ANATOMIC AND PHYSIOLOGIC CONSIDERATIONS FOR REPTILE ANESTHESIA

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ANATOMY AND PHYSIOLOGY
Many aspects of reptilian physiology are similar to those of endothermic vertebrates. However, significant differences exist and these differences may alter both the pharmacokinetics and pharmacodynamics of anesthetic and analgesic drugs. Unfortunately, despite an extensive body of literature exploring reptilian physiology there are very few generalizations that can be applied across the class as a whole.

METABOLISM AND THERMOREGULATION
On average, the resting metabolic rate of reptiles is significantly lower than that of equivalent sized mammals, ranging from one tenth to one third. The metabolic rate is a reflection of the amount of energy expended in a given period and is measured by the rate at which oxygen is consumed. The metabolic rates of reptiles are quite variable with minimum and maximum oxygen consumption rates extending from almost zero to values similar to those of a resting mammal. In general, cellular metabolism decreases as the metabolic rate decreases. Decreases in cellular metabolic rate can result in reduced drug metabolism leading to prolonged inductions, duration of effect, and time for recovery.

Several factors can affect metabolic rate in reptiles. Temperature is the main determinant of metabolic rate in resting reptiles. As temperature decreases the metabolic capacity of cells and organs also decreases. Activity level is also an important determinant of metabolic rate but is a less important consideration in anesthetized patients. Interestingly feeding can also markedly alter metabolic rate with rates increasing 3 to 40 times resting values, and they can remain elevated for up to 7 days. However, it is unclear whether recent feeding has a clinically significant effect on anesthesia in reptiles. In general, surface dwelling species have higher metabolic rates than burrowing species, and species that eat insects or other vertebrates have higher rates than do herbivorous species.

Reptiles are ectothermic and derive their heat from the surrounding environment. Integration of physiology and behavior in all animals is affected by the internal thermal set point or preferred body temperature (PBT). In endotherms the PBT generally remains constant. However, in reptiles the PBT may vary depending upon challenges being placed on the animal. In addition, there is good evidence that reptiles down-regulate their body temperature in response to hypoxia and/or inadequate tissue oxygen delivery (anemia). The optimal body temperature for activity can also be affected by hydration status, as hydration level drops the preferred optimal body temperature for activity also drops. Reptiles undergoing anesthesia should be maintained at the average or the high-end of their PBT range to ensure optimal metabolic function.

CARDIOVASCULAR SYSTEM
The non-crocodilian reptile heart has three chambers, with two completely separate atria and a single anatomically continuous ventricle. The crocodilian heart is more typical of that seen in mammals and birds with two completely divided atria and ventricles. The foramen of Panizza in crocodilians allows for some intravascular shunting to facilitate oxygen conservation during rest and oxygen delivery while diving. In non-crocodilian reptiles the ventricle is divided into two main chambers, the cavum pulmonale and the cavum dorsale, by a septum-like structure, the muscular ridge. The cavum dorsale is further divided into the cavum venosum and the cavum arteriosum in some species. The cavum pulmonale and the cavum dorsale are comparable in function to the right and left ventricles of mammals, respectively. The dorsolateral border of the muscular ridge is free, permitting the flow of blood between the cavum pulmonale and cavum dorsale. However, during ventricular systole the muscular ridge presses against the dorsal wall of the ventricle and separates the cavum pulmonale from the cavum dorsale, thus although exhibiting anatomical continuity of the subchambers, the heart is capable of acting as a two-circuit pump. Three great vessels arise from the ventricle: the pulmonary artery, the right aortic arch and the left aortic arch. The pulmonary artery emerges from the cavum pulmonale to the right of the two aortic arches and divides into the left and right pulmonary arteries. The aortic arches arise from the cavum dorsale. The right aortic arch divides into the subclavian and carotid arteries, and a third branch that unites with the left aortic arch forms the dorsal aorta.

Cardiac shunts can be left-to-right or right-to-left, and may occur simultaneously in both directions. The direction of the net shunt determines whether the systemic or pulmonary circulation receives the majority of the cardiac output. Intracardiac shunts probably have at least three important functions. First, they may stabilize the oxygen content of the blood during respiratory pauses. Second, the right-to-left shunt is at least partly responsible for the increased blood flow to the systemic circuit that reptiles use to increase their rates of heating. Third, a right-to-left shunt directs blood away from the lungs when an animal is holding its breath. Cardiac shunting has varying effects on systemic arterial oxygen levels and can presumably impact inhaled anesthetic uptake and elimination. Large right-to-left shunts may limit the amount of anesthetic uptake early in the anesthetic period and slow anesthetic elimination at the end of anesthesia leading to prolonged inductions and recoveries. Changes in the level and direction of shunts may account for the unexpected awakening seen in some reptiles anesthetized with inhalant anesthetics. In addition to impacting the movement of anesthetic gases, intracardiac shunts will
have implications for patient monitoring, in particular airway gas monitoring and pulse oximetry.

The size and direction of the shunts are ultimately controlled by pressure differences between the pulmonary and systemic circuits and washout of blood remaining in the cavum venosum (cavum dorsale). The pressure differences are principally controlled by cholinergic and adrenergic factors, which regulate the vascular resistance of the pulmonary and systemic circulation but also by the non-adrenergic and non-cholinergic activity. Intracardiac shunting changes in response to various physiologic states, such as apnea, spontaneous ventilation, diving, activity level, metabolic state, thermoregulation, hypoxia, hypercapnia, and recent feeding.

The systemic arterial pressures vary greatly among reptile species in contrast to mammals; in the latter, blood pressure is similar among most species. In a given reptile species, unlike mammals, the normal blood pressure range is affected to a greater degree by environmental stresses, such as habitat, activity level, temperature, and size. Chelonians tend to have the lowest systemic arterial pressures (15–30 mmHg) while some varanids have resting arterial pressures similar to mammals (60–100 mmHg). Systemic blood pressures in snakes correspond to the gravitational stress they are likely to experience. Snakes from arboreal habitats tend to have higher arterial pressures than those that are primarily aquatic. An allometric relationship between arterial blood pressure and body mass has also been described in snakes. As body mass increases so does blood pressure.

Regulation of blood pressure in reptiles is controlled by mechanisms very similar to those of mammals. The cardiovascular system of reptiles responds to both cholinergic and adrenergic stimulation and the presence of a baroreceptor reflex has been well described. The resting blood pressures of reptiles tend to be stable in the absence of external stimuli but may vary with temperature, activity, or state of arousal.

Several anesthetics have been shown to induce cardiovascular changes in reptiles similar to those seen in mammals.

**PULMONARY SYSTEM**

Reptile respiratory anatomy and physiology vary markedly across reptile species. The lungs of non-crocodilian reptiles are suspended freely in the common pleuroperitoneal cavity, and are not located in a closed pleural space. In reptiles, the lungs tend to be sac-like with varying degrees of partitioning. Highly aerobic species such as the varanids tend to have highly partitioned lungs with numerous invaginations and septae, increasing the surface area for gas exchange. Chelonians and lizards tend to have paired lungs while most snakes have a single right lung. The functional units of the lung are referred to as *ediculi* and *faveoli*. Ediculi or faveoli are analogous structures to alveoli in the mammalian lung. Most reptile lungs exhibit areas of both type of parenchyma in addition non-respiratory air sac-like regions. The sac-like structure of the reptile lung may act as a “reservoir” for anesthetic gases and may, in addition to intracardiac shunting, account for some of the unexpected changes in anesthetic depth seen in some reptiles.

The tracheal rings of chelonians are complete and care must be taken when placing an endotracheal tube not to over-distend the trachea. In addition, the trachea bifurcates quite early so inadvertent endobronchial intubation can occur. Many snakes also possess a tracheal lung the significance of which is unclear.

The lungs of reptiles tend to have a larger tidal volume but smaller respiratory surface area relative to a comparable size bird or mammal. Both inspiration and expiration in reptiles are active processes that may exaggerate the respiratory depression associated with most anesthetics. Reptiles routinely become apneic when anesthetized and require manual ventilation.

**Control of Respiration**

Reptiles have variable respiratory patterns but in general are episodic breathers. Numerous studies have demonstrated that pulmonary vascular perfusion is also intermittent, decreasing during breathing pauses. The control of respiration in reptiles is poorly understood. It has been speculated that ventilation may be purely receptor driven or alternatively a central rhythm center is intermittently turned on and off by peripheral receptor input. However, it is more likely that there is an interaction between a central pattern generating system and afferent chemoreceptor input. Carbon dioxide and/or pH changes appear important for stimulating normal ventilation but there is evidence that even under normoxic conditions oxygen tension may play a role in normal ventilation.

**Effects of Inspired CO\(_2\) and O\(_2\)**

There has been considerable interest in the breathing patterns in reptiles in response to varying levels of inspired carbon dioxide and oxygen. The response to inspired CO\(_2\) is quite variable in reptiles. In some species minute ventilation increases while in others it decreases. Inspiration of hypoxic gases increases ventilation in some species, some retain resting minute ventilation, and others decrease ventilation. Inhalation of hyperoxic gases tends to reduce ventilation in chelonians, snakes, and lizards. However, this does not necessarily lead to significant alteration in arterial oxygen tensions. During anesthesia most reptiles are maintained using an inhalant anesthetic delivered in 100% oxygen and this may further compound respiratory depression. In this author’s opinion, however, this is likely a very small contributing factor compared with the effects of anesthetics on central sensitivity and the respiratory musculature. There is evidence that in the green iguana, recoveries from isoflurane anesthesia may be faster when ventilated with room air rather than using 100% oxygen. However, in studies using Dumeril’s monitors, no significant differences in recovery times from isoflurane and sevoflurane anesthesia was found between animals ventilated with room air and 100%
oxygen. This may reflect species differences or methodologic differences.

**RENAL SYSTEM**

Reptiles cannot produce urine more concentrated than plasma; this makes the excretion of nitrogenous wastes more difficult for terrestrial reptiles. Most reptiles excrete nitrogenous waste as uric acid (uricotelic), some turtles and crocodilians can also excrete urea. Urine is very dilute in the reptilian kidney tubule so uric acid remains in solution. Urine empties into the cloaca and then into the bladder or large intestine, where water is reabsorbed causing the uric acid to precipitate resulting in the excretion of nitrogenous waste with relatively little water. The bladder of some reptiles can be used for storage of water to offset water losses associated with droughts. Reptile urine is neither sterile nor a good indicator of kidney function. In addition, many reptiles have specialized salt excreting glands that can excrete very high concentrations of sodium, potassium, and chloride. Many reptiles living in extremely arid environments can tolerate and will normally have marked fluctuations in total body water and plasma osmolality. When faced with limited water supplies rather than maintain normal osmolarity, the plasma osmolarity can rise to levels higher than those known for any other vertebrate species with no apparent ill effects on the animal.

**HEPATIC SYSTEM**

The liver in reptiles appears to be similar in structure and function to that of other vertebrates. Unfortunately very little detail about the liver is known and much of our understanding is based on studies from a limited number of reptile species and only under specific circumstances. The liver in reptiles probably plays important roles in tolerance of anaerobic metabolism, hypothermy, and adaptation to environmental circumstances. In general the liver of reptiles has a lower metabolic capacity compared with mammalian livers and the metabolic rate is very sensitive to changes in temperature. The lowered metabolic capacity of the reptile liver probably accounts for at least some of the prolonged effects commonly seen with drugs such as antibiotics and may partly contribute to the prolonged anesthetic recoveries seen when using drugs that rely on metabolism for recovery.