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Calculation of body surface area of corn snakes (*Pantherophis guttatus*) utilizing computed tomography

Daria G. Hinkle, DVM[1]; Nathan C. Nelson, DVM, MS[2]; Elizabeth G. Duke, DVM[1]; Tara M. Harrison, DVM, MPVM[1]*

[1]Departments of Clinical Sciences, College of Veterinary Medicine, North Carolina State University, Raleigh, NC
[2]Molecular and Biomedical Sciences, College of Veterinary Medicine, North Carolina State University, Raleigh, NC

*Corresponding author: Dr. Harrison (tara_harrison@ncsu.edu)

OBJECTIVE
To determine the K-constant for body surface area calculation from body weight in corn snakes (*Pantherophis guttatus*) through the use of computed tomography (CT) measurements.

ANIMALS
12 adult corn snakes held by North Carolina State University for research purposes underwent CT between November 2022 and January 2023.

METHODS
Each snake had a CT scan, physical examination, and body weight measurement. CT images were uploaded into software able to perform 3-D reconstruction and measure body surface area. The species-specific K-constant was determined using nonlinear regression analysis between body surface area and (body weight in grams)$^{2/3}$.

RESULTS
The mean body weight of the 12 adult corn snakes was 228 g, with a mean body surface area of 505.1 cm^2. The calculated K-constant was 13.6 ($P < .001$). The resulting formula for body surface area in corn snakes is BSA in cm^2 = 13.6 X (body weight in grams)$^{2/3}$.

CLINICAL RELEVANCE
The body surface area formula developed for corn snakes will allow for improved dosing accuracy for medications with low therapeutic safety margins. Additional pharmacokinetic and pharmacodynamic studies are necessary to determine the safety and efficacy of individual medications.

Keywords: body surface area, snake, corn snake, computed tomography, *Pantherophis guttatus*

Pharmacologic dosing in exotic animal species is often extrapolated from treatment plans for dogs and cats.[1–4] Linear extrapolation, the adjustment of dose based on body weight, tends to result in underdosing of smaller animals.[3] Alternatively, a method of extrapolation, based on body surface area (BSA), is commonly used for chemotherapeutic agents due to the small therapeutic ratio of these medications.[4] The formula most commonly used in veterinary medicine is BSA = K X (W)$^{2/3}$ where W is weight in grams and K is a species-specific constant determined by the shape of the species.[5] The use of computed tomography (CT) to determine a species specific K constant has been described in ferrets (*Mustela putorius furo*),[6] rabbits (*Oryctolagus cuniculus*),[7] bearded dragons (*Pogona vitticeps*),[8] and American bullfrogs (*Lithobates catesbeianus*).[9]

As snake anatomy differs greatly from other species of animals due to their lack of appendages and extended body length, it is suspected that snake species K constants may vary greatly even from that of other reptiles. Corn snakes (*Pantherophis guttatus*), a popular snake species among zoological institutions and the pet trade have been found to have a 9.6% prevalence of neoplastic disease with many different reported neoplasms.[10–14] Unfortunately, few snakes are treated for neoplastic disease and treatment has not been found to extend survival times at this time.[10] The goal of this study was to determine the species-specific K constant to develop a formula to calculate BSA from body weight in corn snakes. The accurate calculation of BSA in corn snakes may assist with developing doses of chemotherapeutics to further improve safety and efficacy studies and accurately dose medications for a range of snake sizes.

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Methods

Animals

Twelve adult corn snakes that were approximately 20 years of age and were of varying sizes owned by North Carolina State University were utilized for the study. All snakes had been housed at North Carolina State University since the fall of 2020 and had been managed under human care their entire lives before that. All snakes were behaving and eating normally and did not have injuries that affected their body shape or size. A physical examination was performed by a veterinarian to confirm health and body weight recorded in grams. This study was approved by North Carolina State University's IACUC (#19-769-T).

Procedures

Each snake was placed within a foam pipe insulation tube (Everbilt; Home Depot US, Inc; 1/2″ ID X 1/2″ Wall X 6′ long) to prevent overlap of body segments and decrease movement of the animal. This allowed CT scanning to be completed without the use of sedation or anesthesia. The foam also provided separation of the animal from the table surface to aid segmentation for 3-D reconstruction **(Figure 1)**. A 64-slice helical CT scanner (SOMATOM Perspective; Siemens Healthcare) was used to obtain transverse images with 3 mm slice thickness with an exposure of 130 kVp and 135 to 195 mA (tube current). These images were then uploaded into CT image analysis software (Mimics Innovation Suite; Materialise NV) and viewed in a wide window (window width, 2000 HU; window level, 400 HU). A threshold value of −500 HU with no upper limit was applied to exclude air surrounding the animal, and air within the individual's lungs or gastrointestinal tract was manually filled with a tracing tool so only the external surface area would be calculated. The resulting 3-D surface model **(Figure 2)** was assessed for accuracy and completeness by a single observer (DH), then the CT image analysis software calculated the BSA that was recorded. This procedure, similarly described to determine the body surface area of bearded dragons,[8] was repeated for each of the 12 snakes used in the study.

Statistical analysis

A graph of weight vs BSA for all animals was created and nonlinear regression utilized to determine the K-constant for the equation BSA = K X $(W)^{2/3}$ with BSA as the dependent variable **(Figure 3)**. The *P*-value was calculated to ensure a significant fit. Statistical analysis was performed using R Statistical Software (v4.2.0).[15]

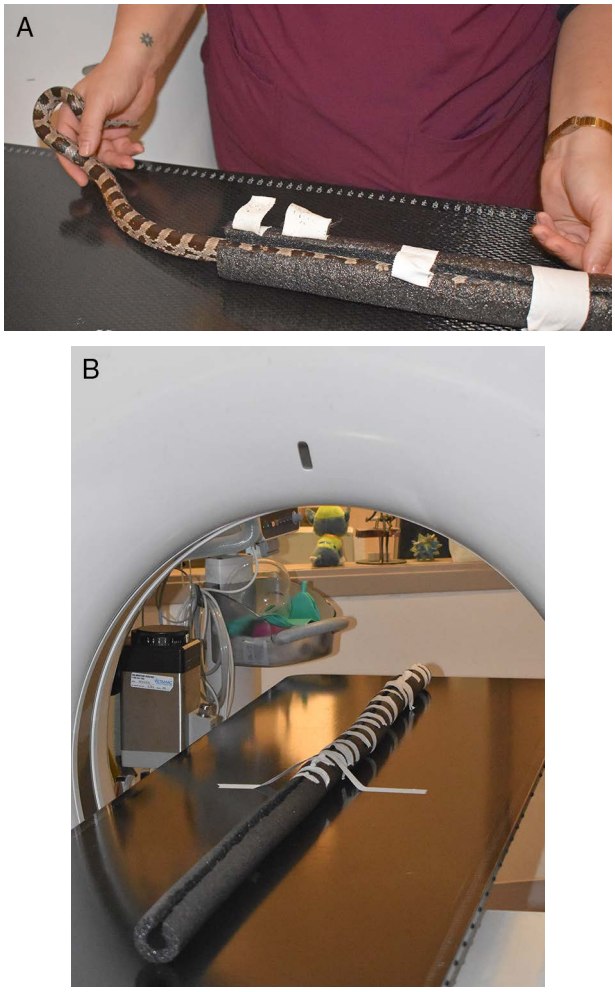

Figure 1—12 adult corn snakes underwent CT scan to measure body surface area (BSA) and calculate a species-specific K-constant for BSA calculation. A corn snake entering the foam pipe insulation to prevent movement and provide separation from the table (A). The snake within foam pipe insulation and centered on the CT table for scanning (B).

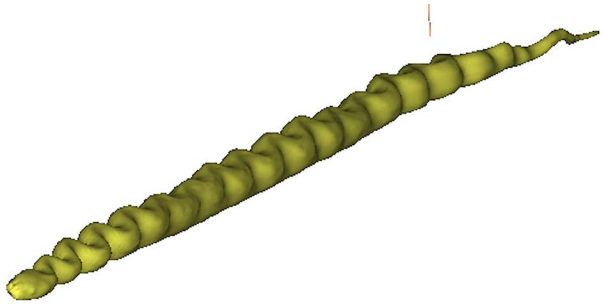

Figure 2—3-D reconstruction of a corn snake used to calculate body surface area as described in Figure 1. The model is angled to show accuracy of details, but the snakes were positioned so there was no contact between body surfaces.

Results

Animals

Twelve adult corn snakes of unknown age were included in the study with 10 females and 2 males represented. Body weight ranged from 148.8 g to 449.7 g with a mean of 228 g (median 214.4 g). All snakes are housed at the university for research

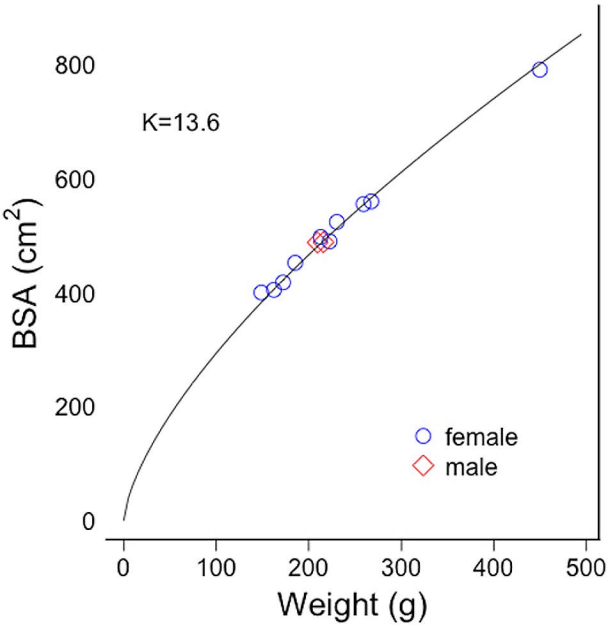

Figure 3—Graph depicting BSA in centimeter squared measured by CT scan as described in Figure 1 vs body weight in grams of the 12 corn snakes with nonlinear regression analysis applied to determine the shape constant (K = 13.6) for the equation: BSA in centimeters squared = K X (body weight in grams)$^{2/3}$.

and teaching purposes and were behaving normally and determined to be healthy on physical exam by a veterinarian (DH). No body contour abnormalities were present that could affect BSA measurement.

BSA measurement

All animals underwent CT imaging between November 2022 and January 2023. The foam provided separation of the animals from the CT table for reconstruction purposes and a dark environment that minimized movement and prevented the need for sedation. One snake had to be rescanned due to movement artifact identified on reconstruction, but clear images were obtained on the second scan without sedation. 3-D reconstruction was performed on all animals using CT image analysis software (Mimics Innovation Suite) and models were visually assessed for completeness. The software measured BSA ranged from 399.7 cm^2 to 789.7 cm^2 with a mean of 505.1 cm^2 (median 488.6 cm^2).

Equation for BSA calculation

Weight and BSA were plotted against each other and nonlinear regression was used to determine the K-constant for the equation BSA = K X (W)$^{2/3}$. The K-constant obtained was 13.6. Regression statistics support a significant fit with $P < .001$.

Discussion

Development of species-specific BSA formulas through the use of CT was initiated using rabbits,[7] and has been additionally applied for the use of ferrets,[6] bearded dragons,[8] and American bullfrogs.[9] The use of CT scans to evaluate BSA formulas is minimally invasive and does not require the euthanasia of any individuals as has occurred previously with some methods such as the tape method[6] or skinning to calculate BSA.[7] Anesthesia was not required in the bearded dragon study[8] as well as the present corn snake study due to reptile's relatively sedentary nature and the ability to appropriately restrain them. Only 1 snake required rescanning due to movement artifact. All final images obtained were of good quality without the use of anesthesia.

A previous study evaluating the body surface area of snakes based on volume yielded the equation: BSA in cm^2 = 15.6 cm^2 X volume (cc)$^{0.64}$. The BSA of the snakes was determined using length and circumference measurements and geometric approximations. Volume was measured by volume of water displacement. This study used snakes from both the Colubridae and Boiidae families. More importantly, the resulting formula from this previous study showed that snakes grow in an isometric fashion indicating that metabolic scaling is applicable.[16]

The CT-derived BSA formula from our results yielded the equation: BSA in cm^2 = 13.6 X (weight in grams)$^{2/3}$. The nonlinear regression model was found to be statistically significant ($P < .001$). The derived K-constant of 13.6 is lower than the similar constant derived by the previous snake study based on a volume of 15.6. This difference in BSA may be due to the previous equation being formulated based on volume or because the study included multiple species of snakes from 2 different families. Additionally, there may be a difference in the accuracy of measurement provided by CT compared to the volume of water displaced or geometric approximations. In comparison to other CT-derived BSA formulas, the K-constant for corn snakes is higher than those of previously studied species.[6–9] The K-constant for rabbits (9.9)[7] and ferrets (9.94)[6] are similar to the K-constant values that are utilized for cats (10.0) and dogs (10.1).[17] The K-constant for American bullfrogs (8.28)[9] was lower than other studied species. The K-constant for bearded dragons (11.6)[8] was higher than the previously studied mammals but is still lower than the K-constant derived in this study.

The higher K-constant for corn snakes may be expected based on their unique elongated anatomy. Metabolic scaling assumes that body surface area correlates with metabolic rate, which could indicate that corn snakes require a higher dose of a given medication compared to other species. However, the metabolic rate of reptiles is temperature dependent, and may also vary by time of feeding especially in snake species that have prolonged fasting periods between meals.[3] The use of metabolic scaling to extrapolate a medication dosage from one species to another will not account for species-specific pharmacokinetic and pharmacodynamic differences.[3] This established K-constant will facilitate calculating dose changes between corn snakes of varying sizes, but pharmacokinetic and pharmacodynamic studies in corn snakes are still necessary to determine specific medications safety and efficacy.

Limitations of the present study include the lack of age data, small population size, and low number of males in the study population. No statistical analysis could be completed based on whether age or sex affected the K-constant through differences in shape or growth rate. Further studies with a larger sample size may be beneficial to address these concerns. This study evaluated only corn snakes to develop a species-specific K-constant. Additional studies of other snake species are indicated to determine if the K-constant differs between snake species and to what extent.

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Disclosures

The authors have nothing to disclose. No AI-assisted technologies were used in the generation of this manuscript.

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