

**Estimation of the body surface area and its impact on the heat transfer by convection in sheep: A
computational way**

Bruno Rodrigo Simão¹, Alex Sandro Campos Maia¹, Patric André Castro¹, Gustavo André Bernado Moura¹,
Vinicius de França Carvalho Fonsêca¹

¹Innovation Group in Animal Biometeorology – INOBIO. Laboratory of Animal Biometeorology, Sao Paulo State University “Júlio de Mesquita Filho” (Unesp), Campus Jaboticabal-SP. Corresponding author: E-mail: bruno@ufersa.edu.br

Abstract: The aim of this work it was to validate the 3D modeling to obtain the body surface area of animals, and determine the impact on the rate of heat transfer by convection in Corriedale sheep when include legs and head in the standard cylindrical model. Five shorn Corriedale sheep weighing between 29 and 105 kg (two breeders, one young male and two young females) were used. A regression equation, standard cylindrical model, hand instrument and 3D modeling were used to obtain surface area. Data were analyzed by least-squares methods and a non-linear regression was applied with geometric adjust in a power function. Pearson correlation was tested. Coefficients were highly significant ($p < 0.01$). Body surface area and weight presented high ($r = 0.99$) correlation. From the power function (allometric equation) adjusted in the regression equation, the coefficient “b” assumed the following values 0.5025, 0.6122 and 0.6391 and the coefficient “a” 0.171, 0.1117 and 0.1045 for Bennett’s equation, 3D modeling’s and instrument’s equation, respectively. Coefficients differences between the present investigation and Bennett’s work can be explained by the intraspecific relationship and range of body weight considered, once he used Merino sheep from 23 to 63 kg and we worked with corriedale sheep from 29 to 105 kg. Considering an animal of 63 kg, Bennet’s equation presented an underestimate value to the body surface area over the 7.3 % and 8 % when compared with hand instrument’s and 3D Model’s, respectively. Furthermore, this error increases at least 3% if we considered a 100 Kg Corriedale sheep. At this condition, 3D model with hand instrument presented less than 1% of the difference. The use of simple horizontal cylinder causes an underestimated on the rate of heat flow by convection because legs and head can represent 35 %, on average, of the total body surface area in a Corriedale sheep of 100 Kg. Thus, 3D modelling seems to be the best way to obtain the animal surface area, and certainly, appears as a tool to improve research involving heat and mass transfer and animal breeding.

Keywords: 3D animal scanning, Photogrammetry, Animal body measurement.

Os autores deste trabalho são os únicos responsáveis por seu conteúdo e são os detentores dos direitos autorais e de reprodução. Este trabalho não reflete necessariamente o posicionamento oficial da Sociedade Brasileira de Biometeorologia (SBBiomet).

The authors of this paper are solely responsible for its content and are the owners of its copyright. This paper does not necessarily reflect the official position of the Brazilian Society of Biometeorology (SBBiomet).

Introduction

The relation between animal measures and its mass are important and have been approached in some studies (McMahon, 1975; Ozkaya & Bozkurt, 2008; Silva et al, 2009). The use of regression equations has been the most commonly way used to obtain the surface area and the investigations about it date back many years ago (Elting, 1926; Bennett, 1973; Finch, 1985). The problem of this is: How much error does have in the results of those equations? Probably, animal breeding over the years is the main source of changes in the relationship between body surface area and mass. Thus, it needs to be improved and applied to different breeds.

Surveys have been developed to get animal body traits using techniques of digital images analysis (Schofield, 1990; Bloemen et al, 1997; Ozkaya & Bozkurt, 2008; Stajniko et al, 2010; Tasdemir et al., 2011), including three dimensional (3D) way (Tillet et al., 1997; Viazzi et al., 2013). The use of 3D kinect and 3D camera has been used to measure body score in cows (Spoliansky et al., 2016; Biondi, 2015), body measurements of cows, like hips distance, body length and height, chest girth and head size (Marinello et al., 2015), locomotion traits of dairy cows (Jabbar et al, 2016) and to estimate body weight and body composition in beef cattle (Gomes et al, 2016). However, 3D models have not been used to obtain body surface area and its associations with other traits.

The horizontal cylindrical model has been used to calculate heat flow by convection in four legged-mammals (Maia et al., 2005), but legs and head were not taken into account. In this sense, Silva and Maia (2012) presented a similar model considering the vertical cylinders and sphere for legs and head, respectively. However, there is no study about the precision of these measures and its impact on the heat transfer by convection. Thus, the aim of this work it was to validate the 3D modeling to obtain the body surface area of animals, and determine the impact on the rate of heat flow by convection in Corriedale sheep when include legs and head in the standard cylindrical model.

Material and Methods

Five shorn Corriedale sheep (*Ovis aries*) weighing between 28 and 105 kg (two breeders, one young male and two young females) were used to validate the computational way (3D modeling) to obtain the body surface area. Animal-use and care protocol was approved by Ethics Committee on the use of animals from Sao Paulo State University, Jaboticabal-SP (Number 16.628/16). A regression equation (Bennett, 1973), standard cylindrical model (Silva & Maia, 2012), hand instrument, and 3D modeling were considered in the present investigation. Empirical function is given by $A=0.171W^{0.5025}$, where A is Surface Area (m²) and W is the body weight (kg). Furthermore, from the cylindrical model, we estimate the impact on the heat transfer by convection when considered legs and head in the modeling.



Figure 1. (a) Handmade measuring instrument. (b) Surface area measurement with measuring instrument. (c) Surface area measurement with 3D Scanner with Artec Studio® and Microsoft Kinect® v2, before the sheared wool. (d) Picturing of young female shorn corriedale sheep in photogrammetry process. (e) Respective young female shorn corriedale sheep in 3D model with texture and meshes.

The handmade instrument (HMI; figure 1.b) based on Elting (1926) was used as a validation method, which consisted in pass a revolving wood cylinder of known area, connected to a counter, a calculator and two whiteboard paint-brushes, over the surface of the animal (figure 1.c), and then multiplying the number of laps of the instrument by the area of the roller marker. This gave an accurate surface-area measurement with low costs and small computations. Furthermore, it was used too an adhesive tape involving the parts that it was not possible measure with the instrument like legs, ears, nose and scrotum. After the involving of adhesive tape in those members, it was cut aided by a scissor. The model it was put in A4 paper and scanned in a conventional printer and the area of parts it was measured and summed to the surface area measured by the instrument. Finally, 3D scanning by Remake® photogrammetry's software with a cellphone camera and/or Artec Studio 11® with Microsoft Kinect® was performed on animals. In this way, at first time, subjects were habituated and conditioned using operant principles to

remain in a static position; in addition, forty minutes before to performed scanning, animals were sedated with a sub dose of 0.05mg/Kg of Assepran 1% (Figure 1.d).

Data were analyzed by the least-squares method (Harvey, 1960) and a non-linear regression was applied with a geometric adjust in a power function. Pearson's correlation was tested.

Results and Discussion

The data attended the presuppositions of the regression analyze (normality; Shapiro-Wilk test, p -value > 0.05), which residuals were independently and identically distributed. Coefficients were highly significant ($p < 0.01$). A high correlation ($r = 0.99$) was observed between body surface area and weight. The adjusted model is called allometric equation, a power function of type: $Y = aX^b$, where "a" and "b" are coefficient constants. The b-value represents the differential growth rate between the body surface area and the animal body weight. For example, if this coefficient were equal to one, it would be an isometric growth. If it greater than one (hyperallometry), it would means that body surface area would increase faster than its mass. Contrary, if it was less than one (hypoallometry), so it means that it increases more slowly than its mass (Reiss, 1989).

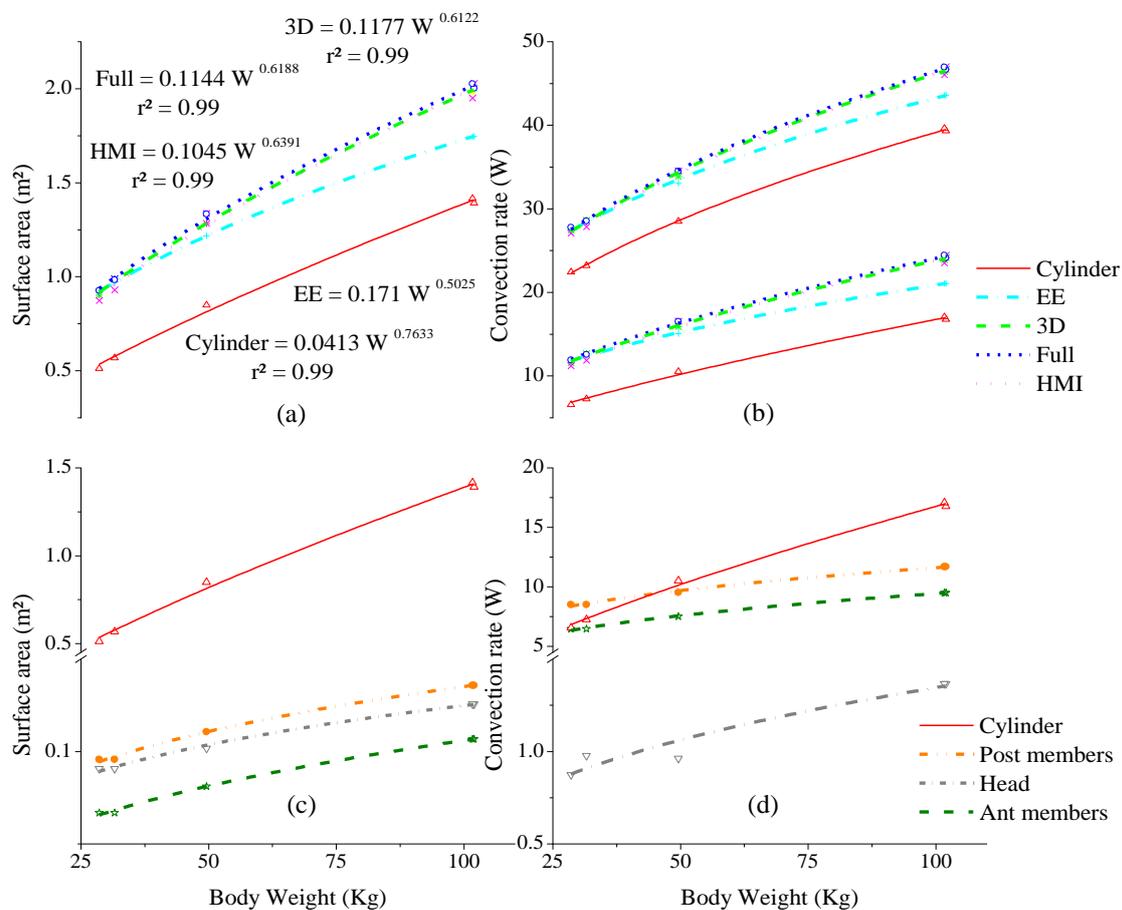


Figure 2. Comparative allometric models of body surface area in Corriedale Sheep and its impact in heat flux by convection. Full: horizontal cylindrical model based in Silva & Maia (2012). Post members: posterior members (legs). Ant members: anterior members (legs).

In this study, the coefficient "b" assumed the following values 0.5025, 0.6122 and 0.6391 and the coefficient "a" 0.171, 0.1117 and 0.1045 for Bennett's equation, 3D modeling's and instrument's equation, respectively. Coefficients differences between the present investigation and Bennett's work can be explained by the intraspecific relationship and range of body weight considered, once he used Merino sheep from 23 to 63 kg and we worked with Corriedale sheep from 29 to 105 kg. Thus, considering an animal of 63 kg, Bennet's equation presented an underestimate value to the body surface area over the 7.3 % and 8 % in comparison with hand instrument's and 3D Model's, respectively (Figure 2a). Furthermore, this error increases at least 3% if we considered a 100 kg Corriedale sheep. At this condition, 3D model with hand instrument presented less than 1% of the difference. In this sense, we can validate the 3D model's as a

precise way for obtaining body surface area in animals. However, is not simple way, being limited by the technology, once the user needs to qualify itself to use it and need of computer with recommended advanced settings. Another limitation is the need of the immobile animal to perform scanning. The limitations of HMI's method is because the instrument it is not commercial and the researcher needs to build the own equipment and use it correctly.

Studies on animal thermal balance to quantify the heat flow by convection (Maia et al., 2005; Maia et al., 2015) usually consider the subjects as a standard horizontal cylinder, without body surface area represented by legs and head. According to our findings, when animals were modeled like a standard horizontal cylinder, body surface area was underestimated in comparison with regression equation, hand instrument, and 3D model; however, when we include the surface area represented by legs and head, values of body surface area presented precise determination (Figure 2a). Legs and head can represent 35%, on average, of the total body surface area. Thus, the uses of full cylindrical model showed a good adjust to obtain the actual surface area. Then, to use only the simple horizontal cylinder model it would be necessary to increase the size of cylinder. These findings are important to improve modeling of biological system, mainly on studies of heat and mass transfer. For example, according equations from Silva and Maia (2013), we performed a simulation of the rate of heat transfer by free convection for animals in this study (Figure 2a and 2b), considering the following input data: Latitude = - 21.37; altitude = 597 m; air temperature = 30 °C; animal surface temperature = 35°C; anterior members dimensions ranged from 0.05-0.07 x 0.4-0.45m; posterior members dimensions varying from 0.07-0.08 x 0.4-0.45m; head diameter ranged from 0.17 to 0.20m. Results showed that the use of simple horizontal cylinder causes an underestimated on the rate of heat flow by convection (Figure 2.b – fitted curves lower; figure 2.d), implying large errors on estimation in the animal thermal equilibrium.

Conclusions

Artec Studio 11® software and the photogrammetry's software Remake® are good commercial software to build 3D models.

A 3D modeling way to obtain surface area of Corriedale sheep was validate. The method seems to be the best way to obtain the animal surface area, and certainly, appears as a tool to improve research involving heat and mass transfer

The adjusted model $A_{(3D)} = 0,1177W^{0,6122}$, can be used as the equation for estimate the body surface area in corriedale sheep.

Surface area represented by legs and head should be include in the standard cylindrical model to estimate heat transfer by convection in four legged-mammals.

Acknowledgements

This study was supported by CAPES with scholarship. Our acknowledgement toto Innovation Group in Animal Biometeorology (INO BIO), to Laboratory of Animal Biometeorology and to Post degree Program in Animal Science from São Paulo State University (Unesp) by the support and structure. Our acknowledgement to Autodesk Company by available the student's license of Remake's software and Artec Company by available a commercial license of Artec Studio 11's software. We thanks so much to sir Amistá, the woodworker that makes the rolling.

References

- ARTEC3D (2016). User Guide ARTEC STUDIO 11. Luxembourg: Artec Industry.
- Biondi, A. (2015). The use of an innovative tool to assess the body condition score, in Conference: XXV Jubilee International Congress of the Hungarian Association for Buiatrics, At Budapest, Hungary, Volume: (1), 3–5. doi: 10.13140/RG.2.1.3192.2640
- Bloemen, H., Aerts, J. M., Berckmans, D., & Goedseels, V. (1997). Image analysis to measure activity index of animals. *Equine Veterinary Journal. Supplement*, 23(23), 16–19.
- Elting, E. C. (1926). a Formula for Estimating Surface Area of Dairy Cattle. *Journal of Agricultural Research*, 33(3), 269–280.

Gomes R A, G. R. Monteiro, G. J. F. Assis, K. C. Busato, M. M. Ladeira, and M. L. Chizzotti. 2016. Technical note: Estimating body weight and body composition of beef cattle through digital image analysis. *J. Anim. Sci.* 94:5414-5422. doi:10.2527/jas.2016-0797

Harvey W R. Least-Squares analysis of data with unequal subclass numbers, Beltsville: U.S.D.A., Public

Horgan, G., Murphy, S., & Simm, G. (1995). Automatic assessment of sheep carcasses by image analysis. *Animal Science*, 60(2), 197-202. doi:10.1017/S1357729800008341

Jabbar, K. A., Hansen, M. F., Smith, M. L., & Smith, L. N. (2016). Locomotion Traits of Dairy Cows from Overhead Three-Dimensional Video. In ICPR (pp. 5–8). Cancun, Mexico.

Maia, A.S.C., Silva, R.G., Loureiro, C.M.B. 2005. Sensible and latent heat loss from the body surface of Holstein cows in a tropical environment. *Int. J. Biometeorol.* 50, 17–22.

Marinello, F., Pezzuolo, A., Cillis, D., Gasparini, F., & Sartori, L. (2015). Application of Kinect-Sensor for Three-Dimensional Body Measurements of Cows. In Precision Livestock Farming '15 (pp. 661–669). European Conference on Precision Livestock Farming.

McMahon, T. a. (1975). Using body size to understand the structural design of animals: quadrupedal locomotion. *Journal of Applied Physiology* (Bethesda, Md. : 1985), 39(4), 619–627.

Mollah, M. B. R., Hasan, M. A., Salam, M. A., & Ali, M. A. (2010). Digital image analysis to estimate the live weight of broiler. *Computers and Electronics in Agriculture*, 72(1), 48–52.

Ozkaya, S., & Bozkurt, Y. (2008). The relationship of parameters of body measures and body weight by using digital image analysis in pre-slaughter cattle. *Arch. Tierz. Dummerstorf*, 51(2), 120–128.

Reiss, M. J. (1989). The allometry of growth and reproduction. *Comparative Biochemistry and Physiology Part A: Physiology* (Vol. 96, p. 182). [https://doi.org/10.1016/0300-9629\(90\)90082-4](https://doi.org/10.1016/0300-9629(90)90082-4)

Schofield, C.P., Marchant, J.A., White, R.P., Brandl, N., Wilson, M., 1999. Monitoring pig growth using a prototype imaging system. *Journal of Agricultural Engineering Research* 72 (3), 205–210.

Silva, E., Júnior, T., Júnior, R., Lopes, M., & FA. (2009). Desenvolvimento e validação de um modelo matemático para o cálculo da área superficial de frangos de corte. *Eng. Agríc.* 1–7.

Silva, R.G. Da & Maia, A.S.C. 2012. Principles of animal biometeorology. New York: Springer. 261 p.

Spoliansky, R., Edan, Y., Parmet, Y., & Halachmi, I. (2016). Development of automatic body condition scoring using a low-cost 3-dimensional Kinect camera. *Journal of Dairy Science*, 99(9), 7714–7725.

Stajanko, D., Vindis, P., & Berk, P. (2010). Estimation of Bull Live Weight Using Thermal Imaging. DAAAM International Scientific Book 2010, 227–236. <https://doi.org/10.2507/daaam.scibook.2010.23>

Tasdemir S, Urkmez A, Inal S (2011) Determination of body measurements on the Holstein cows using digital image analysis and estimation of live weight with regression analysis. *Computers and Electronics in Agriculture* 76, 189–197. doi:10.1016/j.compag.2011.02.001

Tillet, R.D., Onyango, C.M., Marchant, J.A., 1997. Using model-based image processing to track animal movement. *Computer and Electronics in Agriculture* 17, 249–261.

Viazzi, S., Van Hertem, T., Schlageter-Tello, A., Bahr, C., Romanini, C. E. B., Halachmi, I., Berckmans, D. (2013). Using a 3D camera to evaluate the back posture of dairy cows. In American Society of Agricultural and Biological Engineers Annual International Meeting 2013, ASABE 2013 (Vol. 5).