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A Pilot Study on Measurement and Modeling of Surface Area of Horses

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Abstract

The surface area of an animal is of great importance in its interaction with the environment concerning physical parameters but also for the physiological function of the animal, e.g. for data concerning metabolism, heat exchange and dosage of drugs. The aim of this study was to measure body surface area and geometrical body quantities in research horses and to find an equation based on well-defined geometrical quantities to estimate the surface area of a horse. The surface area was measured on ten horses with two independent methods; triangulation and stereophotogrammetry using a video technique. Twenty-three geometrical body dimensions were measured on each horse. Each body dimension was correlated to the measured surface area by stereophotogrammetry. The body dimension/s best correlated to the area was picked for the final formula for estimation of body surface area. It was concluded that it is possible to find an equation to calculate the surface area of a horse based on geometrical body dimensions.

Introduction

The surface area of an animal is of great importance in its interaction with the environment concerning physical parameters but also for the physiological function of the animal, e.g. for data concerning metabolism, heat exchange and dosage of drugs. The body surface area is important for the animal's heat transfer by non-evaporative heat loss (radiation, convection and conduction) due to the temperature difference to the environment and evaporative heat loss by sweating [1]. Also, the surface area relates to the metabolism and can be of importance for nutrition and pharmacology [2]. One of the earliest known studies of measurement of body surface area on animals used a wheel-integrator and chalk to measure one side of the animal [3]. Later in literature four different equations to estimate surface area from body mass (m in kg) in horses have been presented with different results:

- $A = 0.09m^{0.67}$ [4],
- $A = 1.09+0.008m$ [5],
- $A = 0.1m^{0.67}$ [6],
- $A = 0.13m^{0.56}$ [7].

Surface area is a function of geometrical dimension and is not related to the mass. Despite this, [3] showed a good correlation between mass and surface area. However, from a mathematical perspective the correlation between spatial measurement and area ought to be stronger than correlation between mass and area. A study measured several significant geometrical body quantities in cattle for modelling of body surface area [8]. Methods to determine the body surface area have been a wheel-integrator [3], planmeter [9,10], monophotogrammetry [11], approximation of geometric figures [8,12]and stereophotogrammetry [13].

The aim of this study was to measure body surface area and geometrical body quantities in research horses and to find an equation based on well-defined geometrical quantities to estimate the surface area of a horse.

Materials and Methods

Ten research horses were used in the study: nine Standards bred trotters and one Icelandic horse. There were nine geldings and one mare ranging from 4 years to 16 years. The body weight ranged from 392 to 543 kg. We used two independent techniques to measure surface area; stereophotogrammetry and triangulation. The main method was the stereophotogrammetry. Then, we followed up with the more hands-on technique of triangulation to validate that the stereophotogrammetry came to a reliable result. The measurements were done on the right side of the horse. We assumed that the right and the left side of the horse were symmetrical. Both measuring techniques were calibrated by repeated measurements on objects with a defined surface area.

For stereophotogrammetry, the position of the marker is measured at the centerpoint of the marker. This resulted in a slightly too large surface area and the correction factor for the calculated surface area was determined to 0.09501. For triangulation, the measured surface area was slightly too small, since the area within the triangle is plane. The correction factor for estimated surface area by triangulation was set to 1.073.

Stereophotogrammetry: Stereophotogrammetry is a technique to determine the location of one or several points in space using two cameras [14]. To detect a point, a reflector or marker must be used. The horse was divided into twenty-one segments, Fig. 1, and placed within a steel frame. On the boundary of each segment eight markers were attached. Six markers were placed on the frame and used for calibration. The set-up of the equipment is shown in (Fig-1).

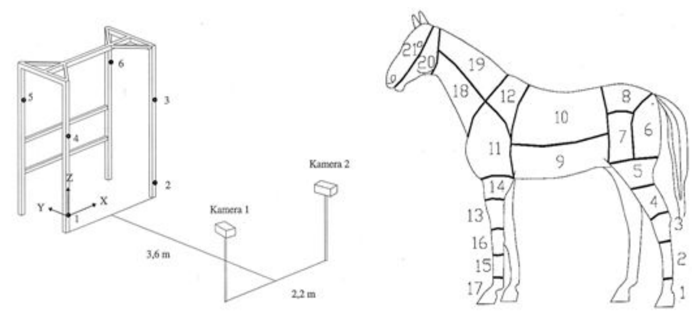

Figure 1: The figure shows the set-up of equipment for stereo photogrammetry and how the horse was divided into 21 segments for measuring.

Using this technique, it is possible to determine the location of the markers i.e. the co-ordinates of each point in space to some points of reference. To calculate the area of a segment a standard procedure from the so-called finite element method is adopted. The basic idea is that each segment with its eight markers can be looked upon as one element with its eight nodes. It is then possible to fit a surface for each segment (or element). The procedure is based on a mapping of such an element from 2D-plane with co-ordinates ξ and η into 3D-space.

Now define eight functions $N1(\xi,\eta)$, $N_8(\xi,\eta)$ in this plane such that for each node there corresponds function that has the value of unity at this node and zero for every other node of the element. The so-called shape functions Ni are polynomials of second order in the variables ξ and η . For an arbitrary point (ξ^*,η^*) in the $\xi\eta$-plane the co-ordinates (x^*, y^*,z^*) of the corresponding point in space is

$$(x,y,z)=(\sum_{i=1}^{8} x_i N_i(\xi,\eta), \sum_{i=1}^{8} y_i N_i(\xi,\eta), \sum_{i=1}^{8} z_i N_i(\xi,\eta)) \quad \text{(Eqn. 1)}$$

Where x_i, y_i, z_i is the known (measured) co-ordinates of the nodes (markers).

Thus, an area is defined over the whole segment. Now recall that if we have a function $z = f(x,y)$ which defines a surface in space then the area A over a region D is

$$A = \iint_D [1 + \left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)]^{1/2} dxdy \quad \text{(Eqn. 2)}$$

With this representation, it is possible to derive the partial derivatives in (2). First define the matrices B, C, and J:

$$B = \begin{bmatrix} \frac{\partial z}{\partial x} \\ \frac{\partial z}{\partial y} \end{bmatrix}, C = \begin{bmatrix} \frac{\partial z}{\partial \xi} \\ \frac{\partial z}{\partial \eta} \end{bmatrix}, J = \begin{bmatrix} \frac{\partial x}{\partial \xi} & \frac{\partial y}{\partial \xi} \\ \frac{\partial x}{\partial \eta} & \frac{\partial y}{\partial \eta} \end{bmatrix} \quad \text{(Eqn. 3)}$$

Then

$B = \text{inv}(J)^*C$ (Eqn. 4)

Finally, by substitution we have

$$A = \iint_{D'} [1 + \left(\frac{\partial z}{\partial x}(\xi,\eta)\right)^2 + \left(\frac{\partial z}{\partial y}(\xi,\eta)\right)]^{1/2} \det(J) dxdy \quad \text{(Eqn. 5)}$$

Where D' is the region in the $\xi\eta$-plane. The integral is computed by a numerical technique called Gauss integration. The calculations were done in MATLAB® (Natick, MA 01760-2098 United States) with functions from MAPLE® (Waterloo Maple Inc., Waterloo, ON Canada).

Triangulation: A well-defined triangle was made with the area of 28.06 cm². The number of triangles that fitted on the right side was calculated to add up to the total body surface area. The triangle was dipped in water-soluble paint before it was put on the horse to know where we had measured.

Body dimensions: Twenty-three geometrical body dimensions were measured on each horse (Fig 2).

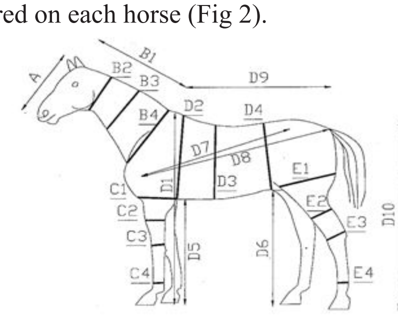

Figure 2: The figure shows the 23 body dimensions measured on the horse.

Each body dimension was correlated to the measured surface area by stereophotogrammetry. The body dimension/s best correlated to the area was picked for the final formula. In case of two body dimensions in the function, the body dimensions that correlated the least to each other were chosen as parameters. The correlations between geometrical body dimension and surface area are shown in (Table 1). The statistical analyses were done in the computer software Statistica [15].

Body Dimension	Correlation (r)	Body Dimension	Correlation (r)	Body Dimension	Correlation (r)
A^2	0.46	**$D1^2$**	**0.92**	$E1^2$	0.28
$B1^2$	0.85	$D2^2$	0.60	$E2^2$	0.74
$B2^2$	-0.60	$D3^2$	-0.36	$E3^2$	0.82
$B3^2$	-0.25	$D4^2$	-0.45	$E4^2$	0.42
$B4^2$	-0.07	$D5^2$	0.90	$BW^{2/3}$	0.66
$C1^2$	0.77	$D6^2$	0.85	-	-
$C2^2$	0.88	$D7^2$	0.79	-	-
$C3^2$	0.83	$D8^2$	0.77	-	-
$C4^2$	0.57	**$D9^2$**	**0.82**	-	-
		$D10^2$	0.92	-	-

Table 1: The results from the correlation coefficient between the (body dimension)^2 and the estimated body surface area from the stereophotogrammetry

Results

Two equations for surface area, A, were derived from the measurements and the mathematical and the statistical analysis:

$A1 = 78\,H\,L - 31\,H^2 - 46\,L^2 [m^2]$ (Eqn. 6)

(Or)

$A2 = 2\,H^2 [m^2]$ (Eqn. 7)

Where

H = height of the withers (D1 in Fig-3) [m]

L = length of the back (D9 in Fig-3) [m]

There was a high correlation (R^2=0.966) between the estimated areas from the two equations. The results from the measurements with the two methods and the two equations (Eqn. 6 and Eqn. 7) are compiled in (Table-2).

Horse	Triangulation	Mac Reflex/Matlab	Eqn.6:A_1	Eqn. 7: A_2
1	4.7	5	5.3	5.2
2	4.2	4.8	4.7	4.7
3	4	4.9	4.8	4.7
4	4.3	5	5	5
5	4	4.7	4.7	4.7
6	3.2	3.9	3.7	3.6
7	4.2	4.8	4.9	4.9
8	4.3	4.8	4.9	5.1
9	4.3	5.3	5.3	5.1
10		5	4.9	4.9

Table2: Comparison between the results of body surface area (m^2) from measurements; triangulation and MacReflex/Matlab and estimations by the two equations Eqn. 6: A1 and Eqn. 7: A2

The estimations of the surface area by the two equations are presented in Fig. 3, where they were compared to surface areas estimated from [4-7]. The results of the equations related closest to [5] (Fig-3).

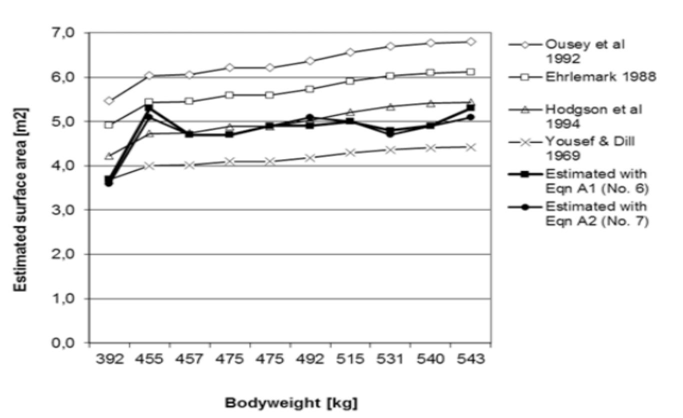

Figure 3: The diagram shows the estimated areas from the two equations No. 6: A1 and No. 7: A2 respectively) as compared to surface area as a function of body weight per different formulas found in literature. $A=0.1m^{0.67}$, $A=0.09m^{0.67}$, $A=1.09+0.008m$ and $A=0.13m^{0.56}$ [4-7]. A is area in m^2 and m is body mass in kg.

Discussion

Measuring technique

When using triangulation, the area within the triangle is assumed to be plain. Since the area most of the time is slightly convex, the total surface area will be underestimated and therefore we derived the correction factor (1.073) after measurement on a curved object with a well-defined surface area. The smaller the triangle, the smaller the error is. However, a too small triangle would not be practical.

The MacReflex-system used for stereophotogrammetry measured the center of the marker. Consequently, the point that was measured was not on the skin but a small distance from the skin. The surface area was then overestimated. Another problem with the MacReflex equipment was that due to the angle of the camera part of the marker could be hidden and in the worst case could give an error of ±1.5 cm. Also, we had a large measuring object, which gave us a large measuring distance. Sometimes, this caused noise when evaluating the results and had to be manually adjusted. The stereophotogrammetry was validated on a defined object and the correction factor was determined to 0.95.

Fitting of function

Equation A1 had the best fit to the measured areas. However, equation A2 is simpler and more practical to use in the field, since the height of the withers is a well-defined measurement and often known by the horse's owner. When only the height of the withers is used, there is a risk to wrongly estimate the surface area, if the horse has extreme combination of body dimensions. In the long run a function ($A = ax^2 + bxy + cy^2$) would be to prefer based on a large amount of horses. Only two body dimensions used as parameters in the equation may not optimal, but a consequence of that only ten horses were used in the experiment. Therefore, equation A2 can be considered a useful equation at this stage after the pilot study. It is very simple to use and the accuracy is easy to estimate, since there are nine degrees of freedom. This gives an error of approximately 4%, which can be considered a good result.

This work has taken the first steps to base surface area estimation on geometrical body dimensions and with a larger material even more reliable functions can be found. Future work will be to measure more horses and horses of different size to verify the equations and to apply the equations in experimental work to administrate drugs.

Conclusion

Despite a relatively small material and a new measuring technique, we concluded that it is possible to find an equation to calculate the surface area of a horse based on geometrical body dimensions.

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