designed to score flesh cover in food animals and was subsequently adapted to measure fatness in horses, using descriptors derived from Quarterhorse broodmares (Henneke et al., 1983).

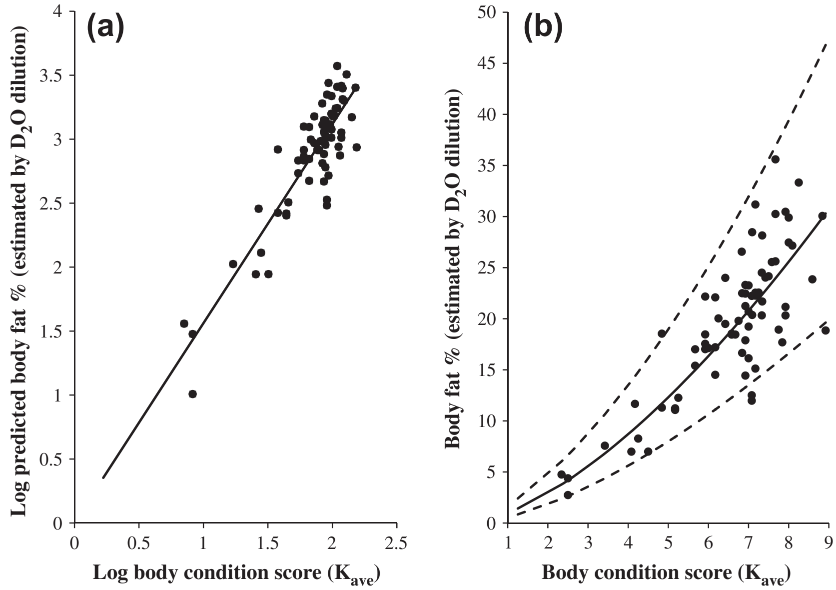

Fig. 3. Scatterplots representing the relationship between body condition score (K_{ave}) and body fat percentage estimated following D_2O dilution as (a) log transformed values and (b) actual values. The solid black line represents fitted values for the univariable regression model of the association (Table 1, Model 1). The broken lines (b) describe the upper and lower 95% confidence limits for the forecast predictions.

We present evidence here that the results using this system are in good agreement with estimates for eTBF% generated following D_2O dilution and when used judiciously may offer a useful, simple and less costly index of body fat content.

The initial validation of the D_2O dilution technique for determination of body fat in *Equidae* was limited to the study of mature Welsh Mountain pony mares (BCS (K_{ave}) 1–7/9). Although the D_2O dilution technique has been widely used in several species, including man, without recourse to any comparable test of its suitability, we have applied the method to a wider range of horses and ponies in terms of breed, sex, age and BCS (Dugdale et al., 2011b).

In agreement with earlier work, the results of this larger study reinforced the important finding that the association between equine BCS and the percentage of BM comprised of fat, whether measured empirically by gross carcass dissection (Martin-Rosset et al., 2008; Dugdale et al., 2011a), by proximate chemical analysis of the cadaver (Dugdale et al., 2011a) or as estimated by the deuterium oxide dilution method (Dugdale et al., 2011b), is non-linear. These earlier studies suggested that the relationship was best described by exponential functions (7 pony mares, body fat% $\propto e^{0.46Kave}$, Dugdale et al., 2011a; 20 French sport horses, body fat $\propto e^{0.56BCS}$; Martin-Rosset et al., 2008). The larger sample size and heterogeneity of breed, age, weight and sex in the present study, considerably reinforced the likelihood that the association is truly exponential.

It is noteworthy that the prediction of body fat content, following the analysis of plasma deuterium enrichments recorded for one emaciated (BCS 1.25/9) and one thin animal (BCS 2.67/9), yielded negative values. A detailed nutritional history was not available for either animal. It is possible that, for such individuals near the lower limits of the BCS range, the presence of starvation-specific, pathological changes may preclude the application of the universal lean tissue hydration factor, which is central to the calculation of fat mass from body water pool size (0.732; Pace and Rathbun, 1945; Dugdale et al., 2011b). Physiological changes associated with starvation or cachexia may include expansion of the extracellular fluid space, serous atrophy/hydropic changes of adipose and other tissues and increased digesta hydration.

Application of the universal hydration factor for the estimation of total body lean tissue mass to data for animals in which this compartment was 'pathologically over-hydrated,' would result in the over-estimation of lean mass. This small over-estimation of lean mass would elicit a comparable under-estimation of the fat mass (calculated by subtraction of lean mass from total BM). For cachexic or emaciated animals, in which actual body fat is minimal (~2% of empty BM [less digesta] for the animal in BCS 1.25/9), calculated lean mass could readily exceed actual BM to generate negative predictions for body fat content. These data suggest that the interpretation of D_2O generated eTBF% may be unreliable for extremely thin animals or when other conditions which might be predicted to perturb hydration status are present.

The predictive ability of BCS in estimating total body fat appeared to be better in animals of a lower BCS as shown by 'flaring' of the confidence intervals of the individual forecast at higher BCSs. Nevertheless, when used as a simple binary test for identifying

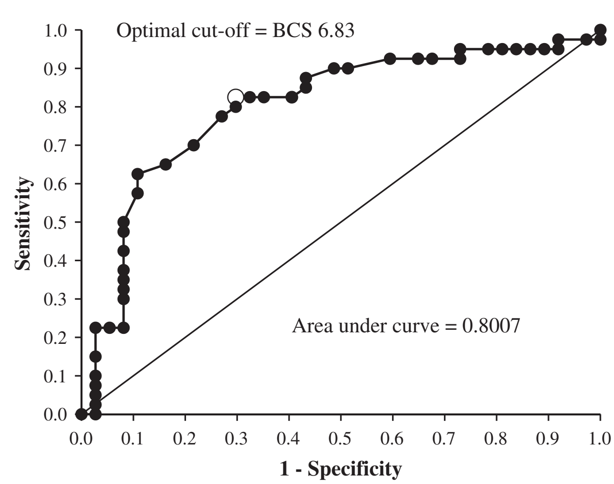

Fig. 4. Receiver operator characteristic (ROC) curve for log transformed body condition scores (K_{ave}) as a predictor of animals which could be expected to have had estimated body fat percentages (D_2O dilution) $\geqslant$ 20% of total body mass ('fat horses'). At the indicated optimal 'cut-off' value (open circle) of BCS (K_{ave}) = 6.83, sensitivity was 82.5%, while specificity was 70.8%. Retrospective application of this 'cut-off' value, correctly classified 76% of the horses in the study (n = 74) for D_2O estimated, body fat percentages above or below 20%.

animals with an eTBF% of >20% BM (in this example), test performance was reasonable for the identification of 'fat' horses and ponies likely to be in need of weight loss management, for this 'cut-off', that would be for those animals which return a BCS of >7/9. At this level, test sensitivity and specificity of ~80% would be considered as good for many obesity-related diagnostic methodologies (Marcadenti et al., 2011).

The observation that BCS was less reliable in detecting changes in body fat content in obese animals was in agreement with earlier work (Dugdale et al., 2010). When a group of overweight and obese ponies underwent a 3 month period of dietary restriction (1% of BM as daily dry matter intake), little change in BCS (K_{ave}, 7.0 ± 0.4–6.7 ± 0.3) was recorded, despite considerable losses of BM ($11.4 \pm 1.9\%$) of which fat, as estimated by D_2O dilution, comprised $45 \pm 19\%$ (Dugdale et al., 2010). Irrespective of changes in BM, ponies in this earlier study largely remained within the less sensitive 'upper' region of the BCS:body fat association, where BCS would have been a less reliable monitor of changes in eTBF%.

As previously noted, the non-linear association between body fat or eTBF% and BCS, dictates that, in this region of the curve, large changes in body fat content are represented by relatively small changes in BCS (Dugdale et al., 2010). These authors also commented that, for animals undergoing active changes in body fat content, whether through bodyweight gain or weight loss, BCS can at best, only monitor changes in external appearance (subcutaneous, inter- and intra-muscular fat) and cannot identify covert changes to the visceral fat mass, which may be the most dynamic reserve during periods of active weight change (Macfarlane et al., 2008). This point was supported in the current study, where the only ultrasound-generated measurement of a regional adipose depot to improve model fit was the depth of the ventro-abdominal retroperitoneal adipose plaque.

Conversely, the D_2O dilution method provides only an overall estimate of total body fat mass. Given the potential significance of specific regional fat depots (e.g. visceral fat) as risk factors for obesity-related disease in other species including man (Kissebah and Krakower, 1994), it is possible that a combination of both BCS and stable isotope methodologies may prove useful in the clinical appraisal of individuals. This is of particular importance in the identification of metabolically obese, normal weight individuals (Ruderman et al., 1998), for which estimations of body fat by BCS alone may be insufficient to detect covert visceral adipose tissue. It is possible that BCS may be more representative of total body fat content where mature animals have been fed to maintenance and regional fat distributions could be considered to be relatively constant. These authors suggested that for obese animals, weekly measures of belly girth (widest point of the abdomen) and/or (where facilities allow) BM, were useful adjuncts to BCS as aids for the monitoring of body fat content (Dugdale et al., 2010).

The accurate determination of BCS of obese animals is also problematic and likely to incur observer errors. For obese animals, in which key bony landmarks have already been obscured by fat, current 'grade descriptors' for each body region are not readily distinguished. For example, under 'Tailhead', selection/differentiation between terms for fat that 'feels soft' (score 6), 'is soft' (score 7) or is 'very soft' (score 8) is highly subjective. The importance of defining descriptors precisely, to minimise error by ensuring that the observer is in no doubt regarding their interpretation, has been raised previously (Teasdale and Jennett, 1974).

A recent study demonstrated greater variation between scores when BCS was performed by horse owners compared to veterinary surgeons (Mottet et al., 2009). To address the current hypothesis, that BCS is a useful index of body fat content as estimated following D_2O dilution, BCS was performed by a single, trained observer for all animals. Given that data were collected across 4 years, it was considered that the use of a single observer would optimise method comparison by limiting the variation in BCS attributable to the use of a changing pool of multiple, less skilled observers. It should be considered that the associations between methods presented here, cannot account for the further variations in BCS recorded by different observers.

It is of interest that a BCS of 7 has been reported as the 'threshold' value above which ponies are predicted to be at increased risk of developing pasture-associated laminitis (Carter et al., 2009). On the strength of this, and current information, the detection of animals in BCS > 7 might constitute a useful welfare indicator. Our study suggested that BCS greater or equal to 6.8 was a reasonable predictor that eTBF% would exceed 20%. Such individuals would probably benefit from a programme of weight loss management. However, wider epidemiological studies are required to better quantify associations between BCS/eTBF% and obesity-related disease.

It has previously been suggested that BCS systems may only permit body fat to be quantified within ±10% (with 95% confidence), which really only enables distinction of three classes: 'thin', 'average' and 'overweight' (Burkholder, 2000). Even with this relatively poor test performance, practical application of the technique would still be warranted to identify thin and overweight animals in need of nutritional intervention.

The application of a BCS system developed for Quarterhorse broodmares to horses or ponies of other or mixed breeds, should be considered with caution (Suagee et al., 2008; Dugdale et al., 2011a,b). Further, the BCS calculation method used in Kohnke's (1992) system has been criticised (Boden, 2011; Marr, 2011). This observational, categoric system is presented as a linearly-ordinal scale with nine discontinuous categories from 1 (emaciated) to 9 (obese). Kohnke's method requires that the mean of six of these discontinuous, regional scores is calculated to generate the overall BCS for the individual, an action which effectively converts data of discontinuous origins to a continuous scale. In the light of our understanding that the relationship between BCS and the predicted variable (body fat content) is not linearly ordinal and that the relative weighting for each body region score on the predicted variable is unknown, this calculation of a mean value could be considered inappropriate (Streiner and Norman, 2008). However, despite its apparent lapse in statistical purity, data from the current study and earlier work, where a 'near perfect' linear association was demonstrated between BCS (K_{ave}) and total body soft tissue (flesh), would support the continued application of this commonly used BCS system for assessment of overall body condition (Dugdale et al., 2011a).

There remains both a requirement and the capacity to improve on Kohnke's (1992) BCS system. Critical appraisal of current grade descriptors and the introduction of less subjective terms to describe 'super-obese' animals, could serve to minimise ambiguity and redundancy in the current range. Understanding the relative importance of 'fatness grades' for each of the body regions assessed would aid in 'weighting' the relative contribution of each anatomical region for the quantification of total body fat. Finally, the consistency of inter-observer applications of any BCS system should be assured in order to optimise its full potential.

Conclusions

This study suggested that while subjective BCS scoring, using the Kohnke (1992) adaptation of the BCS system proposed by Henneke et al. (1983), may be useful in estimating the body fat content of non-obese animals, it was less accurate in the evaluation of obese horses and ponies. The refinement of current BCS descriptors could help to minimise observer errors and potentially allow the introduction of clearer classifications for obese animals

(BCS $\geqslant$ 7). However, in its current form, the BCS system adapted by Kohnke remains a useful predictor for the quantification and monitoring of body fat content in non-obese animals and correctly identifies those individuals for which intervention is required to limit the risk of obesity-related disease.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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References

Boden, L., 2011. Clinical studies utilising ordinal data: Pitfalls in the analysis and interpretation of clinical grading systems. Equine Veterinary Journal 43, 383–387.

Burkholder, W.J., 2000. Use of body condition scores in clinical assessment of the provision of optimal nutrition. Journal of the American Veterinary Medical Association 217, 650–654.

Carter, R.A., Treiber, K.H., Geor, R.J., Douglass, L., Harris, P.A., 2009. Prediction of incipient pasture-associated laminitis from hyperinsulinaemia, hyperleptinaemia and generalised and localised obesity in a cohort of ponies. Equine Veterinary Journal 41, 171–178.

Charette, R., Bigras-Poulin, M., Martineau, G.P., 1996. Body condition evaluation in sows. Livestock Production Science 46, 107–115.

Curtis, G.C., Barfoot, C.F., Dugdale, A.H.A., Harris, P.A., Grove-White, D., Argo, C. McG., 2010. Comparison of two, practical weight loss protocols for the management of overweight and obese horses and ponies. In: Ellis, A.D., Longland, A.C., Coenen, M., Miraglia, N. (Eds.), The Impact of Nutrition on the Health and Welfare of Horses. European Association for Animal Production Publication Number 128, Wageningen Academic Publishers, The Netherlands, p. 237.

Curtis, G.C., Barfoot, C.F., Dugdale, A.H.A., Harris, P.A., Argo, C. McG., 2011. Voluntary ingestion of wood shavings by obese horses under dietary restriction. British Journal of Nutrition 106, S178–S182.

Dugdale, A.H.A., Curtis, G.C., Cripps, P.J., Harris, P.A., Argo, C. McG., 2010. Effect of dietary restriction on body condition, composition and welfare of overweight and obese pony mares. Equine Veterinary Journal 42, 600–610.

Dugdale, A.H.A., Curtis, G.C., Harris, P.A., Argo, C. McG., 2011a. Assessment of body fat in the pony: I. Relationships between the anatomical definition of adipose tissue, body composition and body condition. Equine Veterinary Journal 43, 552–561.

Dugdale, A.H.A., Curtis, G.C., Milne, E., Harris, P.A., Argo, C. McG., 2011b. Assessment of body fat in the pony: II. Validation of the deuterium oxide dilution technique for the measurement of body fat. Equine Veterinary Journal 43, 562–570.

Dugdale, A.H.A., Curtis, G.C., Cripps, P.J., Harris, P.A., Argo, C. McG., 2011c. Effect of season and body composition on appetite, body mass and body composition in *ad libitum* fed pony mares. The Veterinary Journal 109, 379–387.

German, A.J., 2006. The growing problem of obesity in dogs and cats. Journal of Nutrition 136(Suppl.), 1940S–1946S.

Henneke, D.R., Potter, G.D., Krieder, J.L., Yeates, B.F., 1983. Relationship between condition score, physical measurements and body fat percentage in mares. Equine Veterinary Journal 15, 371–372.

Jeffries, B.C., 1961. Body condition scoring and its use in management. Tasmanian Journal of Agriculture 32, 19–21.

Kissebah, A.H., Krakower, G.R., 1994. Regional adiposity and morbidity. Physiology Reviews 74, 761–811.

Kohnke, J., 1992. Feeding and Nutrition: The Making of a Champion. Birubi Pacific, Pymble, Australia, pp. 163–166.

Laflamme, D., 1997a. Development and validation of a body condition score system for cats: A clinical tool. Feline Practice 25, 13–18.

Laflamme, D., 1997b. Development and validation of a body condition score system for dogs. Canine Practice 22, 10–15.

Macfarlane, D.P., Forbes, S., Walker, B.R., 2008. Glucocorticoids and fatty acid metabolism in humans: Fuelling fat redistribution in the metabolic syndrome. Journal of Endocrinology 197, 189–204.

Marcadenti, A., Fuchs, S.C., Moreira, L.B., Wiehe, M., Gus, M., Fuchs, F.D., 2011. Accuracy of anthropometric indexes of obesity to predict diabetes mellitus type 2 among men and women with hypertension. American Journal of Hypertension 24, 175–180.

Marr, C.M., 2011. Clinical grading systems: Can we resolve the needs of clinical practice and those of clinical research? Equine Veterinary Journal 43, 377–378.

Martin-Rosset, W., Vernet, J., Dubroeucq, H., Arnaud, G., Picard, A., Vermorel, M., 2008. Variation of fatness and energy content of the body with body condition score in sport horses and its prediction. In: Saastamoinen, M.T., Martin-Rosset, W. (Eds.), Nutrition of the Exercising Horse. European Association for Animal Production Publication Number 125. Wageningen Academic Publishers, The Netherlands, pp. 167–176.

Mottet, R., Onan, G., Hiney, K., 2009. Revisiting the Henneke body condition scoring system: 25 years later. Journal of Equine Veterinary Science 29, 417–418.

Pace, N., Rathbun, E.N., 1945. Studies on body composition. III. The body water and chemically combined nitrogen content in relation to fat content. Journal of Biological Chemistry 158, 685–691.

Ruderman, N., Chisholm, D., Pi-Sunier, X., Schneider, S., 1998. The metabolically obese, normal-weight individual revisited. Diabetes 47, 699–713.

Sillence, M., Noble, G., McGowan, C., 2006. Fast food and fat fillies: The ills of western civilisation. The Veterinary Journal 172, 396–397.

Streiner, D.L., Norman, G.R., 2008. Health Measurement Scales, Fourth Ed. Oxford University Press, Oxford, UK.

Suagee, J.K., Burk, A.O., Quinn, R.W., Petersen, E.D., Hartsock, T.G., Douglass, L.W., 2008. Effects of diet and weight gain on body condition scoring in Thoroughbred geldings. Journal of Equine Veterinary Science 28, 156–166.

Teasdale, G., Jennett, B., 1974. Assessment of coma impaired consciousness: A practical scale. Lancet 2, 81–84.