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Estimation of body weight and development of a body weight score for adult equids using morphometric measurements[1]

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ABSTRACT: Excessive BW has become a major health issue in the equine (*Equus caballus*) industry. The objectives were to determine if the addition of neck circumference and height improved existing BW estimation equations, to develop an equation for estimation of ideal BW, and to develop a method for assessing the likelihood of being overweight in adult equids. Six hundred and twenty-nine adult horses and ponies who met the following criteria were measured and weighed at 2 horse shows in September 2011 in Minnesota: age ≥ 3 yr, height ≥ 112 cm, and nonpregnant. Personnel assessed BCS on a scale of 1 to 9 and measured wither height at the third thoracic vertebra, body length from the point of shoulder to the point of the buttock, neck and girth circumference, and weight using a portable livestock scale. Individuals were grouped into breed types on the basis of existing knowledge and were confirmed with multivariate ANOVA analysis of morphometric measurements. Equations for estimated and ideal BW were developed using linear regression modeling. For estimated BW, the model was fit using all individuals and all morphometric measurements. For ideal BW, the model was fit using individuals with a BCS of 5; breed type, height, and body length were considered as these measurements are not affected by adiposity. A BW score to assess the likelihood of being overweight was developed by fitting a proportional odds logistic regression model on BCS using the difference between ideal and estimated BW, the neck to height ratio, and the girth to height ratio as predictors; this score was then standardized using the data from individuals with a BCS of 5. Breed types included Arabian, stock, and pony. Mean (±SD) BCS was 5.6 ± 0.9. BW (kg) was estimated by taking [girth (cm)$^{1.48}$6 × length (cm)$^{0.554}$ × height (cm)$^{0.599}$ × neck (cm)$^{0.173}$]/3,596, 3,606, and 3,441 for Arabians, ponies, and stock horses, respectively (R^2 = 0.92; mean-squared error (MSE) = 22 kg). Ideal BW (kg) was estimated by taking [length (cm) × 2.8] + [height (cm) × 4.2] – 611, 606, and 577 for Arabians, ponies, and stock horses, respectively (R^2 = 0.86; MSE = 24). Equids with a BCS of ≥7 had a greater likelihood of being overweight, and the model suggested cutoffs at the 48th and 83rd percentiles for underweight and overweight individuals, respectively. Morphometric measurements were successfully used to develop equid BW-related equations.

Key words: body condition score, body length, girth circumference, height, neck circumference, overweight

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INTRODUCTION

Many horse and pony owners fail to recognize changes in BCS or BW and tend to provide calories in excess of their horse's energy requirements (Harker et al., 2011). As a result, excessive BW has recently become a major health issue in the equine industry (Geor and Harris, 2009). In Virginia, 19% of horses were considered obese, with a BCS ≥ 7.5 (Thatcher et al., 2012), and 21% of pleasure horses at a show in the United Kingdom were categorized as fat or obese, with a BCS ≥ 7 (Harker et al., 2011). Although the BCS system developed by Henneke et al. (1983) has been used to assess equid body condition and adiposity since its development, the ability of this measure to accurately reflect the likelihood of an individual being overweight

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has been called into question (Wilson et al., 2003; Wilson et al., 2005), as well as the ability of untrained owners to accurately assess BCS (Mottet et al., 2009).

Determining a horse's BW is important for weight and feeding management and administration of medication. A livestock scale provides accurate measurement of BW; however, few owners have access to a scale. Instead, weight tapes and equations have been developed to estimate equid BW. Hall (1971) developed a BW equation for adult horses (>147 cm at the withers) where estimated BW (kg) = girth circumference (cm)^2 × body length (cm)/11,880. Owen et al. (2008) revised the denominator for ponies (<147 cm at the withers) to be 10,787.

To assist owners with BW management, new and improved resources are necessary. The objectives of this research were to determine if the addition of neck circumference and height improved existing BW estimation equations, to develop an equation for estimation of ideal BW based on measurements not affected by adiposity, and to develop a method for assessing the likelihood of being overweight in adult horses and ponies.

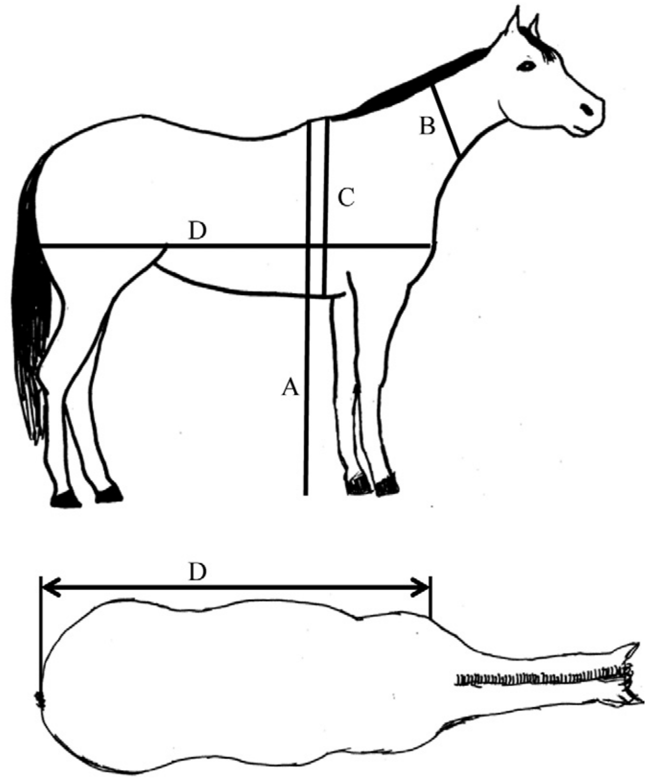

Figure 1. Morphometric measurements collected on 629 horses in Minnesota, including height at the third thoracic vertebra (A), neck circumference located half way between the poll and withers (B), girth circumference at the base of the mane hairs (C), and body length from the point of shoulder to a line that was perpendicular to the point of the buttock (D).

MATERIALS AND METHODS

All experimental procedures were conducted according to those approved by the University of Minnesota (1109B04182). All statistical analyses were performed in R (R Core Team 2012, Vienna, Austria; version 2.15.1).

Morphometric measurements and BW on 629 adult horses and ponies exhibited at the 2011 Western Saddle Club Association (**WSCA**) Champ Show (n = 403) and Minnesota State 4-H Horse Show (n = 226) were collected in September 2011 at the state fairgrounds in St. Paul, MN. Although horses could have been exhibited at both shows, morphometric measurements and BW were only collected once. Both shows were championship shows, were not breed specific, and included halter, driving, western and English pleasure, and speed (game or gymkhana) classes. The WSCA Champ Show had 4,185 entries, with 1,229 individual animals exhibited, whereas the Minnesota State 4-H Horse Show had 2,797 entries, with 543 individual animals exhibited.

Data were collected on adult horses and ponies that met the following criteria: age ≥ 3 yr, height ≥ 112 cm, and nonpregnant mares. For individuals that met those requirements, the following measurements were taken by trained personnel: BCS on a scale of 1 (poor) to 9 (extremely fat; Henneke et al., 1983), height at the third thoracic vertebra, neck circumference located halfway between the poll and withers (Carter et al., 2009), girth circumference at the base of the mane hairs, and body length from the point of shoulder (intermediate tubercle of the humerus) to a line that was perpendicular to the point of the buttock (ischiatic tuberosity; Fig. 1); BW was measured by a portable livestock scale (Weigh-Tronix, Fairmount, MN; model PS2000). To minimize variations due to muscling and hind leg conformational differences, the body length measurement was adapted so the tape measure was not wrapped around the animal to the point of the buttock; rather, the tape measure was held past the animal and a visual perpendicular line was drawn at the point of the buttock. Age, gender, breed, and discipline were also recorded for all individuals measured.

Means and standard deviations of age, BCS, the 4 morphometric measurements, and BW were calculated for all individuals and grouped into breeds and by BCS, gender, breed type, and discipline. Univariate analyses were performed on BCS by age, gender, discipline, and breed type using either linear regression or ANOVA with pairwise comparisons corrected for multiple comparisons using the Tukey honestly significant difference method if necessary.

Determination of Breed Types

Individuals were divided into 4 breed types on the basis of existing knowledge of breeds and conformational difference. These groupings were then confirmed by performing multivariate ANOVA analyses both between and within the breed types. When division was uncertain, a sensitivity analysis was performed to determine if additional breed types were necessary.

Estimation of BW

All individuals were used to develop a linear model to predict scale weight using height, body length, girth and neck circumferences, and breed type. Models based on log-transformed versions of these variables were also considered, and the best model was selected on the basis of model diagnostics and the Akaike information criterion (**AIC**). Leave-one-out cross-validation was used to ensure that data were not overfit. The final model was used to estimate BW for all horses in the sample and then compared to existing BW estimation equations (Hall, 1971; Owen et al., 2008) using mean-squared error (**MSE**). The MSE was computed using leave-one-out cross-validation to ensure a more valid comparison with existing equations.

Estimation of Ideal BW

Horses and ponies with a BCS of 5 were used to develop ideal BW equations as these individuals were assumed to have an ideal BW. This assumption has previously been made in horses (Harker et al., 2011) and dogs (Mawby et al., 2004), which have a similar BCS scale. Only height, body length, and breed type were considered because girth and neck circumferences are both affected by adiposity (Carter et al., 2009; Thatcher et al., 2012). These 3 variables were used to develop a linear model to predict scale weight in individuals with a BCS of 5. Models based on log-transformed values of these variables were also considered. The best model was selected on the basis of model diagnostics, likelihood ratio tests, and the AIC. The best model was used to predict ideal BW for all individuals in the sample. The average difference between ideal and actual BW was also calculated for each BCS.

Development of a BW Score

Overweight and underweight equids were classified as individuals with a BCS ≥ 7 and ≤ 4, respectively (Henneke et al., 1983; Harker et al., 2011; Thatcher et al., 2012). To assess the likelihood of being over- or underweight on the basis of height, body length, girth and neck circumferences, and breed type, an ordinal logistic regression was developed on the basis of BCS using the difference between estimated actual BW and ideal BW, the neck to height ratio, the girth to height ratio, and breed type. A model was selected on the basis of AIC. The linear predictor from the selected model was considered the BW score and was standardized to a 0 to 100 scale by finding the percentile of each score among horses with a BCS of 5, assuming a normal distribution. Finally, cutoff values for both over- and underweight horses were found using receiver operating characteristic (**ROC**) curve analysis, and sensitivity and specificity were calculated.

RESULTS AND DISCUSSION

Population Description

Data were collected from 629 individuals representing 16 breeds and 1 coat color breed registry, as well as several mixed-breed individuals (Table 1). Animals ranged in age from 3 to 32 yr with a mean (±SD) of 11.8 ± 5.6 yr. Older individuals were more likely to be thin (P = 0.009). Individuals with BCS of 2 and 3 had mean ages of 24 and 21 yr, respectively, whereas individuals with BCS of 7 and 8 had mean ages of 12 and 13 yr, respectively. Individuals with a BCS of 5 had a mean age of 11 yr. The majority of individuals were geldings (n = 341) or mares (n = 286), and gender was not associated with BCS (P = 0.975). Body condition score ranged from 2 to 8 with a mean (±SD) of 5.6 ± 0.9. Ponies and saddle horses had higher BCS compared to Arabian and stock horses ($P \leq$ 0.001; Table 2). Individuals participating in speed events (n = 292) and all-around individuals (n = 267) who participated in more than 1 discipline were the 2 most common performance disciplines. Those participating in speed events had a lower mean (±SD) BCS of 5.4 ± 1.0 compared to those classified as all-around animals, who had a mean (±SD) BCS of 5.7 ± 0.9 (P = 0.003). Body condition scores in other performance disciplines, including English (n = 21) and western (n = 44) pleasure, driving (n = 1), and halter (n = 1), were not different from one another or from animals in speed events or those classified as all-around individuals ($P \geq$ 0.05). The performance discipline of 3 individuals was unknown.

The mean BCS of 5.6 observed in the present study is similar to results observed by Wagner and Tyler (2011), Brooks et al. (2010), Owen et al. (2008), and Pratt-Phillips et al. (2010), who report mean BCS of 5.4, 5.7, 5.7, and 5.8, respectively. Similar to our results, Thatcher et al. (2012) also found that middle-aged individuals (9 to 12 yr) were more likely to be overconditioned, and Donaldson et al. (2004) also found no difference in BCS between mares and geldings. Our results also agree with Harker et al. (2011) and Pratt-Phillips et al. (2010), who found that pony breeds had higher BCS compared to other horses, and with Bruce et al. (2010), who found that 69 ponies had a mean BCS of 6.3. Lawrence et al. (1992) also observed that endurance horses had lower mean BCS of 4.7. It is commonly accepted that speed event and endurance horses, which are expected to perform at elevated speeds, would benefit from having lower BCS compared to horses in other disciplines. Excessive body fat has been shown to be

Table 1. Description of breed types, breeds, and mean age, BCS, morphometric measurements, and BWs of 629 adult equines obtained at 2 shows in Minnesota in 2011 (mean ± SD)

Breed type	Breed or breed registry	Total *n*	BCS = 5, *n*	BCS	Age, yr	Height, cm	Body length, cm	GC,[1] cm	NC,[2] cm	Scale weight, kg
Arabian	Arabian	19	6	5.2 ± 1.0	14 ± 6	148 ± 5	144 ± 8	176 ± 8	89 ± 5	408 ± 43
	Arabian × saddle horse crosses	17	6	5.7 ± 1.1	17 ± 6	145 ± 10	146 ± 8	176 ± 10	93 ± 7	413 ± 70
	Arabian × stock horse crosses	26	10	5.4 ± 0.8	14 ± 6	148 ± 6	149 ± 6	180 ± 8	91 ± 6	447 ± 46
Pony	Pony crosses[3]	34	9	5.9 ± 1.0	15 ± 6	133 ± 9	139 ± 10	165 ± 13	87 ± 9	352 ± 72
	Shetland[3]	6	1	5.5 ± 2.0	15 ± 5	119 ± 4	122 ± 5	146 ± 8	77 ± 7	233 ± 29
	Welsh[3]	13	2	6.5 ± 1.0	16 ± 6	127 ± 10	134 ± 10	160 ± 11	87 ± 11	309 ± 63
Saddle	American Saddlebred	6	0	6.0 ± 0.0	15 ± 3	156 ± 3	153 ± 10	185 ± 9	96 ± 6	483 ± 34
	Bashkir Curly	1	0	8	10	154	159	196	114	501
	Morgan[3]	6	2	5.7 ± 1.2	11 ± 5	153 ± 3	152 ± 2	185 ± 4	95 ± 8	491 ± 26
	Mustang[3]	3	1	6.3 ± 1.2	15 ± 8	146 ± 5	148 ± 11	176 ± 9	91 ± 6	433 ± 93
	Paso Fino	1	0	7	12	135	137	163	96	326
	Pinto	2	0	6.5 ± 0.7	15 ± 8	147 ± 2	150 ± 9	180 ± 1	97 ± 1	465 ± 37
	Rocky Mountain	1	0	8	3	143	142	175	90	421
	Tennessee Walking Horse[3]	1	1	5	8	146	150	179	91	439
Stock	American Paint Horse[3]	120	47	5.6 ± 0.8	10 ± 5	153 ± 6	157 ± 9	187 ± 8	95 ± 6	511 ± 56
	American Quarter Horse[3]	324	144	5.5 ± 0.9	11 ± 5	153 ± 6	158 ± 8	187 ± 7	95 ± 6	516 ± 52
	Appaloosa[3]	29	13	5.5 ± 1.0	11 ± 5	155 ± 7	159 ± 9	190 ± 8	96 ± 6	529 ± 61
	Appendix	18	9	5.2 ± 0.7	12 ± 6	156 ± 5	158 ± 7	188 ± 5	95 ± 6	525 ± 41
	Thoroughbred	2	0	3.5 ± 0.7	17 ± 1	157 ± 3	150 ± 2	182 ± 1	99 ± 4	479 ± 37
Population mean		629	247	5.6 ± 0.9	12 ± 6	151 ± 9	155 ± 11	184 ± 11	94 ± 7	489 ± 79

[1]Girth circumference.

[2]Neck circumference.

[3]Equines in these breeds included pure-bred equines and multiple breed crosses that included one parent from the designated breed.

detrimental to performance by increasing the amount of work needed to move the body and difficulties with thermoregulation, which increase as BCS increases (Webb et al., 1990; Scott et al., 1991).

The distribution of BCS observed in this study was similar to the distribution of BCS observed by other researchers (Table 3). Although the BCS distribution was similar among studies, the terminology used to describe the animals was not. Thatcher et al. (2012) described equids with a BCS ≤ 3 as underweight, whereas Harker et al. (2011) described equids with a BCS ≤ 4 as underweight. Thatcher et al. (2012) classified equids with a BCS ≥ 7.5 as obese, whereas Pratt-Phillips et al. (2010) classified animals with a BCS > 7 as obese. Conversely, Harker et al. (2011) classified equids with a BCS of 5 as ideal, 6 as overweight, 7 as fat, and 8 as obese. Finally, Henneke et al. (1983) classified individuals with a BCS of 3 as thin, 5 as moderate, 7 as fleshy, and 8 as fat. For the purposes of this analysis, individuals with a BCS ≥ 7 were classified simply as overweight, whereas individuals with a BCS ≤ 4 were classified as underweight. Standardizing language used to describe BW and adiposity when relying on BCS is necessary to aid in comparing research results and to allow a clear discussion around the issue.

Using this benchmark, 51% of equids evaluated by Thatcher et al. (2012), 37% evaluated by Donaldson et al. (2004), 21% evaluated by Harker et al. (2011), 20% evaluated by Pratt-Phillips et al. (2010), 19% evaluated by Brooks et al. (2010), and 14% of individuals in the current study would be considered overweight, with a BCS ≥ 7. The percentage of horses identified as overweight by Thatcher et al. (2012) is greater than other researchers; however, this could be partially explained

Table 2. Body condition score, age, morphometric measurements, and BW of 4 equine breed types obtained at 2 shows in Minnesota in 2011 (mean ± SD)

Breed type	Total *n*	BCS = 5, *n*	BCS	Age, yr	Height, cm	Body length, cm	GC,[1] cm	NC,[2] cm	Scale weight, kg
Arabian	62	22	5.4 ± 1.0	15 ± 6	148 ± 7	147 ± 8	178 ± 8	91 ± 6	426 ± 55
Pony	53	12	6.0 ± 1.2	15 ± 6	130 ± 10	136 ± 11	162 ± 13	86 ± 10	328 ± 76
Saddle	21	4	6.2 ± 1.0	12 ± 5	151 ± 6	150 ± 8	182 ± 9	96 ± 7	465 ± 55
Stock	493	213	5.5 ± 0.9	11 ± 5	153 ± 6	158 ± 8	187 ± 7	95 ± 6	515 ± 53

[1]Girth circumference.

[2]Neck circumference.

Table 3. Definition and distribution of equine BCS observed in current and past studies

BCS	Current study (n = 629), %	Thatcher et al., 2012 (n = 300), %	Harker et al. (2011) (n = 331), %	Brooks et al. (2010) (n = 1,207), %	BCS description[1]
1	0	0	0	0	Poor
2	<1	0	0	0	Very thin
3	1	2	0	2	Thin
4	7	5	4	7	Moderately thin
5	40	16	35	38	Moderate
6	38	26	41	34	Moderately fleshy
7	12	32	16	14	Fleshy
8	2	15	4	4	Fat
9	0	4	0	1	Extremely fat

[1]Description of BCS from Henneke et al. (1983).

by researchers determining BCS during the summer months when horses have access to calorically dense pasture. Conversely, only 8% of equids in the current study were considered thin, with a BCS $\leq$ 4, which is similar to previous research (Table 3).

In 1998 and 2005, USDA National Animal Health Monitoring System (**NAHMS**) studies estimated that approximately 1.5% and 3.4%, respectively, of the U.S. horse population was overconditioned or obese (NAHMS, 1998, 2005). However, these estimates were based on surveys of horse owners who self-reported the condition of their horse rather than professional assessments of equid BCS using the Henneke et al. (1983) system. The NAHMS survey results provide further evidence that the ability of untrained equine owners to accurately assess BCS is poor (Mottet et al., 2009; Thatcher et al., 2012). These results also support the theory that horse owners are becoming increasingly accustomed to seeing overweight horses and may consider this the new normal (Harker et al., 2011). We encourage the equine industry and university extension programs to provide training to owners on accurate assessment of equid BCS and to establish and utilize a consistent definition for over- and underweight equids.

Evaluation of Breed Types

Breeds were divided into 4 breed types, including Arabian, saddle, stock, and pony (Table 1). To confirm these groupings, a multivariate ANOVA was performed on the 4 morphometric measurements and scale weight, and pairwise differences between all 4 types were different ($P < 0.03$) after the Bonferroni-Holm correction. To determine if additional groupings were necessary, a multivariate ANOVA was performed within each breed type, using breed as the predictor. For Arabian and Stock types, the additional variability explained by breed was small ($R^2 = 0.07$ and 0.009, respectively). For the pony type, the additional variability explained by breed was moderate ($R^2 = 0.22$) and significant ($P = 0.02$). Pairwise differences within the pony breed type suggested that the Shetland breed was different ($P = 0.0084$) after Bonferroni-Holm correction. Therefore, all equations were considered using an additional breed type for the Shetland ponies; however, no significant ($P \geq 0.05$) or practical differences were found. Thus, equids in the Shetland breed were included in the pony breed type for all models. For the saddle type, all breeds had fewer than 6 individuals, and the variability explained by breed was larger ($R^2 = 0.54$) but not significant ($P = 0.42$). Consequently, the small sample sizes resulted in the inability to conclusively assign these breeds to the saddle type group. In addition, evidence that the saddle horses as a group were different than the other breed types led to the decision that this breed type would not be included in equations.

Groupings of equid breed types were similar to groupings previous researchers have made (Pratt-Phillips et al., 2010). Brooks et al. (2010) showed a clear distinction in the morphometric conformation of different breeds; however, conformational difference tended to be related to different types of use. Mean morphometric measurements for each breed type were also similar to previous studies (Table 2). Owen et al. (2008) observed a mean height of 135 cm, scale weight of 344 kg, and BCS of 5.7 for 68 ponies, which are similar to the values observed in the present study. Sadek et al. (2006) measured 166 Arabians and determined that height averaged 149 and 150 cm, body length averaged 147 and 142 cm, and girth circumference averaged 178 and 172 cm for mares and stallions, respectively, similar to the current results.

Estimation of BW

Girth circumference and body length from all individuals (n = 629) were used to develop BW estimation equations. First, a model similar to the one proposed by Hall (1971) and Owen et al. (2008) was considered, and the new denominators found for the 3 breed types were estimated BW (kg) = [girth (cm)^2 × length (cm)]/10,996, 11,069, 10,838 for Arabians, ponies, and stock horses, respectively ($R^2 = 0.89$; MSE = 26 kg).

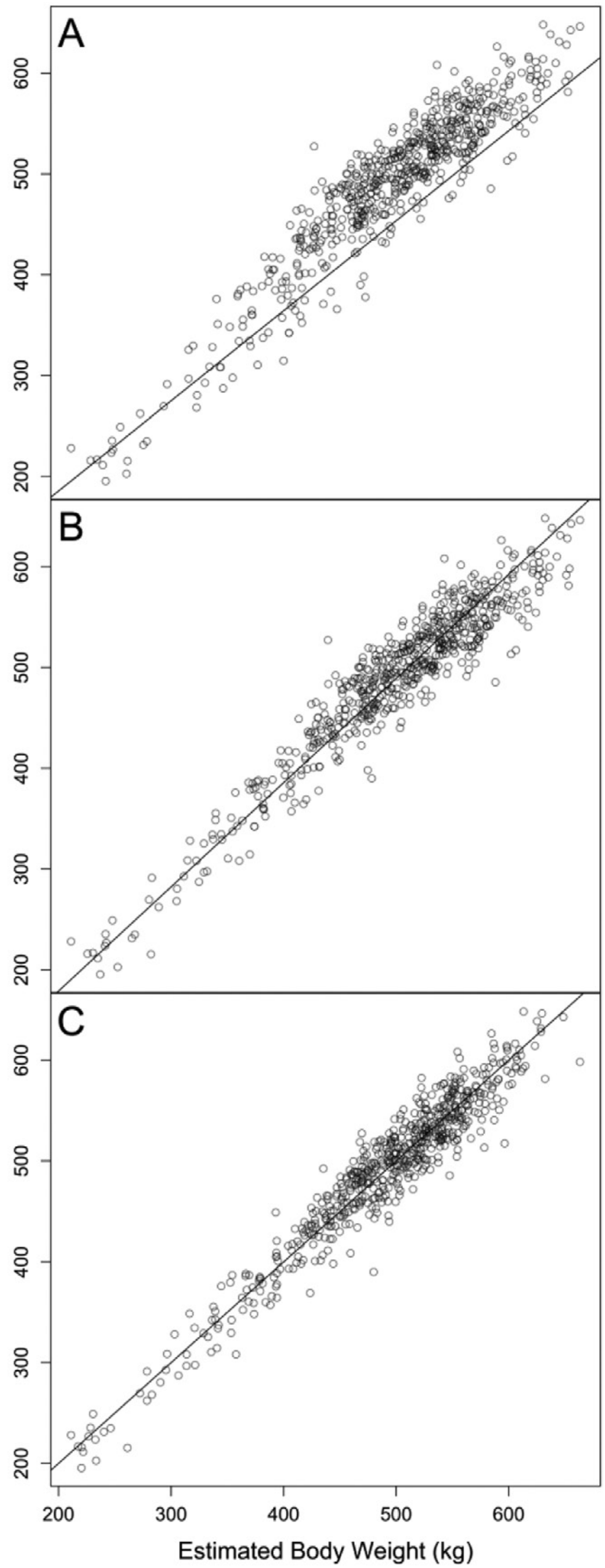

Figure 2. Comparison of estimated equine BW with actual BW using 3 different equine BW estimation equations. (A) Equine BW estimated using equations developed by Hall (1971) and Owen et al. (2008). (B) Equine BW (kg) estimated by [girth (cm)^2 × body length (cm)]/10,996, 11,069, and 10,838 for Arabians, ponies, and stock horses, respectively. (C) Equine BW (kg) estimated by [girth (cm)$^{1.486}$ × length (cm)$^{0.554}$ × height (cm)$^{0.599}$ × neck (cm)$^{0.173}$]/3,596, 3,606, and 3,441 for Arabians, ponies, and stock horses, respectively.

To further improve equid BW estimation equations, height and neck circumference were added to the model, and all powers were permitted to vary by fitting an additive model on the log scale of all variables. The resulting equation for estimated BW (kg) was [girth (cm)$^{1.486}$ × length (cm)$^{0.554}$ × height (cm)$^{0.599}$ × neck (cm)$^{0.173}$]/3,596, 3,606, and 3,441 for Arabians, ponies, and stock horses, respectively ($R^2 = 0.92$; MSE = 22 kg).

Previously, Hall (1971) determined that BW (kg) in adult horses (>147 cm at the withers) could be estimated by [girth circumference (cm)^2 × body length (cm)]/11,880, whereas Owen et al. (2008) determined that BW (kg) in adult ponies (<147 cm at the withers) could be estimated by [girth circumference (cm)2 × body length(cm)]/10,787. The equations developed by Hall (1971) and Owen et al. (2008) used height to determine the appropriate equation when estimating either horse or pony BW. In the current study, breed type was used to determine the appropriate equation. Previously, including breed type was shown to improve accuracy in estimating the BW of Criollo horses (Neder et al., 2009) and miniature horses with a height ≤86.4 cm (Bruce et al., 2010). It is also common for different groups of equids to have separate BW estimate equations. Equations using girth circumference (cm)^2 × body length (cm) have also been developed for weanlings with a denominator of 10,080 (Wilson et al., 2003) and yearlings with a denominator of 10,836 (Wilson et al., 2005). It makes sense that including more specific information, such as breed type, height, and neck circumference, would lead to improved BW estimations.

Figure 2 shows a comparison of the difference between scale weight and estimated weight from the original equations by Hall (1971) and Owen et al. (2008), the same equation but with new denominators based on breed type and the new equation using height, neck and girth circumferences, body length, and a denominator based on breed type. When the original equid BW estimation equations (Hall, 1971; Owen et al., 2008) were applied to the current data, equid BW was underestimated ($R^2 = 0.42$; MSE = 49 kg). However, including girth and neck circumferences in addition to body length, height, and breed type resulted in the most accurate estimation of equid BW, but the equations could prove too complex and difficult for many horse owners to remember and utilize.

To remove the technical barriers that may inhibit some equine owners and professionals from utilizing the new BW-related equations, a fee-based app was developed for use on Apple and Android operating systems. App users select a breed type (Arabian, miniature horse, pony, saddle, or stock) and enter the equid's body length, height, neck circumference, and girth circumference, and the app calculates the equid's estimated BW, ideal BW, and BW score. Since data on miniature and saddle-type horses were not available in the current study, only

Table 4. Scale weight, ideal weight, and the difference between them based on BCS for 3 equine breed types obtained at 2 shows in Minnesota in 2011 (mean ± SD)

	Arabian			Stock			Pony		
BCS	Scale weight, kg	Ideal[1] weight, kg	Difference, kg	Scale weight, kg	Ideal weight, kg	Difference, kg	Scale Weight, kg	Ideal Weight, kg	Difference, kg
2				369	472	–103[2]	216	251	–36[2]
3				445 ± 31	491 ± 48	–45 ± 50	308	324	–16[2]
4	382 ± 63	402 ± 57	–20 ± 26	488 ± 43	507 ± 34	–18 ± 24	249	234	15[2]
5	414 ± 38	414 ± 39	0 ± 19	511 ± 49	511 ± 41	0 ± 25	336 ± 50	336 ± 50	0 ± 17
6	456 ± 46	441 ± 36	15 ± 27	526 ± 52	516 ± 44	10 ± 29	327 ± 80	325 ± 73	2 ± 26
7	428 ± 71	402 ± 54	25 ± 18	530 ± 49	499 ± 40	31 ± 29	352 ± 88	332 ± 85	20 ± 15
8	465	383	82[2]	473 ± 137	432 ± 89	41 ± 50	307 ± 92	276 ± 76	31 ± 20

[1]Ideal BW (kg) calculated as [length (cm) × 2.8] + [height (cm) × 4.2] – 611, 606, and 577 for Arabians, ponies, and stock horses, respectively.

[2]Breed types where only 1 equine was observed per BCS were not included in means discussed.

BW is estimated for saddle type and miniature horses on the basis of equations developed by Hall (1971) and Bruce et al. (2010), respectively. The app, titled "Healthy Horse," is available online in iTunes and Google Play stores. We encourage other researchers to develop estimated BW and ideal BW equations and BW scores for warmblood, saddle type, draft, and miniature horses and other equids, including mules (*Equus caballus* × *Equus asinus*) and donkeys (*Equus asinus*).

Estimation of Ideal BW

The best model to estimate ideal BW included body length, height, and breed type. Ideal BW (kg) was estimated by taking [length (cm) × 2.8] + [height (cm) × 4.2] – 611, 606, and 577 for Arabians, ponies, and stock horses, respectively (R^2 = 0.86; MSE = 24). Models were also fit on the log scale, which would have resulted in an ideal weight range that increased with weight, but model diagnostics showed that the variance was more constant on the original scale.

The MSE of 24 kg translates into approximately a 96-kg ideal BW range (at the 95% confidence level), or about 20% of an adult equid's (500 kg) BW. Although this BW range may be acceptable for Arabians (mean weight of 426 kg) and stock horses (mean weight of 515 kg), it may not be acceptable or practical for ponies (Table 2). The average BW of ponies in the current study was 328 kg; a 96-kg range in ideal BW would account for 30% of their BW.

However, in the model used for adult humans, the range of ideal BW increases with height and is commonly expressed as body mass index (**BMI** = weight [kg]/height2 [cm]). In humans, a 183-cm tall adult human should have an average weight of 73 kg, with an acceptable BW range of 63 to 83 kg (Willett et al., 1999). In this case, the acceptable weight range accounts for 27% of BW. Using BMI to assess being over- or underweight in humans is commonly used and accepted, even though the ideal BW range accounts for 27% of BW. The ideal BW equations developed here for equids have a range of 20% to 30% of BW and appear to be similar to commonly used and accepted human guidelines. Body mass index has also been calculated for horses using the same equation. Donaldson et al. (2004) found a significant correlation (r^2 = 0.60) between equid BCS and BMI. However, BMI is not normally calculated or used in evaluation of equid health and BW management.

The amount of weight loss or gain necessary to achieve a change in BCS has not been well studied. Heusner (1993) estimated an increase in 1 unit of BCS required 16 to 20 kg of weight gain for mature horses. However, researchers have suggested that the amount of weight gain (or loss) necessary to change a BCS likely depends on the mature weight of the equid (NRC, 2007). In the current study, the amount of BW, as measured by a scale, necessary to change 1 BCS averaged 34, 29, and 28 kg for Arabians, ponies, and stock horses, respectively (Table 4), almost double what was suggested previously (Heusner, 1993). However, in all breed types, there were examples of individuals with greater BCS who weighed less than individuals with lower BCS. This is likely due to the physical size and the mature BW range of equids within breed types. For example, a smaller-framed (i.e., body length and height) pony with a BCS of 7 could weigh less than a larger-framed pony with a BCS of 5. When ideal BW was estimated for each equid and subtracted from the scale weight, the differences between each BCS averaged 15, 10, and 17 kg for Arabians, ponies, and stock horses, respectively (Table 4), and were similar to amounts suggested by Heusner (1993). By taking the difference between scale and ideal weight, physical size (i.e., height and body length) and mature BW of the animal are taken into consideration.

Ideal BW and BW amounts necessary to change 1 BCS have practical implications for achieving weight gain or loss in horses and ponies. Owners and professionals can use the calculated ideal BW and amount necessary to change BCS as a target when designing diets for over- or underweight animals. Frequently, horse owners overlook the need to design diets, and therefore caloric intake, for the desired BW vs. the current BW. Likewise, utilizing the BW amounts necessary to change 1 BCS can be used to further refine diets and caloric intakes. Ideally, both methods should be used to induce weight gain or loss in collaboration with an equine nutritionist and veterinarian.

One potential criticism of the ideal BW equations is classifying individuals with a BCS of 5 as ideal and using only measurements from these equids to develop the equations. Several researchers have considered equids with a BCS of 5 as ideal or optimal from body condition (Harker et al., 2011), thermoregulation (Webb et al., 1990), nutritional (Webb et al., 1990; Scott et al., 1991), reproduction (Henneke et al., 1983), and performance (Scott et al., 1991) standpoints. Furthermore, it is generally accepted within the equine industry that individuals with a BCS of 5 are considered to be in ideal body condition or are ideal for their discipline and serve as a standard in show and performance arenas. Owners should be reminded that the Henneke et al. (1983) BCS system was not developed to reflect BW or fitness, but rather, body fat or adipose percentage. Although BCS is frequently used to determine acceptable BW by the equine community and general public, it is our hope that estimated ideal BW and BW amounts necessary to change 1 BCS within breed type will now be used, along with BCS, to accurately assess healthy weight goals for adult horses and ponies.

Development of a BW Score

To assess the likelihood that an individual is over- or underweight on the basis of morphometric measurements, an ordinal logistic regression was fit on BCS. This resulted in the following equation (without intercept): 0.021 × (estimated ideal BW − estimated BW) + 14.25 × (neck circumference:height ratio) + 8.19 × (girth circumference:height ratio) + 0, 0.497, and 0.045 for Arabians, ponies, and stock horses, respectively. To obtain a score between 0% and 100%, scores were converted to a percentile by standardizing the mean (18.68) and standard deviation (0.95) of the score for equids in the same breed type with a BCS of 5 and finding the normal percentile. Normalization of the score allows for reporting of an individual's percentile relative to "normal" horses with a BCS = 5.

For example, an equid that is in the 90th percentile has a BW score that is greater than 90% of normal individuals in the same breed type. Similarly, an equid that falls in the 10th percentile has a BW score that is less than 90% of individuals. A ROC curve analysis was employed to determine cutoff values for overweight (BCS ≥ 7) and underweight (BCS ≤ 4) individuals, and

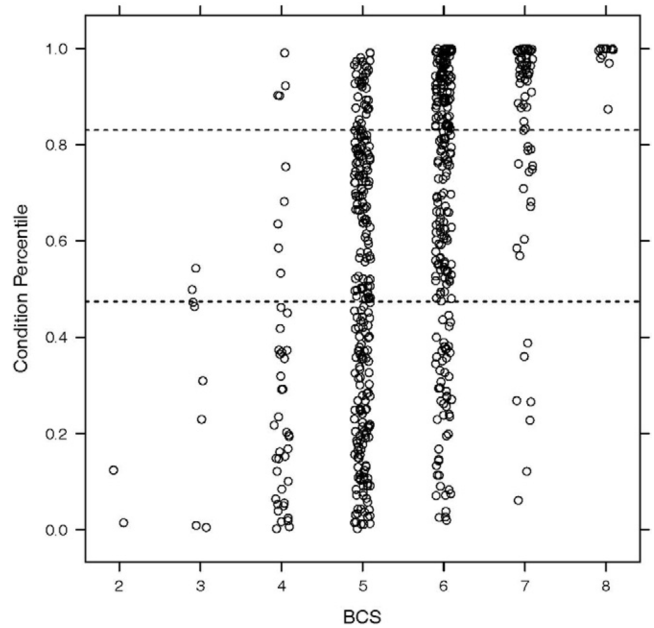

Figure 3. Determination of cutoff values for overweight (BCS ≥ 7) and underweight (BCS ≤ 4) individuals based on receiver operating characteristic curve analysis of 629 equids exhibited at 2 shows in Minnesota in 2011.

cutoff values were the 83rd and 48th percentiles, respectively. On the basis of these cutoff values, the sensitivity was 0.75 and 0.792, and the specificity was 0.75 and 0.69 for detecting overweight and underweight horses, respectively (Fig. 3). The sensitivity and specificity values suggest that single cutoff values may not be useful in practical management settings, providing further evidence that equid owners should seek out professional assistance and use estimated ideal BW, BW amounts necessary to change 1 BCS, and BCS to accurately assess healthy weight goals for adult equids.

Summary

Equids exhibited at 2 Minnesota championship shows had a mean BCS of 5.6, and 14% of equids were considered overweight, with a BCS ≥ 7. Ponies and saddle horses had higher BCS, equids in speed events had lower BCS, and older equids were more likely to be thin. Dividing horses into breed types with a unique denominator and adding height and neck circumference resulted in improved BW estimation equations. Height and body length were used to develop ideal BW equations, and differences between ideal BW and scale weight averaged 10 to 17 kg per BCS. A BW score was developed, and the model suggested cutoffs at the 48th and 83rd percentiles for underweight and overweight individuals.

Development of more accurate equations to estimate equid BW and the newly developed ideal BW equations should help equid owners and professionals manage horses and ponies, especially individuals that are over- or underweight. Owners can use results from both equations, along with BCS, to better manage equid BW, to design diets with appropriate caloric intake, and to establish BW goals. We encourage the equine industry and university extension programs to provide training to owners on proper use and accurate assessment of BCS. We also challenge the equine industry to adopt consistent language when classifying horses as underweight, overweight, and obese. These adoptions will make comparison of research results possible and will help bring further awareness to the growing problem of excessive BW in the equine industry.

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