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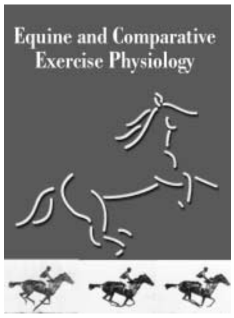

A simple field technique for estimation of body surface area in horses and ponies

JC Sneddon[1,*], R Walton[2] and A Bond[3]

[1]School of Biological & Earth Sciences, Liverpool John Moores University, Byrom Street, Liverpool L3 3AF, UK
[2]Woodville Riding School and Boarding Kennels, Raby Road, Thornton Hough, Wirral, UK
[3]14 Cooper Road, Wetherby, West Yorkshire, LS22 6RX, UK
*Corresponding author: j.c.sneddon@livjm.ac.uk

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Abstract

This study aimed to produce a weight-independent algorithm for determination of body surface area (BSA; cm^2) to within 5% accuracy of the directly determined value in selected horses and ponies under field conditions. Quantification of BSA in equines has applications in the fields of energy budgeting, growth, thermoregulation, conformation and drug kinetics. A simple algorithm for determining BSA to ±5% accuracy was produced for Shetland ponies, Shire horses, Welsh Mountain Section A ponies and Hanoverian mature horses and foals. The accuracy of the method was ±8% for Welsh Mountain-type ponies and Hanoverian two-year-olds. The data were produced by tiling of the shoulder region on one side of the animal with chalk and adapting a simple geometrical integrative technique. Linear anthropometric measurements were of limited use in predicting BSA in that they produced algorithms of ±5% accuracy for ponies of uniform conformation only (Welsh Mountain Section A ponies). The relevant equations were:

$$\text{Body surface area} = \frac{\text{surface area of shoulder region on one side} \times 2}{10} \times 100$$

for Arab-based breeds (Welsh Mountain-type and Section A ponies and Hanoverian horses and foals) and

$$\text{Body surface area} = \frac{\text{surface area of shoulder region on one side} \times 2}{16} \times 100$$

for UK native breeds (Shetland ponies and Shire horses), where 'surface area of shoulder region on one side' was defined by the anterior margins of the *supraspinatus* and *deep pectoral*, and the posterior margin of the *triceps* muscles. This tiling procedure fulfilled the aim of the study and also provided quantitative information on proportional differences in areas of body regions between and within these selected breeds.

Keywords: horses; surface area; measurement

Introduction

Body surface area (BSA; total or effective) evidently has a fundamental impact on energy expenditure in mammals, with associated physiological phenomena as diverse as thermoregulation and drug distribution in circulation[1]. Direct estimation of BSA under field conditions in large mammals continues to constitute a surprising area of neglect in the scientific literature.

In horses, approximately 60% of the energy produced via metabolic processes is lost as heat across the body surface at rest, and up to 80% is lost during exercise or under harsh environments[2–6]. Horses have a relatively small surface area in relation to their volume (1:90–100 *vs.* 1:35–40 in humans[6]) and so are particularly prone to overheating[5–7]. Horses and ponies encompass a wide range of body size. They are also kept under a range of husbandry conditions, for a range of sporting and leisure purposes, and are generally long-lived compared with other species of commercial livestock. As with other livestock, their nutritional requirements vary widely not only with age, metabolic status and body size[8], but also with work requirements and husbandry conditions. Calculation of total or proportional heat loss through the body surface is obviously not possible without a reasonable estimation of BSA, or at least effective BSA, i.e. that component of surface area exposed to the environment[8]. Accurate data on the influence of surface area on energy expenditure are currently lacking from standard data on nutritional requirements in domestic animals and livestock[9–11]. Furthermore, comparative metabolic research still contains controversy on the appropriate metabolic exponent/exponents of body weight applicable to commercial livestock[8,12]. There is considerable backing for the influence of surface area as an exponent (body weight$^{0.67}$), particularly for young animals[8]. More recently[12] it has been argued that fasting metabolic rate is not always an appropriate yardstick for metabolic comparisons between species, given the fundamental influence that change in physiological state has on these exponents. Variation in physiological status is linked with variation in heat production. This brings a value for BSA into any discussion of metabolic power laws.

Weight-based and model-based methods of estimating BSA in mammals

Using Rübner's unpublished information, Meeh[13] devised the widely published equation:

$$S = kM_{\mathrm{b}}^{2/3},$$

where k is an empirically determined constant which varies for each species, S is surface area and M_{b} is body mass. Large variations (10–20%) exist in the value of k but have little (<10%) impact on the value for surface area that is acceptable for many applications where rough estimations of surface area are required[1]. A theoretical analysis of appropriate exponents for the Meeh equation across species and ages can be found[8,14,15], while the arguments continue[1]. Exponents of body weight ranging from 0.6 to 0.8 have been reported as providing acceptably accurate estimations of BSA in a range of large mammals[1,16,17]. Pragmatism usually dictates that estimations of BSA in mammals be based on some derivation of Meeh's equation, especially in comparative studies[5,13,17–20].

A disadvantage of a weight-based estimation of BSA is that no account can be taken of *effective* surface area, i.e. the area of surface exposed to the environment, if an animal changes posture and pelt status[21]. In animals showing marked variations in body shape across a species, the Meeh equation and all its derivatives cannot be applied as the exponent of 2/3 assumes self-similar scaling of the body geometry. In addition, weight-based algorithms for estimation of BSA are often based on estimations of body weight, as there are rarely facilities for direct measurement of body weight in field situations. Weight-calibrated measuring tapes commonly used for such estimations introduce another layer of assumption into any estimation of BSA.

An alternative approach for estimating BSA in mammals has been that of simple mathematical modelling[21]. Data for a wide diversity of mammals imply relatively constant partitioning of weight and surface area among the body segments (head:trunk, forelimbs:hind limbs). A simple model consisting of three classes of cylinder, representing the three classes of body segment, was used to test for geometric similarity by comparison with an independent subset of data. It was concluded that many adult land mammals largely do exhibit geometric similarity over a substantial weight range[21].

Direct methods for measurement of BSA in mammals

Empirical determination requiring direct measurement of BSA in mammals has involved the following:

- covering animals with cloth or paper or another substance;
- using a planimeter;
- resolving the body surface to geometrical shapes;
- skinning;
- the use of photographic silhouettes; and
- integration with a roller of known surface.

These methods are reviewed and discussed elsewhere[1,16]. Skinning animals produces unacceptable degrees (up to 60%) of systematic error in the estimation of BSA, due to an uncontrollable degree of skin stretching[22]. Tiling standing animals appears to produce the most reproducible results[16].

Estimating surface area from cadavers[5,6] produces bias in the data owing to the lack of standardization in measurement procedures and/or alterations in the surface area to volume ratio that can be inferred from animals in a supine position and/or rigor mortis. Marlin (D Marlin, 1995, personal communication) tiled three Thoroughbred horses with 2 cm^2 paper tiles and found no significant differences between left and right sides, and systematic error to be within 5% with three repetitions. McDowell *et al.*[16] devised a simple accurate integrator for tiling the body surface of cattle with chalk. Systematic error between replicates and sides was surprisingly small (±0.043%). A modification of this method was thus developed for the current study.

The aim of this study was to produce a pragmatic, weight-independent algorithm for determining equine body surface area to within 5% accuracy of a direct

Table 1 Physical characteristics of experimental animals

Breed	*n*	Age range (years)	Height range (cm)	Estimated weight range (kg)	Condition score*	Sex data	
						♀	♂
Shire Horse	8				2–4	6	2
Shetland Pony	8				2–4	4	4
Welsh Mountain Pony Section A[24]	7	11–21		289–298[a]	2–5	6	1
Welsh Mountain Pony type[23]	7	5–25	121–138			4	3
Hanoverian Horse							
Foals	6	0.25–0.33		206–230[b]	2–3	2	4
Two-year-olds	6	2		520–620[b]	4–5	5	1
12-year-olds	6	12		560–839[b]	3–5	1	5

[a] Determined with an electronic balance.
[b] Determined using a weigh band.
* After Carroll and Huntington[35].

measurement on selected equine breeds, including foals and two- and 12-year-old Hanoverian horses, under field conditions.

Data for the algorithms were taken from a series of students' honours projects undertaken between 1995 and 2002. Arab-based breeds (Welsh Mountain-type and Section A ponies and Hanoverian horses) and UK native breeds (Shetland ponies and Shire horses) - encompassing a wide range of equine body size - were used as experimental subjects.

As none of the experimental subjects were in heavy work and thus subject to large variations in muscle development, it was hypothesized that a relatively invariant region of the body surface dominated by a large area of bone would provide the most useful parameter for such an algorithm, e.g. the surface area of the shoulder region.

Material and methods

Experimental animals

The studies were conducted between December 1996 and March 1997 for Welsh Mountain-type ponies[23], Welsh Mountain Section A ponies[24], and Shire horses and Shetland ponies[25]. The Hanoverian horses were studied in June - July 2001[26]. The Welsh Mountain-type ponies were located at The Wirral and Woodville Riding Schools on the Wirral peninsula[23], and the Section A ponies at Leahurst, the Veterinary Field Station of Liverpool University, also on the Wirral peninsula[24]. The Shires and Shetlands were located at single establishments in Congleton (Cheshire) and Wetherby (North Yorkshire), respectively[25]. The Hanoverian horses were located at Woodville Riding School on the Wirral peninsula[26]. All animals except the Hanoverians were in set winter coat; the Hanoverians were in set summer coat. All horses were out at grass. Their physical characteristics are summarized in Table 1.

Anthropometric and surface area measurements

Horses were groomed clean and manes were tied up clear of the neck. The linear anthropometric

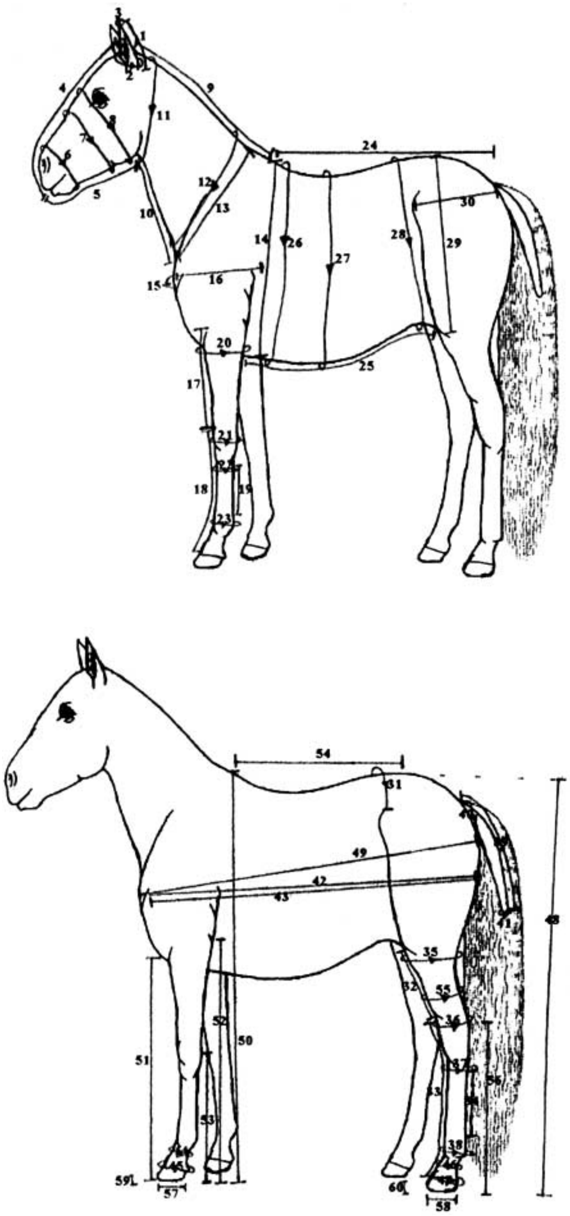

FIG. 1 Diagrams showing the positions of linear anthropometric measurements (cm) used in the analysis to test for a surface area algorithm (refer to Tables 2 and 3 for anatomical descriptions of the measurements)

measurements made are displayed and described in Fig. 1 and Tables 2 and 3. Regional area measurements were made on the head, neck, shoulder, barrel, quarters and upper and lower fore and hind legs, separated at knee and hock, respectively[27]. Appropriate combinations of a talcum powder-covered sponge rectangle or calibrated sponge roller of known surface area (adapted from McDowell *et al.*[16]) were used as tiling apparatus for the body surface. Systematic accuracy and efficiency were optimized by using roller dimensions of 10 cm length × 4 cm diameter for ponies, foals and Shetlands; and 14.7 cm length × 5.1 cm diameter for two- and 12-year-old Hanoverians and Shires. Sponge rectangle area was 6 cm^2 or 2 cm^2 depending on size of the subject or area of the body surface region to be tiled (Fig. 2). The dimensions of the tiling apparatus were 1% of the barrel surface area for the rollers and 0.1% of the hind-leg surface area for the sponges.

Given the data in the literature corroborating the existence of bilateral symmetry in mammals (Marlin, personal communication; references 16 and 21), the medium-sized breeds Welsh Mountain-type[24] and Hanoverians[26] were tiled on the left side only. The remaining subjects were tiled on both sides[23,25].

In all cases the body surface on a given side was tiled three times (Fig. 2) with talcum-coated geometric integrators. Care was taken to press the pelage hard against the skin when dealing with winter coats, to reduce systematic error from air trapped between the hairs or from the measurement process (Fig. 2). Individual data for the head, neck, shoulder (anterior margins of the *supraspinatus* and *deep pectoral*, and posterior margin of the *triceps* muscles), barrel (area between vertical lines at the posterior margin of the *triceps*, and from mid-line to the point of the *tuber coxae* and posterior margin of the *latissimus dorsi*), quarters and upper and lower fore and hind limbs were also recorded[8].

Table 2 Description of the linear anthropometric measurements (1–30) made on Welsh Mountain-type ponies at Leahurst[24] and used in analyses to investigate a weight-independent algorithm for body surface area. See Fig. 1 (top) for a schematic representation of the linear measurements. Italicized measurements were used in subsequent studies on Hanoverians, Shires and Shetlands

Linear anatomical dimension (cm)	Number
Total longitudinal length of ear	1
Diameter of ear base	2
Diameter of ear tip	3
Length from tip of poll to middle of upper lip	4
Length from mid-lower lip to gullet	5
Circumference of muzzle at the widest point	6
Circumference of head below anterior margin of cheek	7
Circumference of skull at anterior margin of eyelids	8
Length from poll to wither along crest	9
Length of anterior midline of neck (gullet to base of neck)	10
Circumference of head/neck junction	11
Circumference of neck/shoulder junction	12
Length of anterior margin of shoulder (*scapula*): withers to point of shoulder	13
Circumference of barrel mid-wither behind posterior margin of *deltoid* muscle	14
Distance from mid-breast to posterior margin of *deltoid* muscle at point of shoulder	15
Width of lateral aspect shoulder	16
Length from top of foreleg to below knee	17
Length from lower knee of foreleg to coronet	18
Length of foreleg cannon	19
Circumference of upper foreleg at elbow	20
Circumference of knee at widest point	21
Circumference of cannon below knee	22
Circumference of foreleg fetlock	23
Length from mid-wither to root of tail	24
Ventral length of belly	25
Circumference of barrel behind wither	26
Circumference of barrel at widest point	27
Circumference of junction between quarters and barrel anterior to *tuber coxae*	28
Length of lateral aspect of quarters from mid-croup to groove of stifle	29
Lateral width of quarters from tuber coxae *to root of tail*	30

Table 3 Description of the linear anthropometric measurements (31–60) made on Welsh Mountain-type ponies at Leahurst[24] and used in analyses to investigate a weight-independent algorithm for body surface area. See Fig. 1 (bottom) for a schematic representation of the linear measurements. Italicized measurements were used in subsequent studies on Hanoverians[26], Shires and Shetlands[25]

Linear anatomical dimension (cm)	Number
Distance between *tuber coxae* over loin	31
Length of anterior margin of gaskin	32
Length from anterodorsal margin of hock joint to coronet	33
Length of posterior margin of hind-leg cannon	34
Circumference of widest point of upper hind leg	35
Circumference of hind leg above hock	36
Circumference of cannon below hock	37
Circumference of hind-leg fetlock	38
Length of dock	39
Circumference of tail at root	40
Circumference of dock at root	41
Horizontal distance from mid-breast to buttock (following body contour)	42
Horizontal distance from point of shoulder to buttock (following body contour)	43
Widest circumference of foreleg pastern	44
Circumference of foreleg coronet	45
Widest circumference of hind-leg pastern	46
Circumference of hind-leg coronet	47
Height from croup to ground	48
Distance from point of shoulder to point of ischium (following contour of body)	49
Vertical height at withers	50
Length of forelimb along anterior aspect	51
Length from *olecranon process* to ground	52
Length from dorsal margin of knee to ground	53
Length from mid-wither to croup (along contour of back)	54
Circumference of mid-gaskin	55
Length from point of hock to ground	56
Longest length of fore hoof	57
Longest length of back hoof	58
Widest width of fore hoof	59
Widest width of back hoof	60

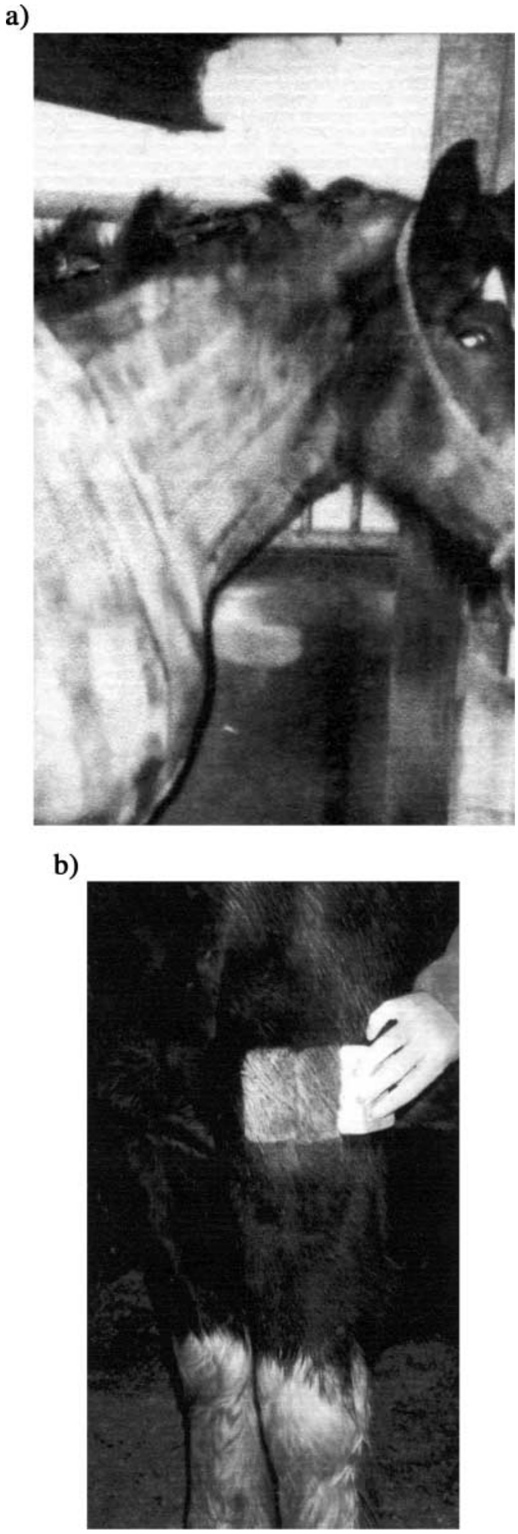

FIG. 2 Depiction of the tiling procedure for calculation of body surface area (cm^2) with sponge roller (a) and sponge pads (b) dipped in talc

Up to 60 linear anthropometric measurements were made in the 1997 study on Welsh Mountain and Section A ponies, to provide data of potential pragmatic use for the production of an algorithm to predict BSA[24]. The ethos behind the linear measurements chosen was to measure all dimensions on the body surface that were practically accessible and of possible use as variables in surface area algorithms (see Tables 2 and 3, and Fig. 1). Later studies on Shire and Shetland ponies and Hanoverian horses[25,26] refined these anthropometric measurements to those in italics (Tables 2 and 3).

Statistical methods

Analysis of effects of breed and age on regional surface areas (% total surface area)

After testing for normality, one-way ANOVA (analysis of variance) and the Tukey *post hoc* test were used to assess the effects of breed and age on regional surface area data (% BSA). $P < 0.05$ was taken as significant.

Investigation to produce a weight-independent total surface area algorithm

Linear least-squares regressions were performed using absolute surface area data (cm^2) as the dependent variable and all permutations of linear anthropometric measurements as the independent variable.

Results

Figures 3–5 give absolute data for regional and total surface area (cm^2) for all breeds and for different ages in Hanoverian horses. Significant differences in regional and total surface areas were observed between breeds (Figs 3–5) and between ages of Hanoverian horses (Fig. 4).

Proportional surface areas (% BSA) scaled with broad similarity across all breeds (Fig. 6). However, there were several significant differences that can be summarized as follows:

- Shetlands and Shires had proportionately more leg surface area than mature and two-year-old Hanoverians, but relatively less leg surface area than Welsh Mountain ponies;
- Shetlands and Shires had relatively smaller barrel surface areas than mature and two-year old Hanoverians, and relatively larger shoulder surface areas than all other breeds;
- Shetlands had relatively larger neck and head surface areas than Shires; and
- Hanoverian foals had proportionally greater leg surface areas than mature Hanoverian horses and two-year-old Hanoverians, as well as relatively greater hindquarter surface areas than two-year-olds.

The coefficient of variation for absolute (cm^2) surface area data was, on average, less than 10% across all experimental subjects. There was no significant effect of body side[23,25] on body surface area, for either regional surface area data (% BSA or cm^2) or

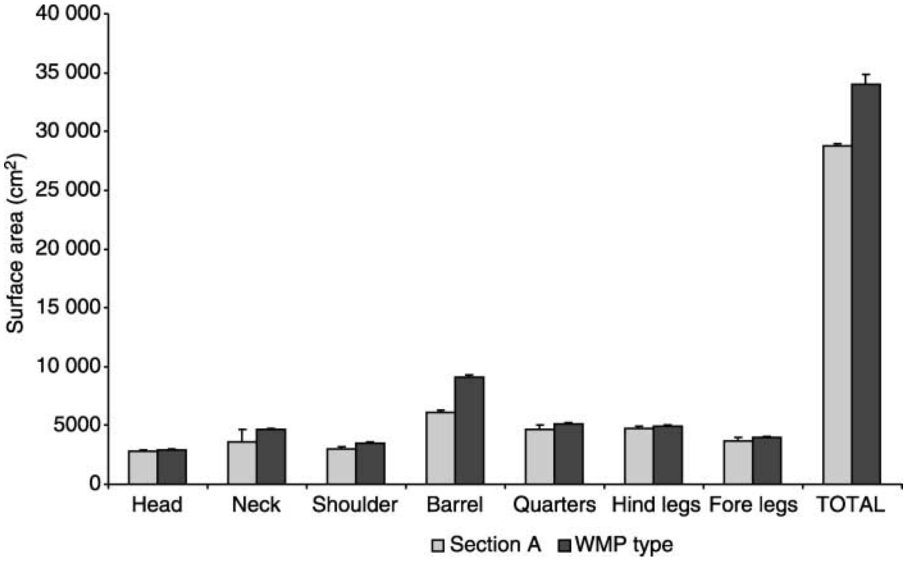

FIG. 3 Mean regional surface areas (cm^2) of Welsh Mountain Section A ponies (Section A) and Welsh Mountain-type ponies (WMP type) ($n = 7$). Bars indicate standard error of the mean

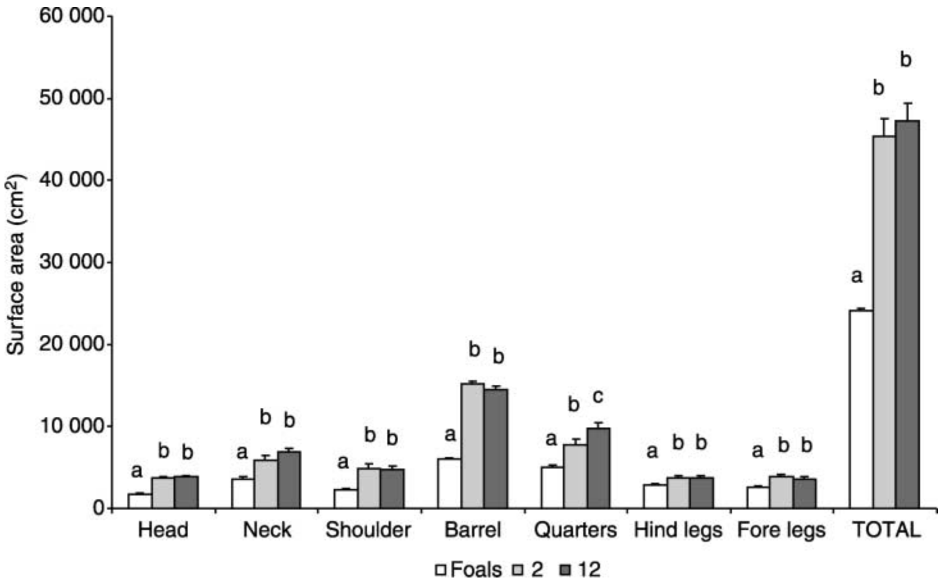

FIG. 4 Mean regional surface areas (cm^2) of Hanoverian foals, two-year-olds and 12-year-olds tiled on one side ($n = 6$). Bars indicate standard error of the mean; histograms with differing letters (a, b or c) are significantly different at $P < 0.05$

whole body surface area data (cm^2), for any individual. Replicate data within individuals showed a systematic error of less than 5%[23-26].

Weight-independent algorithms for estimation of BSA (cm^2)

Algorithms for BSA based on linear anthropometric measurements

There was limited value in the use of linear anthropometric measurements (Fig. 1, Tables 2 and 3) to estimate BSA. Equations (1)-(3) below give the only significant regressions obtained, where y is body surface area (cm^2) (these were for one study only[24]):

$$\log y = 3.08 + 0.818 \log x_{30} \quad (r^2 = 0.87,\ P < 0.05) \tag{1}$$

where x_{30} is the linear dimension of measurement no. 30 between the *tuber coxae* and the root of the tail (cm) (Fig. 1, Table 2);

$$\log y = 3.17 + 0.368 \log x \quad (r^2 = 0.91,\ P < 0.05) \tag{2}$$

where x is the surface area of the shoulder region (cm^2) (Fig. 7); and

$$\log y = 1.99 + 0.815 \log x_{49} + 0.46 \log x_6 \quad (r^2 = 0.90,\ P < 0.05) \tag{3}$$

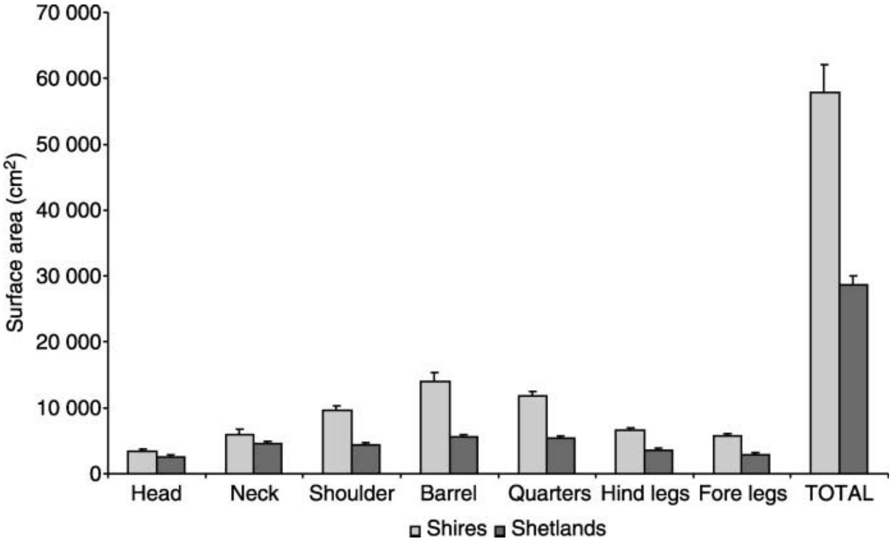

FIG. 5 Mean regional surface areas (cm^2) of Shire horses and Shetland ponies ($n = 8$). Bars indicate standard error of the mean

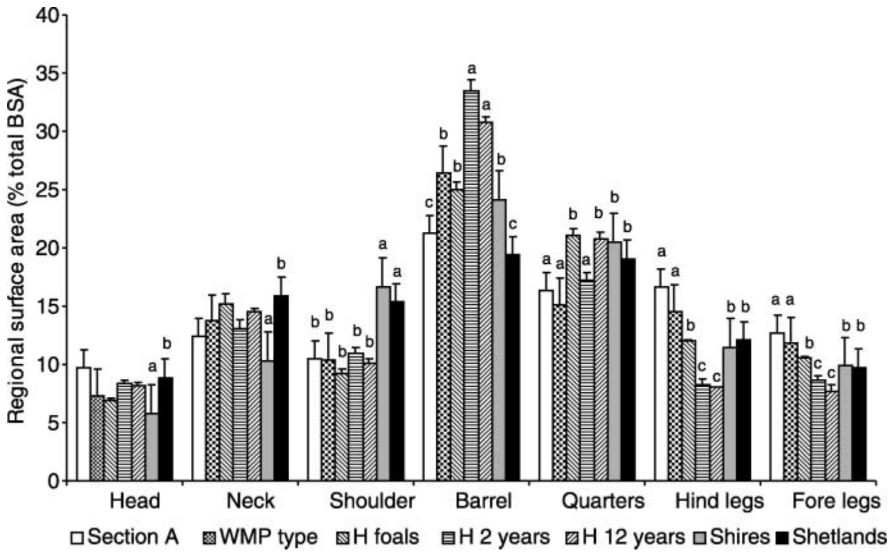

FIG. 6 Mean regional surface area as a percentage of total body surface area (BSA) for all breeds (Section A – Welsh Mountain Section A ponies; WMP type – Welsh Mountain-type ponies; H – Hanoverians). Bars indicate standard error of the mean; histograms with differing letters (a, b or c) are significantly different at $P < 0.05$

where x_{49} is the linear dimension of measurement no. 49 from the point of the shoulder to the point of the *ischium* and x_6 is the circumference of the muzzle (Fig. 1, Tables 2 and 3).

Algorithms for BSA based on regional surface area of the shoulder (%)

Arab-based breeds

The following was found for Welsh Mountain-type ponies at Woodville (± 8%† accuracy, $n = 7$)[23] and Leahurst (± 5% accuracy, $n = 7$)[24], and for Hanoverian foals, two- and 12-year-olds (± 5%, 8%* and 1% accuracy, respectively, $n = 6$)[26]:

$$\text{Body surface area} = \frac{\text{surface area of shoulder region on one side} \times 2}{10} \times 100. \quad (4)$$

UK native breeds

The BSA algorithm based on regional surface area of the shoulder (%) for Shire horses (± 4% accuracy) and Shetland ponies (± 4% accuracy), $n = 8$, three

* These individuals had relatively large/varied barrels compared with other groups (Fig. 6)

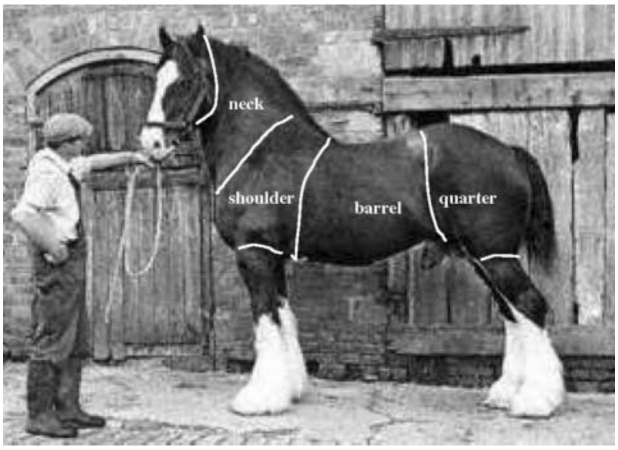

FIG. 7 Photograph illustrating the positions of the regional surface areas

replicates[25], was:

$$\text{Body surface area} = \frac{\text{surface area of shoulder region on one side} \times 2}{16} \times 100. \quad (5)$$

In equations (4) and (5), 'surface area of shoulder region on one side' was defined by the anterior margins of the *supraspinatus* and *deep pectoral*, and the posterior margin of the *triceps* muscles. The denominators (10 and 16) relate to the regional surface area (%) of the shoulder region in these breeds, which are 10 and 16% of BSA, respectively.

Equations (4) and (5) and Fig. 8 indicate that tiling the body surface gave consistent estimations largely within acceptable degrees of accuracy compared with the direct measurement of BSA for all breeds.

In addition, the shoulder region was found to be a pragmatically accessible region of the body to tile in all individuals, compared with other regions of the body.

Discussion

The aim of this study was to produce pragmatic, weight-independent algorithms for determination of BSA in a selection of equine breeds, and in Hanoverian horses of different ages, to within 5% accuracy of directly measured values, under field conditions.

The absolute and regional values for BSA (Figs. 3–6) agreed with the overall data trends for body surface proportions of mammals modelled by Prothero[21], although the methods for attainment of reference values for surface area measurements in that study, and in the literature in general, are not clearly described[1,17]. The finding that subjects tiled on both sides were bilaterally symmetrical to within 5% confirmed published information, as did information on the systematic accuracy of the technique, which was also within 5%[16,21]. Integration of body surface regions using the chalk tiling procedure is the most valid method for estimating BSA in horses to date and produced algorithms for determining BSA that were generally applicable across breeds and ages (equations (4) and (5)). As hypothesized, the regional area of the shoulder produced the most acceptable predictions of BSA in all breeds and ages (equations (4) and (5); Fig. 8). The shoulder region, definable by the anterior margins of the *supraspinatus* and *deep pectoral*, and the posterior margin of the *triceps* muscles, consists mainly of a large area of bone overlaid by a relatively

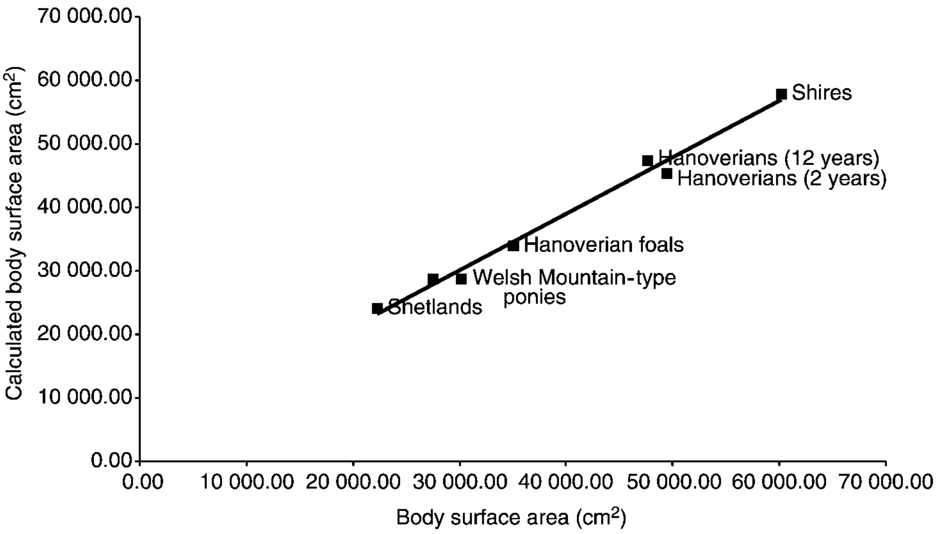

FIG. 8 Linear regression from algorithms for prediction of body surface area (cm^2) from shoulder surface area in Shetlands, Shires (equation (4)) and other breeds (equation (5)) ($r^2 = 0.99$, $P < 0.0001$, $F = 392.87$)

thin layer of muscle[27]. It is thus possibly subject to relatively little quantitative variation within breeds if individuals are in light or no work and muscle development is thus a relatively insignificant variable. Whether the same could be said for elite equine athletes is unknown. It is interesting to speculate whether the same logic could apply to measurement no. 30 from the *tuber coxae* to the root of the tail in equation (1).

Linear anthropometric measurements were of limited use in the estimation of BSA. Equations (1)-(3) are applicable only to Welsh Mountain Section A ponies despite equation (2) incorporating a surface area measurement. These ponies were bred on the same stud and were relatively uniform in conformation, whereas the other studies included individuals of far more diverse conformation and size. Where there is uniformity in body size in quadrupeds, linear anthropometric estimations of BSA are reported to be acceptably accurate[28]. The linear measurements found to be unrelated to BSA could be discarded from future studies in terms of their use for producing surface area algorithms.

Body surface is a three-dimensional variable and linear measurements can estimate only in one dimension, and will be particularly subject to variation in conformation and condition score. Calibrated girth-measuring tapes for estimation of BSA are also subject to this shortcoming. In contrast, geometrical tiling integrates the body surface in three dimensions, although it still simplifies the body surface to a series of geometrical shapes[16]. This modified tiling procedure did provide an acceptable degree of accuracy for determination of BSA in equines *in vivo*. The modified tiling technique produced ±5% accuracy in the determination of BSA in Shetlands, Shires, Welsh Mountain Section A ponies, Hanoverian 12-year-olds and Hanovarian foals. It produced ±8% accuracy in determination of BSA for Welsh Mountain-type ponies and Hanovarian two-year-old horses. These findings are summarized in Fig. 8. The smaller the tiles the more accurate will be the true estimation of BSA; however, this has to be offset against the time required for assessing the surface area of large animals, particularly when estimations are being made for comparative purposes.

The barrel region constituted the largest proportion of BSA in all animals (Fig. 6) as well as the widest source of variation in the regional data (19-33% BSA; Fig. 6). Algorithms for the estimation of BSA thus need to be independent of such variation. The combined surface areas of the fore and hind limbs (Figs 3-6) equalled or exceeded that of the barrel across all breeds. Presumably the legs of horses constitute a significant surface area for thermoregulatory purposes in the form of thermal windows[29]. The proportion of muscle to BSA and the capacity for metabolic activity in horses can lead to thermal stress despite an advanced capability for evaporative cooling[5-7].

Shetland ponies and Shire horses have been selectively bred for their draught capacities. It was not therefore surprising to find that they possessed significantly heavier necks and quarters and shorter limbs than the Arab-based breeds. This study corroborated the findings of Prothero[21] that small mammals are not scaled-down versions of large ones. This was demonstrated by differences in regional development between breeds and ages. Shetlands had relatively large heads compared with Shires, perhaps indicating a minimal cranial capacity housing of the brain. Kinetic perceptive mammals require a minimal amount of central nervous tissue for integration of sensory and locomotory control[30].

The significantly larger regional surface areas in the fore limbs, hind limbs and hindquarters in Hanoverian foals compared with more mature horses indicated an initial preferential growth rate in the propulsive anatomy. This has obvious implications for locomotion in a precocial species of mammal and would have been governed by an evolutionary drive for predator avoidance. In line with this, foals were 51% of mature body size and by two years of age the Hanoverian horses had reached 96% of their mature body size[26]. These data are in agreement with nutritional work on Arab-based breeds of horse[9,31,32]. Interestingly, two-year-olds had proportionately smaller quarters than 12-year-olds, perhaps reflecting a lack of muscular development with maturity or work. Whether the same growth and maturity patterns hold true for muscle development in native heavy breeds is unknown.

Conformational studies using mass and linear anthropometric data have been linked to sport performance in horses[33,34]. Estimation of three-dimensional muscle development could add significant value to such conformational studies.

In conclusion, chalk tiling the body surface with appropriate geometric integrators provided an acceptably accurate (within 5-8% of directly measured values) and cost-effective, weight-independent method of determining BSA for the range of breeds and ages of horse in this study, under field conditions (Fig. 8). Unlike weight-based calibrated girth tapes, which are based on a linear measurement, this technique was also sufficiently sensitive to reveal interesting three-dimensional information on differential development of body regions between and within these breeds. This information could be applicable to the quantitative assessment of sporting or draught potential. It would be interesting to apply the chalk integrator technique to other breeds of horse and commercial livestock to develop a database of algorithms for estimating BSA, particularly in field conditions where the use of more sophisticated techniques for surface profiling would be logistically challenging.

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