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Application of Linear, Quadratic and Cubic Regression Models to Predict Body Weight from Different Body Measurements in Domestic Cats

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ABSTRACT

The aims of this study were to predict body weight (BW) from different body measurements and to determine the best regression model for domestic cats. For this aims, a total of 48 adult Turkish cats (20 females & 8 males Turkish Angora; 13 females & 7 males Turkish Van) were used. In the study, wither height (WH), body length (BL) and head circumference (HC) were assumed as independent variables, whereas body weight was used as dependent variable. Linear, quadratic and cubic effects of the independent variables were included in the assumed model as $Y= b_0 + b_1X + b_2X^2 + b_3X^3 + e$. Where Y = body weight; b_0 = the intercept; X = independent variables, (WH, BL, or HC); b_1, b_2 and b_3 = regression coefficients and e = random error. Conceptual predictive (*Cp*) and Akaike information criterion (*AIC*) were used to determine the most suitable model among the assumed models. The model that has the smallest *Cp* and *AIC* values is the best model. The R^2 values from the regression indicate the BL ($R^2 = 0.50$) to be moderately related to the BW. Neither the quadratic term nor the cubic term was significant for all body traits, whereas the linear term was highly significant ($p < 0.001$) for all independent variables. Since the maximum number of independent variables is three, there were seven possible different models. It can be concluded that cat body weight was explained with the following model. (BW) = - 4.53 + 0.11 WH + 0.13 BL with p- values, <0.001, 0.0083, and <0.001 for the intercept, b_1 and b_2, respectively with $R^2 = 0.57$.

Key Words: Cat; Regression analysis; Body weight estimation

INTRODUCTION

In a domestic cat population, body weight is an important trait that is used in evaluating body condition (Erat & Arikan, 2010) and health status (Lund *et al*., 2005) of cats, in computing dosages and in prescribing drugs. Body weight and condition score are also often used for assessing nutritional condition of dog and cat (Laflamme, 1997; Esfandiari & Youssefi, 2010).

A lot of techniques, which are simple or sophisticated and expensive or inexpensive, are available to get information on animal's body traits. The easiest way to assess an animal's body mass is to weigh the animal. However, under some situations scale may not be available and prediction of body weight from body measurements could be preferred practically (Latshaw & Bishop, 2001).

Multiple regression analysis has been used widely to describe quantitative association between dependent (body weight) and independent variables (hearth girth, body length & wither height etc.) in animal studies (Cankaya, 2009). Several studies on cattle, sheep and goat (Mohammed & Amin, 1997; Wilson *et al*., 1997; Atta & El khidir, 2004; Topal & Macit, 2004; Adeyinka & Mohammed, 2006; Bagui & Valdez, 2007), dog and cat (Pendergrass *et al*., 1983; Valdez & Recuenco, 2003), horse and donkey (Pearson & Ouassat, 1996; Marante *et al*., 2007) and poultry (Latshaw & Bishop, 2001; Grona *et al*., 2009) have been conducted to predict body weight from body measurements.

The body weight estimation from using external body measurements on domestic cats is scarce. Valdez and Recuenco (2003) estimated the body weight of Philippine domestic cats using some external body measurements. Therefore, the present study was designed to predict body weight of Turkish cats (*Felis catus*) from wither height, body length and head circumference and to choose the most appropriate regression model.

MATERIALS AND METHODS

Source of data: A total of 48 adult Turkish cats (20 females & 8 males Turkish Angora; 13 females & 7 males Turkish Van) were used (Fig. 1). All cats were solid white in color and sexually intact. Averages of weight and age for these cats were 3.39 kg and 2.71 years, respectively.

Measurements: Live body weight (BW), wither height

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(WH), body length (BL) and head circumference (HC) were measured. The measurements of the body traits were described in Erat and Arikan (2010). The BW was taken with a scale of 5 g of precision. A cloth tape was used for measuring the WH, BL and HC. The WH was the distance from the floor beneath the cat to the top of withers. The BL was the distance from the point of the shoulder to the ischiatic tuberosity. The HC was measured by wrapping the cloth tape around the circumference of the cat's head just behind the ears and across the forehead. The BW was recorded in kilograms and the other measurements were recorded in centimeters. All measurements were taken from the left side of the cats.

Statistical analysis: In the present study, the WH, BL and HC measurements were used as independent variables, while the BW was considered as a dependent variable. Linear, quadratic and cubic effects of the independent variables were considered as shown in the following model (Heinrichs *et al*., 1992):

$$Y = b_0 + b_1X + b_2X^2 + b_3X^3 + e$$

Where Y = body weight; b_0 = the intercept; X = independent variables, either the WH, BL, or HC; b_1, b_2 and b_3 = regression coefficients; and e = random error. Conceptual predictive (*Cp*) and Akaike information criterion (*AIC*) (Kaps & Lamberson, 2004) were used to determine the most suitable model among the assumed models.

The *Cp* and *AIC* statistics were defined by (Kaps & Lamberson, 2004) as:

$$Cp = p + \frac{(MS_{RES} - \hat{\sigma}_0^2)(n - p)}{\hat{\sigma}_0^2}$$

Where: MS_{RES} = residual mean square for the candidate model.

$\hat{\sigma}_0^2$ = variance estimate of the true model.

n = the number of observations.

p = the number of parameters of the candidate model (the number of independent variables + 1).

Usually, the estimate of variance from the full model, which is the model with the maximal number of parameters, is used. Then:

$$\hat{\sigma}_0^2 \cong MS_{RES-FULL}$$

$$AIC = n\log(SS_{RES} / n) + 2p$$

Where: SS_{RES} = Residual sum square, n and p are explained above.

Phenotypic correlations between the BW and the external body parameters were also calculated. Statistical analyses were performed using MEANS, REG and CORR procedures of SAS v.8.2 (The SAS Institute Inc., Cary, NC) statistical package program.

Table I: Descriptive statistics for body traits of the Turkish cats

Body trait	N	Mean	SE[a]	Min.	Max.	CV[b] (%)
Body weight (kg)	48	3.39	0.11	1.81	5.52	21.92
Wither height (cm)	48	26.31	0.29	22.00	31.00	7.73
Body length (cm)	48	37.06	0.45	29.00	44.00	8.39
Head circumference (cm)	48	25.06	0.28	21.00	29.00	7.87

[a] Standard Error, [b] Coefficient of Variation

Fig. 1: Turkish Angora (left) and Turkish Van (right) cats. Photos were taken by Serkan Erat

RESULTS AND DISCUSSION

Descriptive statistics for the body traits of Turkish cats are given in Table I. The BW showed the highest variation among the traits measured. Erat and Arikan (2010) reported that similar averages of these body measurements were 3.64 kg for the BW, 26.93 cm for the WH, 37.21 cm for the BL and 26.09 cm for the HC, for both Turkish cats. Hendriks *et al.* (1997) reported an average body weight of 3.80 kg for both gender of intact cats and Allan *et al.* (2000) reported an average body length of 37.00 cm for their cats. These values were in agreement with the averages of body weight and length of Turkish cats in the present study.

Table II presents regression analysis results of cat body weight on different body measurement using individual observations. The R^2 values from the regression analysis indicated that the BL (R^2 =0.50) was connected in medium level with the BW. The quadratic term and the cubic term were insignificant for all body traits, whereas the linear term was highly significant (P < 0.001) for all independent variables. Several studies, conducted to predict body weight for different animal species, reflected that the heart girth was one of the greatest body weight predictors (Heinrichs *et al*., 1992; Pearson & Ouassat, 1996; Wilson *et al*., 1997; Gueye *et al*., 1998; Valdez & Recuenco, 2003; Atta & El khidir, 2004; Adeyinka & Mohammed, 2006). However, Aziz and Sharaby (1993) reported that height at withers could be considered as a better estimator for body weight than hearth girth. Wickersham and Schultz (1963) reported that wither height could be one of the best skeletal measurements in some instances since it is not influenced by body condition. Sulieman *et al*. (1990) also reported that body length and wither height were less variable than hearth girth, because hearth girth was the most variable measurement influenced by body condition and by physiological status of the animal in some instances.

Table II: Regressions of the Turkish cats' body weight on various body measurements using individual observations

Measurement	Intercept	Linear	Quadratic	Cubic	$(R^2)^a$	Model p-values
Wither height	- 2.08	0.20799***			0.32	< 0.001
	- 7.83	0.64580	- 0.00828		0.33	< 0.001
	- 147.15	16.59213	- 0.61377	0.00763	0.34	< 0.001
Body length	- 2.86**	0.16878***			0.50	< 0.001
	- 1.14	0.07507	0.00127		0.50	< 0.001
	- 60.71	5.02473	- 0.13478	0.00124	0.51	< 0.001
Head circumference	- 1.81	0.20757***			0.30	< 0.001
	-12.18	1.04404	- 0.01677		0.31	< 0.001
	- 92.87	10.82266	- 0.40967	0.00524	0.32	< 0.001

**P<0.01, ***P < 0.001

[a] R^2 is the coefficient of determination which gives the proportion of variability in Turkish cat body weight (Y) explained by body measurements (Xs)

Table III: Conceptual predictive (*Cp*) and Akaike information criterion (*AIC*) for selecting an optimal model for predicting body weights of the Turkish cats

Number of independent variables in Model	p[a]	df[b]	*Cp*	*AIC*	R^2	SSE[c]	Variable in Model[d]
2	3	45	3.0980	- 63.9419	0.5705	11.17945	WH BL
3	4	44	4.0000	- 63.1250	0.5809	10.90727	WH BL HC
2	3	45	7.6375	- 59.3383	0.5272	12.30477	BL HC
1	2	46	8.7279	- 58.4392	0.4978	13.07086	BL
2	3	45	18.2044	- 50.0743	0.4266	14.92422	WH HC
1	2	46	27.0831	- 44.1013	0.3230	17.62097	WH
1	2	46	29.2176	- 42.6812	0.3026	18.15009	HC

[a] The number of parameters of the candidate model. [b] degree of freedom. [c] residual sum square

[d] WH=Wither height, BL= Body length, HC= Head circumference

Therefore, linear model with wither height and body length compared to the models in Table III could be better skeletal measurements for predicting body weight as in the present study. Additionally, head circumference seems first to be accounted for predicting body weight.

In the present study, results of seven possible different models are depicted in Table III. The *Cp* and *AIC* were used to detect the most suitable model (Table III). The value of *Cp* for the model with the WH and BL was found to be better than other models in Table III. Also, there was a bit better in R^2 for models with the WH, BL, HC compared to the model with the WH and BL. The *AIC* value was also the smallest for the model with the WH and BL. Results revealed that the model with the WH and BL could explain cat body weight better than other models (Kaps & Lamberson, 2004). The parameter estimates were b_0 = - 4.53, b_1 = 0.11 and b_2=0.13, for the intercept, the WH, and BL, respectively. So the model became; cat body weight (BW) = - 4.53 + 0.11 WH + 0.13 BL with p- values, <0.001, 0.0083 and <0.001 for the intercept, b_1 and b_2, respectively with R^2 = 0.57. Aziz and Sharaby (1993) also used *Cp* statistics for comparing efficiency of different models in addition to determination coefficient (R^2) and adjusted R^2. They found that heart girth may be better for predicting body weight of Najdi sheep than wither height based on R^2 and adjusted R^2. However, they concluded that wither height was a better predictor than hearth girth for predicting body weight of Najdi sheep based on *Cp* statistic. Neter *et al.* (1996) reported that the bias of the regression model was small when subsets of independent variables with small *Cp* values had a small total mean squared error and *Cp* value was near *p*. *AIC* was also used for model selection by others (Akaike, 1987; Bozdogan, 1987). Bozdogan (1987) described *AIC* as a simple and versatile procedure and reported that *AIC* had provided a new and modern way of thinking on how to solve many important statistical modeling problems. Beal (2005) showed that *AIC* for multivariate model selection was superior to heuristic methods such as forward selection, backward elimination, stepwise regression and minimizing Root of Mean Square Error (RMSE) using simulated data with a known underlying model. Valdez and Recuenco (2003) found that addition of second and third variable to regression equations slightly increased R^2 values but their R^2 values were never below 0.70.

Table IV: Phenotypic correlations between the body measurements of the Turkish cats

	WH	BL	HC
BW	0.57***	0.71***	0.55***
WH		0.47**	0.47**
BL			0.58***

**P<0.01, ***P<0.001

WH=Wither height, BL= Body length, HC= Head circumference

Phenotypic correlations of the BW with the BL, WH and HC traits were also calculated (Table IV). It was found that the BW showed the highest correlation coefficient value with the BL (*r*=0.71; p<0.001) followed by the correlation coefficient values with the WH (*r*=0.57; p<0.001) and the HC (*r*=0.55; p<0.001). Similarly, positive correlation coefficients of body weight with external body measurements were also reported for mongrel dogs (0.76 for length: weight; 0.85 for circumference: weight & 0.41 for height: weight) (Pendergrass *et al*., 1983), Philippine domestic cats (Valdez & Recuenco, 2003) and for Turkish cats (Erat & Arikan, 2010).

CONCLUSION

Body length was the highly correlated with body weight and combining body length with other body measurements (wither height & head circumference) in multiple regression produced higher R^2. *Cp* and *AIC* values could be used to choose the best suitable model among the assumed models. Despite shortcomings of the cat data, an attempt was made to predict the body weight of the cats from different body measurements. Therefore, the formulas found in the present study could be helpful for an approximate estimation of cat body weight with caution since R^2 values were either low or medium level. Others factors such as gender and age of a cat may also affect body weight estimation. However, for convenience of users who work under field conditions, prediction equations can be constructed without considering those effects.

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REFERENCES

Adeyinka, I.A. and I.D. Mohammed, 2006. Accuracy of body weight prediction in Nigerian Red Sokota goats raised in Northern Eastern Nigeria using linear body measurements. *Pakistan J. Biol. Sci*., 9: 2828–2830

Akaike, H., 1987. Factor analysis and AIC. *Psychometrika*, 52: 317–332

Allan, F.J., D.U. Pfeiffer, B.R. Jones, D.H.B. Esslemont and M.S. Wiseman, 2000. A cross-sectional study of risk factors for obesity in cats in New Zealand. *Prev. Vet. Med*., 46: 183–196

Atta, M. and O.A. El khidir, 2004. Use of heart girth, wither height and scapuloischial length for prediction of liveweight of Nilotic sheep. *Small Rumin. Res*., 55: 233–237

Aziz, M.A. and M.A. Sharaby, 1993. Collinearity as a problem in predicting body weight from body dimensions of Najdi sheep in Saudi Arabia. *Small Rumin. Res*., 12: 117–124

Bagui, N.J.G. and C.A. Valdez, 2007. Live weight estimation of locally raised adult purebred Brahman cattle using external body measurements. *Philippine J. Vet. Med*., 44: 36–42

Beal, D.J., 2005. SAS® code to select the best multiple linear regression model for multivariate data using information criteria, *Proc. 13th Annual Conference of the South East SAS Users Group*. http://analytics.ncsu.edu/sesug/2005/SA01_05.PDF

Bozdogan, H., 1987. Model selection and Akaike's information criterion (AIC): the general theory and its analytical extensions. *Psychometrika*, 52: 345–370

Cankaya, S., 2009. A comparative study of some estimation methods for parameters and effects of outliers in simple regression model for research on small ruminants. *Trop. Anim. Health Prod.*, 41: 35–41

Erat, S. and S. Arikan, 2010. Body mass index and different body measurements of Turkish Angora and Van cats in two different locations. *J. Anim. Vet. Adv*., 9: 118–122

Esfandiari, B. and M.R. Youssefi, 2010. First report of *Taenia taeniaeformis* in Persian leopard (*Panthera pardus saxicolor*) in Iran. *Pakistan Vet. J*., 30: 253–254

Grona, S.G., F.A.E.M. Bernardo and C.A. Valdez, 2009. The relationship of body weight to certain external body measurements in adult fighting cocks. *Philippines J. Vet. Med*., 46: 113–118

Gueye, E.F., A. Ndiaye and R.D.S. Branckaert, 1998. Prediction of body weight on the basis of body measurements in mature indigenous chickens in Senegal. *Livest. Res. Rural Dev*., 10: Online edition. http://www.lrrd.org/lrrd10/3/sene103.htm

Heinrichs, A.J., G.W. Rogers and J.B. Cooper, 1992. Predicting body weight and wither height in Holstein heifers using body measurements. *J. Dairy Sci*., 75: 3576–3581

Hendriks, W.H., M.F. Tarttelin and P.J. Moughan, 1997. Seasonal hair growth in the adult domestic cat (*Felis catus*). *Comp. Biochem Physiol*., 116A: 29–35

Kaps, M. and W.R. Lamberson, 2004. *Biostatistics for Animal Science*. CABI Publishing, Cambridge

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

Latshaw, J.D. and B.L. Bishop, 2001. Estimating body weight and body composition of chickens by using noninvasive measurements. *Poult. Sci*., 80: 868–873

Lund, E.M., P.J. Armstrong, C.A. Kirk and J.S. Klausner, 2005. Prevalence and risk factors for obesity in adult cats from private US veterinary practices. *Int. J Appl. Res. Vet. Med*., 3: 88–96

Marante, R.P., E.B. Torres and C.A. Valdez, 2007. Body weight estimation of local born thoroughbred horses (*Equus caballus*) using external body measurements. *Philippines J. Vet. Med*., 44: 114–122

Mohammed, I.D. and J.D. Amin, 1997. Estimating body weight from morphometric measurements of Sahel (Borno White) goats. *Small Rumin. Res*., 24: 1–5

Neter, J., M.H. Kutner, C.J. Nachtsheim and W. Wasserman, 1996. *Applied Linear Regression Models*, 3rd edition. Irwin, Chicago

Pearson, R.A. and M. Ouassat, 1996. Estimation of the liveweight and body condition of working donkeys in Morocco. *Vet. Record*, 138: 229–233

Pendergrass, P.B., C.M. Bartley, F. Nagy, L.J. Ream and R. Stuhlman, 1983. A rapid method for determining normal weights of medium-to-large mongrel dogs. *J. Small Anim. Prac*., 24: 269–276

Sulieman, A.H., A.R. Sayers and R.T. Wilson, 1990. Evaluation of Shugar, Dubasi and Watish Subecotypes of Sudan desert sheep at El Huda National Sheep Research Station. *ILCA Res. Rep. No. 18.* Gezira Province, Sudan,

Topal, M. and M. Macit, 2004. Prediction of body weight from body measurements in Morkaraman sheep. *J. Appl. Anim. Res*., 25: 97–100

Valdez, C.A. and F.C. Recuenco, 2003. Bodyweight estimation in adult Philippine domestic cat (*Felis catus* Linnaeus) using external body measurements. *Philippines J. Vet. Med*., 40: 92–99

Wickersham, E.W. and L.H. Schultz. 1963. Influence of age at first breeding on growth, reproduction, and production of well-fed Holstein heifers. *J. Dairy Sci*., 46: 544–549

Wilson, L.L., C.L. Egan and T.L. Terosky, 1997. Body measurements and body weights of special-fed Holstein veal calves. *J. Dairy Sci*., 80: 3077–3082

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