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# BODY MASS ESTIMATES FROM BONE AND TOOTH MEASUREMENTS IN WHITE-TAILED DEER, *Odocoileus virginianus*

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## ABSTRACT

The distal forelimbs and mandibles of 110 female and 240 male white-tailed deer (*Odocoileus virginianus*) from the Piedmont National Wildlife Refuge, Georgia, were used to examine the relationship between metacarpal dimensions, first lower molar occlusal surface area, and mandibular width versus body mass. The strongest correlation was found between female metacarpal proximal area vs. body mass ($R^2$ = 0.74). The combined-sexes metacarpal proximal area vs. body mass displayed a lower correlation ($R^2$ = 0.54). The female first lower molar surface area vs. body mass produced the highest dental correlation ($R^2$ = 0.56). The study suggests that body mass estimates using postcranial and tooth measurements are more accurate when the sex of the animal is known.

***Keywords:*** body mass estimates, white-tailed deer

## INTRODUCTION

A number of ecological variables are associated with body mass, therefore accurately predicting body mass is vital in paleoecological and archaeological studies. Mammalian body mass has been correlated with characteristics such as energy expenditure in locomotion (McNab 1990), gestational period (Millar 1977), thermoregulation (Owen-Smith 1988), and niche ecology (Martin 1990). Also, body mass distributions in mammalian communities have been employed to infer paleoenvironmental conditions (Legendre 1986). Additionally, in zooarchaeological studies, estimated body masses for recent mammalian prey species have been used to determine the quantity of animal protein in early-human diets (Emerson 1978; Purdue 1987).

A review of body mass estimating techniques reveals that distal limb bone measurements strongly correlate to body mass. In extant and extinct mammals, both linear and areal postcranial measurements have been utilized. For example, Alexander et al. (1979) measured the diameter and length of femora, tibiae, metatarsals, humeri, ulnae, and metacarpals from 37 mammalian species in seven orders and developed equations to predict body weight among terrestrial taxa. Scott (1983) used recorded weights from literature and 45 postcranial dimensions to create a series of regression equations for the Bovidae. Anyonge (1993) estimated the body mass of six species of Plio-Pleistocene carnivores using multiple measurements of the femora and humeri of 28 extant carnivore species.

Dental measurements have been employed as predictors of body mass as well. Gingerich (1974) used the length and width of lower molars and premolars in 19 extant mammalian species to estimate body mass of closely related extinct sympatric species. Gingerich et al. (1982) utilized upper and lower dental measurements from extant primate species to predict the weights of Oligocene anthropoids. Legendre (1986) measured the first lower molar (m1) in modern mammals and demonstrated that body mass and tooth area regression equations are more robust when developed for different dietary guilds.

Several previous studies have addressed the correlation of morphology and body mass in white-tailed deer (*Odocoileus virginianus*), the focus of the present study. Roseberry and Klimstra (1975) used not only bone measurements, but chest girth and hindfoot lengths in addition to the dentary and diastema lengths in the lower mandible to develop regression equations. Emerson (1978) used astragular and Purdue (1987) used metacarpal dimensions to generate regression equations as well. More recently, Batchelor and Mead (2007) measured hoof width and found a positive correlation with body mass in a combined-sexes sample. The goal of the present study is to investigate further the correlations between body mass and osteological and dental measurements in a sample of white-tailed deer of known age, sex, and weight from a single location in central Georgia.

## MATERIALS AND METHODS

Selected cranial and postcranial material was collected from 350 white-tailed deer (240 males, 110 females) at the U.S. Fish and Wildlife hunter check station on the Piedmont National Wildlife Refuge in Round Oak, Georgia, during the fall of 2001 (see Morris 2003 for details). At the check station, deer were weighed, aged, and sexed. Full or dressed weights (the majority of deer were eviscerated) were taken using balance scales. Estimates of live weights for field dressed deer were generated using the regression equation developed by Hammerstrom and Camburn (1950). The right or left dentary was pulled from each deer and age was established on the basis of tooth eruption and wear (Thompson 1958). The distal portion (carpals, metacarpals, and hooves) of the right forelimb was taken from each carcass (the left was used if the right was damaged). The mandible and lower forelimb from each deer were marked with corresponding metal numbered tags attached with plastic cable-ties. The metacarpals and jaws were cleaned, catalogued, and entered into the mammalogy collection at the Georgia College Natural History Museum.

Using digital calipers, the following four measurements (to the nearest 0.01 mm) were recorded on each metacarpal: proximal width (MCPW), proximal depth (MCPD), distal width (MCDW), and distal depth (MCDD) (see Figure 1 in Purdue 1987). The following three measurements were obtained on each mandible: m1 occlusal width (OW) and m1 occlusal length (OL) were taken at the occlusal surface, and mandible width (MW) was taken at m1 perpendicular to the occlusal surface bisecting the tooth root. Metacarpal proximal area (MCPAR), metacarpal distal area (MCDAR), and m1 surface area (m1AR) were determined as follows: $MCPAR = (MCPW/2) \bullet (MCPD/2) \bullet (\pi)$; $MCDAR = MCDW \bullet MCDD$; and $m1AR = OL \bullet OW$. Log transformed data for each variable or combination of variables versus body mass was analyzed as a combined-sexes group and then separately as female and male subgroups. For the 15 comparisons, least squares (linear) regressions were carried out and equations and $R^2$ values were generated.

## RESULTS

Varying degrees of correlation exist between the combined-sexes, female, and male white-tailed deer variables and body mass (Table I). The following three strongest correlations were seen in the female subgroup: F-MCPAR vs. body mass ($R^2$ = 0.74), F-m1AR • MCDW vs. body mass ($R^2$ = 0.66), and F-MCDAR vs. body mass ($R^2$ = 0.57). The only combined-sexes equation with an $R^2$ value greater than 0.50 was A-MCPAR vs. body mass ($R^2$ = 0.54). The strongest male correlation was M-MCPAR vs. body mass ($R^2$ = 0.48).

***Table I.*** Linear regression equations (log transformed data) for each variable (mm or mm$^2$) versus body mass (kg) for 350 white-tailed deer from the Piedmont Wildlife Refuge in central Georgia. Metacarpal proximal area: MCPAR = (metacarpal proximal width/2) • (metacarpal proximal depth/2) • π. Metacarpal distal area: MCDAR = metacarpal distal width • metacarpal distal depth. First lower molar occlusal surface area: m1AR = m1 length • m1 width. Mandibular width: MW = width of mandible measured perpendicular to occlusal surface and bisecting the tooth root. A = both sexes; F = female; M = male; BM = body mass; MCDW = metacarpal distal width.

| Character | Regression equation | $R^2$ value |
|---|---|---|
| A-MCPAR vs. BM | Y = 1.5887X – 2.5591 | 0.54 |
| F-MCPAR vs. BM | Y = 2.2164X – 3.9403 | 0.74 |
| M-MCPAR vs. BM | Y = 1.7325X – 2.9535 | 0.48 |
| A-MCDAR vs. BM | Y = 1.5707X – 2.6861 | 0.41 |
| F-MCDAR vs. BM | Y = 2.1737X – 4.3133 | 0.57 |
| M-MCDAR vs. BM | Y = 1.6845X – 3.0106 | 0.33 |
| A-m1AR vs. BM | Y = 0.9687X – 0.3086 | 0.26 |
| F-m1AR vs. BM | Y = 1.1944X – 0.8135 | 0.56 |
| M-m1AR vs. BM | Y = 0.8448X – 0.0379 | 0.17 |
| A-(m1AR • MW) vs. BM | Y = 0.8166X – 0.9110 | 0.25 |
| F-(m1AR • MW) vs. BM | Y = 0.9953X – 1.5150 | 0.53 |
| M-(m1AR • MW) vs. BM | Y = 0.6882X – 0.4892 | 0.16 |
| A-(m1AR • MCDW) vs. BM | Y = 0.9519X – 2.9118 | 0.48 |
| F-(m1AR • MCDW) vs. BM | Y = 0.9532X – 2.9259 | 0.66 |
| M-(m1AR • MCDW) vs. BM | Y = 0.9127X – 2.7195 | 0.35 |

## DISCUSSION

Since paleontologists and archaeologists often need to estimate the body mass of extinct species, estimates for modern taxa derived from osteological and dental measurements can be of great value. In the current study, based on associated $R^2$ values, the most robust regression equations for white-tailed deer were found in the female only subgroup. Purdue (1987) used similar metacarpal measurements from female and male white-tailed deer collected from eight localities in five states. In his study, females consistently produced lower $R^2$ values than males, whereas the regressions performed in the present study produced the opposite trend (Table I). This difference is likely due to the high number of young males in the present sample. Previous studies of white-tailed deer indicate that females and males reach 95% of maximum body mass by 3.5 and 4.5 years respectively (Roseberry and Klimstra 1975; Strickland and Demarais 2000). In the current study, males were strongly represented by the 0.5 to 2.5 year classes, while females were more numerous in the 2.5 to 5.5 year range, closer to the age where females reach 95% of maximum body mass (Morris 2003). Also, the intersexual differences in mean body weight in the present study may have been more pronounced had the deer been obtained before "rutting" season, as it has been shown that male deer experience a significant reduction in body mass during this season (Strickland and Demarais 2000).

The difference in sex-specific growth rates likely influenced the weak correlation observed when using m1 as a predictor of body mass. Legendre's (1986) analysis using m1 produced strong correlations among groups that included all mammals ($R^2$ = 0.98) and artiodactyls and perissodactyls ($R^2$ = 0.95). The difference in Legendre's m1 results and those calculated in this paper, again, are likely due to the age distribution of specimens. However, a cursory examination of herbivore cheek teeth indicates a general increase in occlusal surface area as the animal ages, due to the progressive wear of teeth that taper inward towards the occlusal surface. Occlusal area may continue to increase with wear even though the animal has already reached maximum weight.

For the paleontologist or archaeologist, the most useful predictors of body mass are those determined using a single skeletal element and those that show strong correlation for both sexes. It is often not possible to determine if fossilized material recovered from a locality belongs to the same individual, or to determine the sex of an isolated element. Since metacarpal proximal area showed the strongest correlations (Table I) in the combined-sexes, female-only, and male-only subgroups, it appears to be the most useful predictor of body mass in this study. Regressions using tooth measurements or a combination of tooth and mandible or metacarpal measurements did not increase $R^2$ values significantly. This study also suggests that sex-specific regressions yield more accurate estimates of body mass in this species. Further studies which include a more even representation of age classes may strengthen body mass correlations for both females and males. However, since it has been demonstrated that body mass may vary by 30% over a year's time in white-tailed deer (Moen and Severinghaus 1981), the $R^2$ values for the body mass regressions generated in this study may be as high as can be expected.

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