

Selected cardiopulmonary values and baroreceptor reflex in conscious green iguanas (*Iguana iguana*)

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Objective—To determine selected cardiopulmonary values and baroreceptor response in conscious green iguanas (*Iguana iguana*) and to evaluate the use of blood gas analysis and pulse oximetry in this species.

Animals—15 healthy juvenile green iguanas.

Procedures—Baseline cardiopulmonary values were determined in 15 conscious iguanas breathing room air. Effects of 100% O₂ inspiration were also measured (n = 6), and the baroreceptor reflex was characterized by exponential sigmoidal curve fitting analysis.

Results—Conscious iguanas had a mean ± SD resting heart rate of 52 ± 8 beats/min, respiratory rate of 28 ± 6 breaths/min, and systolic, mean, and diastolic arterial blood pressures of 69 ± 10 mm Hg, 62 ± 12 mm Hg, and 56 ± 13 mm Hg, respectively. Mean arterial pH at 37°C was 7.29 ± 0.11, Pao₂ was 81 ± 10 mm Hg, and Paco₂ was 42 ± 9 mm Hg; corrected for a body temperature of 30°C, mean arterial pH at 37°C was 7.38 ± 0.12, Pao₂ was 54 ± 15 mm Hg, and Paco₂ was 32 ± 7 mm Hg. Inspiration of 100% O₂ did not change heart and respiratory rates but increased Pao₂ to 486 ± 105 mm Hg (corrected value, 437 ± 96 mm Hg). A baroreceptor reflex was evident, with mean heart rates ranging from 30 ± 3 beats/min to 63 ± 5 beats/min and mean arterial blood pressures ranging from 42 ± 3 mm Hg to 58 ± 3 mm Hg.

Conclusions and Clinical Relevance—This study provided needed information on cardiopulmonary values in healthy green iguanas, the application and limitation of arterial and venous blood gas analysis, and the accuracy of pulse oximetry. (*Am J Vet Res* 2011;72:1519–1526)

Cardiopulmonary values are often determined in ill and anesthetized green iguanas (*Iguana iguana*) to assess cardiovascular and respiratory performance; however, values in healthy green iguanas are not available for comparison, making clinical interpretation difficult. In addition, anesthesia monitoring techniques such as arterial and venous blood gas analyses, pulse oximetry, and direct arterial blood pressure measurements commonly used in human and companion

ABBREVIATIONS

BP ₅₀	Mean arterial blood pressure recorded at the midpoint of the heart rate range
DAP	Diastolic arterial blood pressure
G _{mean}	Mean gain (or sensitivity) of baroreceptor reflex
HR	Heart rate
MAP	Mean arterial blood pressure
Sao ₂	Arterial oxygen saturation
SAP	Systolic arterial blood pressure

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mammal medicine have not been validated for use in reptiles.^{1–3} Therefore, application and interpretation of invasive and noninvasive monitoring techniques is in its infancy, which makes diagnosis of cardiopulmonary disease and monitoring of anesthesia challenging.

Determination of arterial blood gas values provides information on pulmonary function, whereas venous samples are used for metabolic assessments.⁴ However, in most reptiles, catheterization of a peripheral artery for blood pressure and blood gas measurements is difficult, leading to noninvasive monitoring techniques such as pulse oximetry being more commonly used. Although studies^{5,6} have been conducted to determine the accuracy of pulse oximetry in anesthetized reptiles,

little cardiovascular research has been undertaken involving conscious reptiles.

Association of blood gas values with physiologic status in reptiles is particularly difficult because of the unique aspects of their respiratory anatomy and physiology, which differ from those of mammals and birds.⁷ For example, reptiles have the unique ability to tolerate varying degrees of hypoxia, are capable of converting to anaerobic metabolism, and possess intrapulmonary shunts, which bypass gas exchange in the lungs. Large intrapulmonary shunts reduce the efficiency of gas exchange and consequently cause a reduction in PaO_2 .⁷ Healthy cardiovascular performance is also closely linked to thermoregulation in reptiles.⁸ Studies⁹ of cardiopulmonary physiology in snakes have demonstrated a positive correlation between habitat and arterial blood pressures. Additionally, aquatic, terrestrial, and arboreal snakes have different cardiovascular responses to gravity, with arboreal species having higher arterial blood pressures and more effective regulation than aquatic species.^{9–12} To the authors' knowledge, no reports exist of similar adaptations in terrestrial versus arboreal species of lizards.

Information on arterial blood pressure in conscious green iguanas, a strictly arboreal species, is restricted to the effects of posture and hemorrhage.¹³ In reptiles, low PaO_2 is the primary drive for an increase in respiratory rate.⁷ The baroreceptor reflex plays a vital role in the moment-to-moment control of blood pressure and HR in other animal species.^{14–16} In reptiles, a baroreceptor reflex in response to hemorrhage and body tilting has been demonstrated, with snakes serving as the primary example in research, yet important natural history-specific differences exist in snakes.¹⁷ For example, aquatic snakes are less effective at maintaining blood pressure than terrestrial and arboreal snakes. The sensitivity (gain) of the baroreceptor reflex, when expressed as a percentage change in HR per unit pressure change, is approximately the same in reptiles, amphibians, and mammals.^{11,13,14} In addition, the ultrastructural appearance of the baroreceptors of lizards is similar to that of mammals.¹⁷

Green iguanas are diurnal and semiarboreal. To understand the importance of circadian rhythms in lower vertebrates, arterial and venous blood gas values need to be determined at various points during a 24-hour period. Reference values from healthy conscious animals are also needed to better understand iguanid cardiopulmonary physiology and interpret findings in sick or anesthetized iguanas. The objectives of the study reported here were to establish reference ranges for cardiopulmonary variables in conscious, healthy green iguanas breathing room air, to investigate the effects of 100% inspired oxygen on arterial blood gas values, and to characterize the baroreceptor reflex and control of blood pressure in this species.

Materials and Methods

Animals—Fifteen juvenile green iguanas with a mean \pm SD body weight of 0.79 ± 0.14 kg were purchased from a commercial breeding facility in El Salvador. Iguanas were individually housed in clear plastic cages with paper substrate in a room maintained

at 26.7°C. Each enclosure was provided with mercury halide basking lamps that allowed 1 end of the cage to reach 33.3°C. Iguanas were fed a mixture of leafy green vegetables once daily and had access to water *ad libitum*. The day following arrival, each animal was physically examined and weighed. Iguanas were acclimated to their new setting for 10 days before the study began, and all experimental procedures were performed at room temperature (30°C). Study protocols were approved by the University of Georgia's Institutional Animal Care and Use Committee. The study consisted of 2 parts.

Study protocol for part 1—A venous blood sample was collected from the ventral tail vein to determine PCV and total solids concentration. Fifteen iguanas were treated with butorphanol^a (1 mg/kg, IM), and anesthesia was induced with propofol^b (10 mg/kg, IV) administered via the ventral tail vein. Afterward, the trachea of each animal was intubated with a 2.0-mm uncuffed endotracheal tube, and a surgical plane of anesthesia was maintained with isoflurane^c (2.5%) in 100% O_2 . Intermittent positive pressure ventilation was provided with a pressure-cycled ventilator^d set at 8 breaths/min and a maximum inspired pressure of 5 cm H_2O . During anesthesia, each iguana received lactated Ringer's solution^e (30 mL/kg) intracoelomically.

Each iguana was positioned in right lateral recumbency, and a skin incision was made from the caudal edge of the left tympanic scale to the tip of the shoulder. Following blunt dissection, the jugular vein and common carotid artery were exposed. Two strands of 4-0 silk suture^f were passed around each vessel to allow for temporary ligation. Each vessel was temporarily occluded, and a small incision was made through the vessel wall to allow placement of a 50- μm sterile polyethylene tube^g into the lumen. The caudal suture was then removed, and both catheters were advanced 2 cm in a caudal direction. Catheters were flushed with heparinized saline (0.9% NaCl) solution before being sutured in place with 4-0 polydioxanone.^h A subcutaneous tunnel underneath the cervical skin was created to permit the catheters to exit on the dorsal surface of the neck. The cervical musculature and skin were closed in a routine manner, and the catheters were sutured to the dorsal neck surface with 4-0 polydioxanone.^h The catheters were capped with blunt 23-gauge needlesⁱ and injection ports.^j Anesthesia was subsequently discontinued, and iguanas were returned to their cages once they had recovered, where they were allowed to rest for 24 hours before cardiopulmonary measurements were obtained. Catheters were flushed twice daily with 0.2 mL of heparinized saline solution throughout the study.

Measurements began with resting respiratory rate, which was determined by direct observation from outside each iguana's enclosure. Iguanas were then manually restrained for determination of baseline (9 AM to 11 AM) HR and direct arterial blood pressures. The arterial catheter was connected to a calibrated monitor,^k and HR, SAP, MAP, and DAP were recorded. Immediately thereafter, venous and arterial blood samples were collected anaerobically into heparinized syringes for determination of arterial and venous blood gas values. A reflectance pulse oximeter^l probe inserted into the

oral cavity at the level of the carotid artery was used to determine relative SaO_2 at the time of arterial blood sampling. A gag was used to maintain the oral cavity open, facilitating probe placement. Body temperature was measured by use of a digital thermometer with an esophageal probe.

Blood samples were analyzed immediately after collection by use of a portable analyzer.^m Values measured included pH, PCO_2 , PO_2 (at 37°C and corrected for a body temperature of 30°C), and blood lactate concentration, whereas bicarbonate concentration, base excess, and SaO_2 were derived on the basis of human normograms or curves. Oxygen saturation as measured by pulse oximetry was then compared with SaO_2 as measured by arterial blood gas analysis. To identify any circadian effects, paired arterial and venous blood samples were collected between 9 AM and 11 AM and 3 PM and 5 PM for comparison.

To detect the effects of 100% inspired oxygen, baseline (9 AM to 11 AM) arterial blood gas values, including RR and HR, were determined in 6 of the 15 conscious green iguanas while they were breathing room air. Iguanas were then administered 100% oxygen delivered via face mask for 5 minutes, and a second arterial blood sample was collected and analyzed. Oxygen administration was then discontinued, and a third arterial blood sample was collected and analyzed 10 minutes thereafter. Blood gas values were corrected for the body temperature of the iguanas.

Study protocol for part 2—Six iguanas from the group used in part 1 were sequentially connected, via the arterial catheter and pressure transducer,ⁿ to the same monitoring device^k to record HR, SAP, DAP, and MAP. The venous catheter was connected to an injector assembly with a 100- μ L glass syringe^o to accurately inject small volumes of drugs. Each iguana, maintained in an open-ended opaque plastic tube to reduce external stimuli, received bolus injections of the vasodilator sodium nitroprusside^p (1 to 50 μ g/kg, IV), and the maximal decreases in MAP and associated maximal baroreceptor-mediated increases in HR were recorded. The iguanas then received bolus injections of the vasoconstrictor phenylephrine^q (1 to 50 μ g/kg, IV), and the maximal increases in MAP and maximal baroreceptor-mediated decreases in HR were recorded. The incremental bolus injections of sodium nitroprusside and phenylephrine (1, 2, 4, 8, 12, 16, 20, 24, 30, 40, and 50 μ g of each drug/kg) were each given over 1 second in a Latin square design. All injections were performed in triplicate and administered 3 to 5 minutes apart to allow the responses to subside completely such that pressures returned to pretreatment values before another injection was given.

Twenty-four hours later, evaluation of baroreceptor responses to phenylephrine and sodium nitroprusside was repeated 15 minutes after an injection of the selective β -adrenoceptor antagonist atenolol^p (1 mg/kg, IV). After an additional 24 hours, the baroreceptor reflex responses to phenylephrine and sodium nitroprusside were again repeated 15 minutes after an injection of the selective muscarinic receptor antagonist methylatropine^p (1 mg/kg, IV). At the completion of all studies, iguanas were used for teaching exercises from which

they were not recovered, euthanized, and submitted for gross postmortem examinations.

Statistical analysis—To determine the appropriate summary measures of central tendency to use in describing arterial and venous blood gas values, all variables were tested for normality of data distribution by use of the Shapiro-Wilk test. Means were then used as the measure of central tendency for all normally distributed data, and medians were used for all those that were not normally distributed. All statistical analyses were performed by use of statistical software.⁴

For part 1 of the study, descriptive statistics (mean, median, SD, and range) were computed for morning and afternoon values of each blood gas variable assessed. Results are reported as mean \pm SD. A paired *t* test was then used to compare the mean morning and afternoon values of arterial and venous blood gas variables for data that were normally distributed (PO_2 , bicarbonate concentration, total plasma CO_2 concentration, and base excess) and respiratory rate. Values measured in the morning and afternoon of variables with nonnormally distributed values (pH, PCO_2 , lactate concentration, and SaO_2) were compared by use of a Wilcoxon matched-pairs signed rank test. An ANOVA was performed to assess whether there were significant differences in blood gas values at various inspired oxygen concentrations (room air and 100% oxygen) and 10 minutes after discontinuation of administration of oxygen. Contrast analyses were performed for variables for which results of ANOVA were significant to enhance identification of oxygen concentrations that had significant effects on blood gas values. A value of $P < 0.05$ was considered significant for all statistical tests.

For part 2 of the study, the baroreceptor-mediated changes in HR were analyzed by exponential sigmoidal curve-fitting analyses by use of the following baroreceptor values: HR, MAP, maximum HR plateau, minimum HR plateau, range, G_{mean} , lower threshold, upper threshold, and goodness of data fit.⁸⁻¹⁰ Nonlinear regression with least squares techniques was used to obtain maximum likelihood estimates of parameter values. The reflex parameters included G_{mean} ; maximum and minimum HR plateau; range of the baroreceptor reflex (ie, upper plateau – lower plateau); BP_{50} ; lower and upper threshold, which represent the MAP at which the baroreceptors begin to alter HR and reach saturation, respectively; and correlation coefficients to indicate how well the calculated curves approximated the data. Mean arterial blood pressure and HR were related by the following formula:

$$P_2 = P_1 + (P_U - P_L)/(1 + e^{A(MAP - BP_{50})})$$

in which P_2 is HR, P_U is the upper plateau, P_L is the lower plateau, and A is $-4.56 \times (G_{mean}/[P_U - P_L])$. The upper threshold was calculated by use of the following formula:

$$BP_{50} - 1.317 \times ([P_U - P_L]/4.56 \times G_{mean})$$

Lower threshold was calculated by use of the following formula:

$$BP_{50} + 1.317 \times ([P_U - P_L]/4.56 \times G_{mean})$$

The data, presented as mean \pm SEM, were analyzed by use of a Student paired *t* test.¹⁸ Values of *P* < 0.05 were considered significant.

Results

Animals—All green iguanas were judged healthy on the basis of visual, physical, and gross necropsy findings. Blood PCVs and total solids concentrations were all within reference limits for green iguanas. All iguanas recovered from anesthesia without complication, and all were eating and behaving as usual the day after catheter placement.

Part 1 measurements—Mean \pm SD baseline (9 AM to 11 AM) RR and HR in conscious green iguanas were 28 ± 6 breaths/min and 52 ± 8 beats/min, respectively. Systolic arterial blood pressure was 69 ± 10 mm Hg, MAP was 62 ± 12 mm Hg, and DAP was 56 ± 13 mm Hg. The pulse pressure was 14 ± 7 mm Hg. Oxygen saturation as measured by pulse oximetry was $86 \pm 6\%$. Data for all variables were normally distributed.

Arterial and venous blood gas values determined in the morning (baseline) and afternoon were summarized (Table 1). Additionally, P_{O_2} , P_{CO_2} , and pH were

corrected for body temperature at 30°C. In conscious green iguanas, the mean baseline arterial pH was 7.29 ± 0.11 , P_{aO_2} was 81 ± 10 mm Hg, and P_{aCO_2} was 42 ± 9 mm Hg at 37°C. The corrected baseline arterial pH was 7.38 ± 0.12 , P_{aO_2} was 54 ± 15 mm Hg, and P_{aCO_2} was 32 ± 7 mm Hg. Arterial P_{O_2} values were significantly lower in the morning than in the afternoon. The mean S_{aO_2} was also significantly lower in the morning ($92 \pm 6\%$) than in the afternoon ($95 \pm 3\%$). No significant circadian differences were found in any of the other arterial blood gas variables evaluated, nor were any found in venous blood gas variables. Oxygen saturation as measured by pulse oximetry ($86 \pm 6\%$) was lower than the baseline S_{aO_2} ($92 \pm 5\%$).

The effects of 100% inspired oxygen on arterial blood gas variables (P_{aO_2} , P_{aCO_2} , and S_{aO_2}) were summarized (Table 2). The P_{aCO_2} increased significantly from a baseline value of 86.6 ± 29.7 mm Hg to 485.8 ± 105.4 mm Hg (55 ± 20 mm Hg to 437 ± 96 mm Hg corrected for a body temperature of 30°C) following administration of 100% inspired oxygen for 5 minutes. The P_{aO_2} decreased significantly to 140 ± 94.1 mm Hg 10 minutes following discontinuation of administration of oxygen. The P_{aCO_2} did not change significantly with

Table 1—Mean \pm SD arterial and venous blood gas values as determined at 37°C in 15 conscious green iguanas (*Iguana iguana*) breathing room air.

Variable	Arterial			Venous		
	9 AM to 11 AM	3 PM to 5 PM	<i>P</i> value	9 AM to 11 AM	3 PM to 5 PM	<i>P</i> value
pH	7.29 ± 0.11 (7.38 ± 0.12)	7.29 ± 0.11 (7.38 ± 0.12)	0.499 (0.500)	7.31^* (7.36 ± 0.13)	7.25^* (7.32 ± 0.15)	0.594 (0.729)
P_{CO_2} (mm Hg)	42 ± 9 (32 ± 7)	46 ± 10 (35 ± 8)	0.186 (0.187)	49^* (36 ± 7)	56^* (42 ± 11)	0.084 (0.056)
P_{O_2} (mm Hg)	81 ± 19 (54 ± 15)	94 ± 21 (64 ± 16)	0.043 (0.044)	46 ± 23 (30 ± 15)	37 ± 15 (24 ± 9)	0.929 (0.878)
Lactate (mmol/L)	2.7 ± 1.1	4.2 ± 3.4	0.192	2.3^*	3.5^*	0.975
Bicarbonate (mmol/L)	20 ± 4	22 ± 4	0.111	22 ± 5	24 ± 4	0.128
Total plasma CO_2 (mmol/L)	22 ± 4	24 ± 5	0.134	24 ± 5	25 ± 4	0.126
Base excess (mmol/L)	-6.3 ± 5.5	-4.3 ± 5.3	0.199	-5 ± 6	-4 ± 6	0.306
S_{aO_2} (%)	92 ± 6	95 ± 3	0.027	84^*	49^*	0.064
Sp_{O_2} (%)	86 ± 6	ND	ND	ND	ND	ND
RR (breaths/min)	28 ± 6	23 ± 6	0.984	27 ± 6	24 ± 6	0.970

Values in parentheses are corrected for a body temperature of 30°C. Data are reported as mean \pm SD unless indicated otherwise. *Values are reported as medians. ND = Not determined. Sp_{O_2} = Oxygen saturation as measured by pulse oximetry. A value of *P* < 0.05 was considered significant. Arterial and venous blood samples were collected in the morning and afternoon to determine the effect of circadian rhythm on blood gas parameters.

Table 2—Baseline HR (9 AM to 11 AM), respiratory rate, and arterial blood gas parameters of 6 conscious green iguanas breathing room air, following administration of 100% oxygen via face mask for 5 minutes and at 10 minutes after discontinuation of administration of oxygen.

Parameter	Baseline	5 min	10 min
HR (beats/min)	55 ± 13	54 ± 15	56 ± 14
Respiratory rate (breaths/min)	23 ± 12	21 ± 11	18 ± 12
pH	7.30 ± 0.18 (7.38 ± 0.18)	7.26 ± 0.13 (7.37 ± 0.14)	7.34 ± 0.16 (7.43 ± 0.17)
P_{aCO_2} (mm Hg)	45 ± 17 (34 ± 11)	55 ± 8 (40 ± 6)	42 ± 27 (37 ± 16)
P_{aO_2} (mm Hg)	87 ± 30 (55 ± 20)	$486 \pm 105^*$ (437 ± 96)	140 ± 94 (109 ± 95)
Lactate (mmol/L)	4.8 ± 6.1	6.4 ± 7.3	3.8 ± 6
Bicarbonate (mmol/L)	21.4 ± 1.9	20.2 ± 11.8	21 ± 11.4
Total plasma CO_2 (mmol/L)	23 ± 1.6	27.2 ± 6.5	26.2 ± 5.2
Base excess (mmol/L)	-4.8 ± 5.2	-1.8 ± 8.3	-1.2 ± 5.5
S_{aO_2} (%)	92 ± 6	100 ± 0	98 ± 1

*Values differ significantly (*P* < 0.05). See Table 1 for remainder of key.

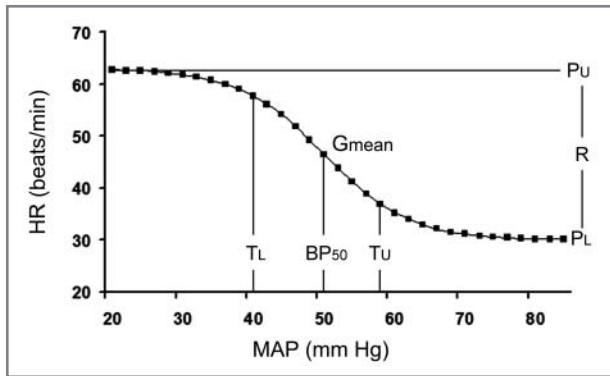


Figure 1—Baroreceptor reflex curve constructed from the means of data collected from 6 conscious green iguanas. Baroreceptor responses were evaluated in response to phenylephrine and sodium nitroprusside administered IV at concentrations ranging from 1 to 50 $\mu\text{g}/\text{kg}$. Notice that the x-axis starts at 20 mm Hg and the y-axis starts at 20 beats/min. PL = Lower plateau. Pu = Upper plateau. R = Range. T_L = Lower threshold. T_U = Upper threshold.

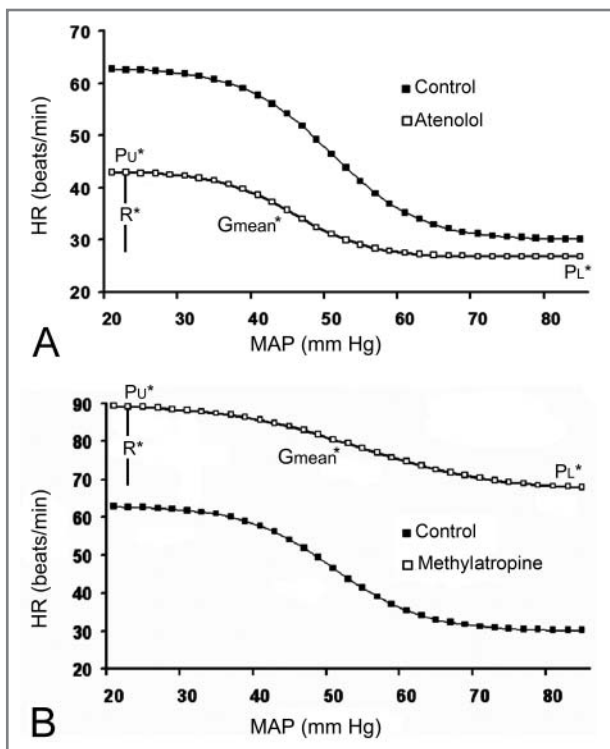


Figure 2—Baroreceptor reflex curves constructed from the means of data collected from 6 conscious green iguanas that received the selective β -adrenoceptor antagonist atenolol (1 mg/kg, IV; A) and the selective muscarinic receptor antagonist methylatropine (1 mg/kg, IV; B) or received nothing (control) 15 minutes after IV administration of phenylephrine and sodium nitroprusside (1 to 50 $\mu\text{g}/\text{kg}$). *Values differ significantly ($P < 0.05$) between drugs. See Figure 1 for remainder of key.

different concentrations of inspired oxygen (room air baseline, 45.4 ± 17.2 mm Hg; 100% oxygen, 55.3 ± 8.4 mm Hg). However, this increase in Paco_2 is considered clinically relevant. There were no significant changes in pH, lactate concentration, bicarbonate concentration, total plasma CO_2 concentration, base excess, respiratory rate, and HR.

Part 2—Resting mean MAP, HR, and baroreceptor reflex values for 6 conscious iguanas were sum-

marized (Figures 1 and 2). The effects of atenolol and methylatropine were summarized (Table 3). Atenolol significantly reduced resting HR but did not significantly affect BP_{50} . The administration of methylatropine increased resting HR but did not significantly affect BP_{50} .

Discussion

Little information is available for the clinical assessment of cardiovascular and pulmonary performance in reptiles. Reptilian cardiopulmonary function is substantially different from that in mammalian and avian species, and baseline cardiopulmonary values have not been published for most reptile species. In addition, the small size of the typical reptile evaluated in veterinary practice often imposes limitations on the type of diagnostic equipment used. Due to the lack of reference data from healthy reptiles, clinical interpretation of findings can be difficult. Most data on cardiopulmonary function in reptiles have been obtained from anesthetized animals and do not represent typical values because of the cardiopulmonary depressant effects of the anesthetic agents used.

Numerous studies have been conducted to characterize the cardiovascular response of snakes to gravitational challenges, but studies involving arboreal lizard species such as green iguanas are lacking. In snakes, pooling of blood in dependent vasculature is counteracted by reflexogenic increases in HR and peripheral resistance.¹⁹ When the close phylogenetic relationship between snakes and lizards (order Squamata) is considered, it is conceivable that similar adaptations exist for iguanas. Compared with findings in conscious grey ratsnakes (*Elpaha obsoleta*),²⁰ respiratory rate and HR were higher in the green iguanas in the present study. Systolic arterial blood pressure, DAP, and MAP in green iguanas were also higher than those reported for ratsnakes.²⁰

Direct arterial blood pressure measurements are regularly determined in anesthetized humans and other animals to evaluate cardiovascular function.⁴ Arterial blood pressure is a function of HR, stroke volume, blood volume, and arterial compliance. Anesthetic agents routinely used in reptilian anesthesia such as isoflurane can greatly compromise cardiovascular homeostases.⁴ Studies²⁰ in snakes have shown that IV administration of ketamine HCl (35 to 47 mg/kg) produces a 2-fold increase in arterial pressures. Conscious green iguanas in the present study had lower baseline arterial blood pressures than those reported for domestic mammals (SAP, 100 to 160 mm Hg; MAP, 80 to 120 mm Hg; and DAP, 60 to 100 mm Hg).⁴ In domestic mammals, SAP < 80 mm Hg is associated with inadequate cerebral perfusion and corrective measures are indicated.⁴ However, arterial blood pressures measured in the present study appeared to reflect typical values for green iguanas and should serve as a reference value when assessing cardiovascular function in awake or anesthetized animals. Iguanas may have had a stress response to manual restraint, and consequently, values may be slightly higher than they would be without restraint.

Peripheral pulse pressure is the difference between SAP and DAP. In humans, pulse pressure is approxi-

Table 3—Effects of atenolol and methylatropine administration on baroreflex parameters in 6 green iguanas.

Parameter	Control	Atenolol	Methylatropine
HR (beats/min)	48 ± 2	36 ± 2*	79 ± 2*
MAP (mm Hg)	51 ± 2	48 ± 3	52 ± 2
Maximum HR plateau (beats/min)	63 ± 5	43 ± 2*	89 ± 6*
Minimum HR plateau (beats/min)	30 ± 3	27 ± 2	68 ± 4*
Range (beats/min)	33 ± 4	16 ± 2*	21 ± 4*
G _{mean} (beats/min/mm Hg)	-1.37 ± 0.15	-0.77 ± 0.04*	-0.38 ± 0.03*
Lower threshold (mm Hg)	42 ± 3	38 ± 3	39 ± 3
Upper threshold (mm Hg)	58 ± 3	52 ± 3	61 ± 3
Goodness of fit of data (%)	95 ± 1	94 ± 1	94 ± 1

Data are reported as mean ± SEM.
*Values differ significantly ($P < 0.05$).

mately 40 mm Hg and should be < 60 mm Hg.²¹ Mean baseline pulse pressure (14 ± 7 mm Hg) in iguanas of the present study was considerably lower than human pulse pressure; however, resting pulse pressures in healthy reptiles have not been reported and are not available for comparison.

Arterial blood gas analysis is a standard monitoring tool in human and domestic mammal anesthesia to assess cardiopulmonary performance.²² Oxygenation of arterial blood is measured by determination of PaO₂, whereas acid-base status is assessed by determination of pH and PaCO₂. Both arterial blood gas analysis for PaO₂ and PaCO₂ and venous blood gas analysis will provide information on ventilation status, which is a measure of pulmonary performance. Reference values reported for arterial blood gas variables in domestic mammals breathing room air at sea level are PaO₂ of 90 to 100 mm Hg and PaCO₂ of 35 to 45 mm Hg.²² In the present study, PaCO₂ values of conscious green iguanas breathing room air were within the reference limits reported for companion mammals. Similar to the PCO₂ in the green iguanas, venous PCO₂ of mammals is usually 3 to 6 mm Hg higher than PaCO₂ and is a reflection of tissue PCO₂. Venous blood gases are affected by local tissue metabolism and low blood flow.³ Reference limits for venous blood gas values in humans are as follows: pH, 7.32 to 7.42; PCO₂, 41 to 51 mm Hg; PO₂, 25 to 40 mm Hg; and bicarbonate concentration, 24 to 25 mEq/L. Corrective measures are indicated when the pH is < 7.2 or > 7.6 and PCO₂ is < 25 mm Hg or > 60 mm Hg. The baseline venous blood gas values in the study iguanas were similar to those reported for humans and domestic mammals. Additionally, studies^{23,24} involving humans with acute respiratory failure and chronic obstructive pulmonary disease have shown that venous blood gas evaluation can accurately predict arterial blood gas values for pH, PCO₂, and bicarbonate concentration. More studies are necessary to evaluate whether these findings also apply in reptiles.

Arterial and venous blood gas values reported in the present study should be interpreted with caution. Although pH, PCO₂, and PO₂ were measured directly, all other values were calculated on the basis of the human oxygen-hemoglobin dissociation curve. In addition, values corrected for body temperature produced by the handheld blood analyzer machine used in the present study were determined on the basis of human algorithms.²⁵ The reptilian oxygen-hemoglobin dissociation curve differs from the mammalian curve and may be

further influenced by body temperature. Consequently, study results would be most accurately presented on the basis of a green iguana oxygen-hemoglobin dissociation curve. Values from previous studies in reptiles must also be interpreted with caution when making comparisons among study findings because of differences in acid-base balances and other factors among reptilian species as well as body temperature differences. In a study⁶ of anesthetized green iguanas, PaO₂ and venous PO₂ did not differ significantly; however, in our study, PaO₂ and venous PO₂ did differ significantly. Arterial blood gas values reported here are similar to values reported for domestic mammalian species and values in a previous study²⁶ in iguanas. In the present study, the PaO₂ of iguanas was comparable with that of conscious grey ratsnakes breathing room air.²⁰ However, PaCO₂ in snakes breathing room air was lower than in the study iguanas. In addition, baseline SaO₂ in iguanas was lower than in the ratsnakes.

Administration of 100% inspired oxygen in conscious green iguanas resulted in a significant increase of PaO₂, which was detected by arterial blood gas analysis. No changes in respiratory rate, HR, and other blood gas values were detected following administration of oxygen. It appears that green iguanas respond with increases of PaO₂ similar to those in domestic mammals when breathing 100% oxygen. The respiratory rate of iguanas in the present study did not decrease during administration of oxygen as commonly believed because of the respiratory drive in reptiles. This should be considered when treating reptiles with compromised respiratory function in which oxygen supplementation would be beneficial. Arterial PO₂ in the iguanas after 10 minutes of breathing room air following administration of 100% oxygen were higher than the alveolar PO₂ predicted from the ideal alveolar gas equation. This interesting finding is most likely attributable to right-left shunting.

Comparison of arterial and venous blood gas values and respiratory rate at 2 time periods in the study iguanas revealed higher PaO₂ and Sao₂ values in blood samples obtained in the afternoon versus morning. No significant changes were detected in all other arterial blood gas values or any of the venous values tested. Although we do not believe this finding was artifactual, the small study sample size should be considered when making conclusions. Various factors can affect reptilian metabolism. In our study, body temperature did not differ between the morning and afternoon. However,

because reptilian metabolism can increase as a result of physical activity and feeding,⁷ it is possible that either factor could have resulted in a momentary increase in metabolic activity and ventilation, explaining the findings. Both CO₂ and lactate concentrations in the afternoon were higher, supporting this supposition.

The present study provided needed information on the applications and limitations of arterial and venous blood gas analysis and pulse oximetry in conscious green iguanas. Although the difference was not significant, oxygen saturation as measured by pulse oximetry was lower than the Sao₂ indicated by arterial blood gas analysis. Additional studies are necessary to clearly elucidate respiratory function in green iguanas and the accuracy of various monitoring modalities.

With respect to the effects of the drugs evaluated in the present study, atenolol administration significantly reduced resting HR but did not significantly affect BP₅₀. Prior to administration of atenolol, changes in MAP elicited significant changes in HR. After injection of atenolol, G_{mean} was substantially diminished because of the loss of cardiac-adrenoceptor function. As expected, the upper HR plateau (ie, tachycardia) was substantially lower after administration of atenolol, whereas the lower plateau (ie, bradycardia) was largely unaffected by the β-adrenoceptor antagonist. As such, the range of the baroreceptor reflex was substantially reduced by atenolol administration. In contrast, treatment with atenolol did not alter the upper or lower MAP thresholds, indicating that atenolol did not affect baroreceptor reflex function per se.

Methylatropine administration resulted in an increase in the iguanas' resting HR but did not significantly affect the BP₅₀. Prior to methylatropine administration, changes in MAP elicited robust changes in HR. After injection of methylatropine, G_{mean} was substantially diminished because of increased firing of the sinoatrial node and conduction through the atrioventricular node of the heart. Consequently, the range of the baroreceptor reflex was substantially reduced.

Baroreceptor reflex-mediated responses were robust, and vagal efferents and sympathetic efferents contributed approximately equally to the changes in HR. The data suggested that withdrawal of vagal tone could not compensate for the loss of β-adrenoceptor function with respect to eliciting baroreceptor-mediated tachycardia and that activation of cardiovagal drive could compensate for the loss of withdrawal of the sympathetic nerve input with respect to eliciting baroreceptor-mediated bradycardia.

A previous clinical study²⁶ revealed that administration of atropine (0.2 mg/kg, IV) or glycopyrrolate (0.01 mg/kg, IV) failed to have a significant effect on HR. Our findings disagree with those findings; however, the methods of drug administration and blood pressure measurement used in these studies were different, possibly explaining the lack of concordance.

- a. Torbugesic, 10 mg/mL, Fort Dodge Animal Health, Overland Park, Kan.
- b. Rapinivet, 10 mg/mL, Schering Plough, Kenilworth, NJ.
- c. Isoflurane, Abbott Laboratories, Abbott Park, Ill.
- d. Small animal ventilator (VT-5000), BAS Vetronics, Bioanalytical Systems Inc, West Lafayette, Ind.

- e. Hospira, Lake Forest, Ill.
- f. Perma-Hand Silk Suture, Ethicon Inc, Cornelia, Ga.
- g. BPE-T50, Instech Laboratories Inc, Plymouth Meeting, Pa.
- h. PDS II, Ethicon Inc, Cornelia, Ga.
- i. Becton-Dickinson Precision Glide needles, Franklin Lakes, NJ.
- j. Becton-Dickinson Venflon Injection Port, Franklin Lakes, NJ.
- k. SurgiVet 3 Parameter Advisor Vital Signs Monitor, Smiths Medical North America, Waukesha, Wis.
- l. V3301 Surgivet Pulse Oximeter, Smiths Medical North America, Waukesha, Wis.
- m. I-Stat analyzer and EG4+ cartridges, Abbot Point of Care, Princeton, NJ.
- n. DPT-400 Deltran IV disposable pressure transducer, Columbia Medical Inc, Redmond, Ore.
- o. 100-μL 700 Series Hamilton Glass Syringe, Harvard Apparatus, Holliston, Mass.
- p. Sigma-Aldrich Corp, St Louis, Mo.
- q. Stata, version 10, Stata Corp, College Station, Tex.

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