Reptile Cardiology: A Review of Anatomy and Physiology, Diagnostic Approaches, and Clinical Disease

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Abstract

Reptile cardiology is in its infancy. Veterinarians treating reptiles should develop a basic knowledge of reptile cardiovascular anatomy and physiology. Cardiology is vital to interpreting the results of various diagnostic tests and planning an effective therapeutic plan for a case. This article will provide a review of the anatomy and physiology of the reptilian cardiovascular system, the common diagnostic tests used to assess cardiac function, and the common disease presentations associated with the cardiovascular system. Copyright 2005 Elsevier Inc. All rights reserved.

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Reptile cardiology is an underdeveloped specialty of reptile medicine. During the 1950s-1970s, a significant amount of research was done to elucidate the cardiac physiology of reptiles.[1] Although a great deal is known regarding the function of the reptile heart, its application to clinical veterinary medicine has been limited. More recently, research has focused on the application of the physiologic data, which should improve our ability to diagnose and treat cardiac disease in captive reptiles.[2-4] Current research studies include, characterizing the heart and respiration rates in reptiles with distinct behavioral strategies, describing the variation in resting and maximal heart rate, and determining the factors that influence those parameters.[2,3,5] In addition, new vascular systems also have been discovered recently.[6] It will be important for the veterinary clinician to remain current and use this emerging data to interpret and manage cardiac disease in their reptile patients.

Anatomy and Physiology

Historically, the noncrocodilian heart (lizards, snakes, chelonians) has been classified as a three-chambered organ. However, some authors consider the sinus venosus an additional chamber, and thus classify the noncrocodilian heart as a four-chambered organ.[7] The major difference be-
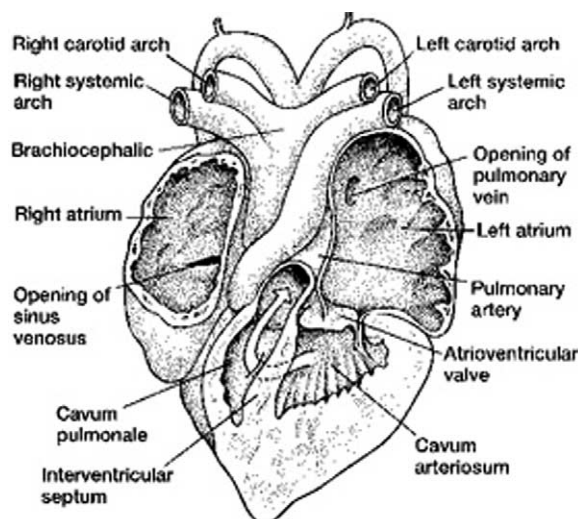
Figure 1. Lizard heart. (Drawing courtesy of K.V. Kardong).

tween the crocodilian and noncrocodilian heart is that there is a complete ventricular septum in crocodilians, while the septum or ridge is incomplete in squamates and chelonians. In the noncrocodilian heart, the ridge is comprised of muscle and minimizes the mixing of oxygenated and deoxygenated blood. In some chelonians, this ridge is well developed, and almost separates the ventricle into two chambers.

Because of the three-chambered arrangement, blood flow through the reptilian heart is quite different from mammals. Blood from the precaval, postcaval, and hepatic veins drain into the sinus venosus, a muscular structure located on the dorsal surface of the right atrium. During atrial diastole, blood drains from sinus venosus to the right atrium. The right atrium of snakes can be larger than the left.[7] During atrial systole, the blood drains into the cavum venosum of the ventricle. Deoxygenated blood entering the right side of the ventricle does not mix with oxygenated blood from the left side. The atrioventricular valves occlude the interventricular canal between the cavum arteriosum and cavum venosum during atrial systole (Fig 1). The reptile ventricle is comprised of both compact and spongy myocardium. The ventricle is divided into three subchambers. The most ventral cavum pulmonale extends cranially into the pulmonary artery. The dorsally situated cavum arteriosum and cavum venosum receive blood from the left and right atria, and are connected by an interventricular canal. Mixing of well-oxygenated and poorly oxygenated blood is avoided by a series of muscular ridges in the ventricle, and by the timing of ventricular contrac-

tions. The left and right aortic branches receive blood from the cavum venosum. The atrioventricular valves partially occlude the interventricular canal during atrial systole. The pulmonary artery, which branches in reptiles with two functional lungs, arises from the cavum pulmonale and carries deoxygenated blood to the lungs. The aortic branches arise from the cavum venosum and carry oxygenated blood to the systemic circulation. Under normal respiration conditions, 60% of the cardiac output enters the lungs, whereas 40% enters the systemic circulation.

In varanid lizards, ventricular pressure separation and high systemic blood pressure have evolved as an adaptation to an active predatory lifestyle and elevated metabolic rates. The Savannah monitor (*Varanus exanthematicus*) can reflexively synchronize its heart rate and ventilation, providing efficient diffusion of oxygen into the lungs.[8] In a number of snake genera, including *Vipera, Natrix,* and *Thamnophis*, ventricular pressure separation does not occur. In *Python molurus*, however, the systemic blood pressure is similar to mammals, and considerably higher than most other reptiles except for varanid lizards. But pythons are, in contrast with the varanid lizards, inactive predators. Wang and coworkers[3] proposed that ventricle pressure separation and the high blood systemic pressure in this python was related to a high oxygen consumption digestion or its use of shivering thermogenesis during egg incubation.

The heart of most snakes is located at a point one-third to one-fourth of its length caudal to the head. In some aquatic species, the heart is located in a more cranial position. The snake heart can be visualized percutaneously in snakes less than 2 m by placing the animal in dorsal recumbency and visually locating the beating heart. The chelonian heart is located on the ventral midline where the humeral, pectoral, and abdominal scutes of the plastron intersect. In most species of lizards, the heart is encased in the pectoral girdle. Varanids are an exception, as their heart is located more caudally in the coelomic cavity.

Cardiac rates in reptiles are generally lower than in mammals or birds. Numerous factors contribute to variation in heart rate (HR), including body size, temperature, oxygen saturation of the blood, respiratory ventilation, postural or gravitational stress, hemodynamic equilibrium, and body sensory stimuli.[2,5] In reptiles, increased ambient temperatures are associated with increased HR and decreased stroke volumes. Interestingly, the

relationship between HR and oxygen consumption does not remain constant as external conditions change. Cardiac function is maximized when a reptile is maintained within its preferred temperature range. Perturbed hemodynamics, including alterations in water balance or the ionic and pharmacological status of the blood, also can affect the HR. Reptiles that experience blood loss as a result of surgery or trauma can become tachycardic to ensure that the tissues remain oxygenated and to compensate for the hypovolemia. Also during acute hemorrhage, snakes are capable of maintaining hemodynamic stability, by shifting interstitial fluid to the vascular space.[5]

Reptiles are ectotherms and are dependent on their environmental temperature to regulate their core temperature. The cardiovascular system is essential to the regulation of the reptile body temperature. Basking reptiles increase the rate of heat absorption by increasing their heart rate, while during cooling periods reptiles decrease their heart rate to minimize heat loss. Changes in systemic circulation also occur during times of heat absorption. Vasodilation of the peripheral circulation during basking can increase body temperature, while vasoconstriction occurs during cooling.

Respiration can also affect HR. During normal respiration, pulmonary resistance is minimal and blood flow to the lungs and heart rate is maximized. However, when a reptile is experiencing voluntary apnea (eg, diving event) pulmonary resistance increases, often resulting in decreased blood flow to the lungs and a reduced HR.

Bradycardia is a natural event in reptiles during diving and extended breath-holding. With a reduced HR there is an increase in the peripheral resistance, which can lead to the redirection of blood to vital organs, such as the brain and heart. During extended breath-holding events, reptiles can switch from aerobic to anaerobic glycolysis. This is met with a variety of physiologic changes, including an acidemia. This acidemia can be further exacerbated by the decrease in oxygen exchange that occurs as the pulmonary blood flow is restricted. To compensate, blood is shunted from the right to left to ensure that blood flow continues to the systemic circulation. Once normal breathing resumes, pulmonary resistance decreases, the HR increases, and the shunting of the blood is discontinued. These physiologic changes may occur when certain anesthetics are used. Dissociative agents, alpha-2 agonists, and propofol are all routinely used to anesthetize reptiles, with

all three known to cause cardiopulmonary depression. To counter these affects, the reptile patient may be positive pressure ventilated during an anesthetic event.

The hemoglobin in the erythrocytes is responsible for the transportation and exchange of oxygen; however, there are great differences in oxygen affinity between different reptilian species. In general, aquatic reptiles have a lower oxygen affinity than terrestrial species. This may be an adaptation to the need of maximal unloading of oxygen in the systemic circulation during the apneic diving period.

Systemic circulation, as in other vertebrates, consists of arterial, venous and lymphatic vessels. Snakes also possess a vertebral venous plexus (VVP). The VVP is comprised of a network of spinal veins coursing within and around the vertebral column. In climbing snakes, directing the head vertically can induce jugular collapse. In these cases, the cephalic efflux is shunted into the plexus. The plexus, which is supported by the surrounding bones, remains open and provides a route for venous return, which is important in the maintenance of cerebral blood supply.[6]

The renal portal system is a unique component of the circulatory system of lower vertebrates. Historically, parenteral drug administration into the tail or caudal extremities was not recommended because of the potential side effect (nephrotoxicosis) associated with drug passage through the renal portal system. Although there are reports of nephrotoxicosis associated with the administration of aminoglycosides in reptiles, a review of these cases suggests that the toxicosis were attributed to high doses of gentamicin rather than the route of administration.[9,10]

Recent work has suggested that the risks associated with parenteral administration of drugs into the caudal extremities may not pose as great a risk as once thought. Holz and coworkers[11] evaluated renal perfusion in red-eared sliders (*Trachemys scripta elegans*). The research suggested that the renal portal system most likely serves to perfuse the kidneys during times of water conservation. Holtz and coworkers[11] proposed that a valve located between the abdominal and femoral veins may regulate blood flow through the kidneys. At times of water conservation, a valve in the abdominal vein would close, redirecting blood through the iliac veins and into the kidneys.

To determine whether the renal portal system has any affect on drug pharmacokinetics in snakes, Holz and coworkers[12] evaluated injection

Figure 2. Young *Boa constrictor*: note the swelling in the region of the heart.

site on the pharmacokinetics of carbenicillin in carpet pythons. The snakes each received a 200 mg/kg IM dose of carbenicillin in either the cranial or caudal epaxial musculature. Five months after the injection, the snakes again received a 200 mg/kg IM injection of carbenicillin; however, the site of the injection was reversed from the previous example. There was no significant difference in the pharmacokinetics between injection sites.

Diagnostic Testing: Assessing Cardiac Function

The anamnesis is an important component to the work up of a cardiac case. Many of the clinical signs reported in cases with cardiac disease are nonspecific. Reptiles with cardiac disease may appear lethargic or depressed. Normally active animals, such as tortoises, may appear exercise intolerant. Reptiles are obligate nasal breathers, so a history of open mouth breathing also may be an indication of cardiac disease. This information, in addition to any deficiencies in husbandry that may affect cardiac function (eg, hypothermia or dehydration), is vital to making a diagnosis and can only be obtained from a detailed history.

The reptile heart should be assessed as part of a routine physical examination. Clinical cardiac disease may manifest itself with very nonspecific signs, varying from swelling in the area of the heart (Fig 2), peripheral edema, ascites, cyanosis, anorexia, weight loss, and sudden death (Fig 3). In snakes, the size of the heart can be roughly estimated. Heart contractions can be observed by movements of the ventral scutes. Because the reptilian heart sounds are of very low amplitude and cannot be consistently auscicled using a standard

stethoscope, many clinicians do not include a cardiac assessment with their examination. However, the stethoscope can be used to assess the heart in those reptile species where it is feasible. The placement of a damp cloth over the area of the heart will reduce the friction caused by the bell housing rubbing on the scales, and improve the clinician's chances of being able to assess the heart. In some species, such as the marine iguana (*Amblyrhynchus cristatus*), the heart can be ausculted without the application of a damp cloth. An ultrasonic Doppler or ECG also can be used for a cardiology examination, and will be discussed in detail later.

When performing a physical examination on a reptile, it is important to consider the environmental temperature. If the reptile's body temperature is less than optimal, the results of the examination may be misleading. For example, a reptile maintained at a low environmental temperature may appear bradycardic when the condition is actually a result of its response to the environment. An expected baseline heart rate may be calculated for a reptile maintained within its preferred optimal temperature zone using a formula based on allometric scaling. The predicted heart rate per minute can be calculated using: $33.4 \times (Wt_{kg}^{-0.25})$.[13] The 33.4 is a k constant.

Hematology and plasma biochemistries are important diagnostic tests that provide insight into the working physiology of the patient. It is important to incorporate these tests into the routine screening of reptiles. Because reptiles with cardiac disease can present in very different physiologic states, it is important to evaluate the patient's results with respect to their physical examination findings. Elevations in creatine ki-

Figure 3. *Epicrates cenchria cenchria* (rainbow boa): on necropsy, the pericardium was filled with uric acid depositions (gout), which lead to cardiac arrest.

nase activity appear to be highly correlated to cardiac muscle in the green iguana.[14] Alterations in the aspartate aminotransferase may also occur with damage or injury to the cardiac muscle. Imbalances noted with electrolytes, enzymes, proteins, and minerals should be addressed when developing a treatment plan.

The ECG can be an invaluable tool for monitoring cardiac function in reptiles. Unfortunately, this diagnostic test is used sparingly by many veterinarians because of our limited understanding regarding its interpretation. Because the HR is tied to environmental temperature, it is important to maintain a reptile within its preferred optimal temperature range when performing this test. The reptilian ECG has many of the same characteristics of a mammalian ECG, and is comprised of three primary wave complexes: P, QRS, and T. An SV wave, represented by the depolarization of the sinus venosus, may precede the P wave in some species. In snakes, the electromechanical depolarization starts with the SV wave followed by sinal contraction, then the P wave followed by atrial contraction, and finally the R wave followed by ventricular contraction. The T wave indicates ventricular repolarization. In a study with red-eared sliders (*Trachemys scripta elegans*), this repolarization phase was very prolonged, with QT intervals of 1.41 seconds and a mean R-R interval of 2.38 seconds.[15] A shortened TP interval was also reported, and represented one-quarter of the cardiac cycle. The ST interval, which was associated with repolarization of the ventricle, appeared to be affected by the heart rate.

One of the problems encountered with the interpretation of the reptilian ECG are low electrical amplitudes, which provide small readings that can be difficult to interpret. Because of this limitation, placement of the electrode is very important. The placement of electrodes in reptiles varies slightly from that described for mammals. Electrodes can be attached to the skin's surface using self-adhesive electrodes, inserting hypodermic needles through the skin and attaching the electrodes to the needles, or using standard alligator clips. For snakes and lizards, the self-adhering skin electrodes provide excellent electrical contact. In snakes, the electrodes should be placed approximately 2 heart lengths cranial and caudal to the heart. In lizards, where the heart is situated within the level of the pectoral girdle (eg, green iguanas, skinks, chameleons and water dragons), electrodes should be placed in the cer-

vical region rather than on the forelimbs. In chelonians, the cranial leads also should be placed in the cervical region, lateral to the neck and medial to the forelimbs.

Currently, the interpretation of the ECG can be difficult because of limited reference material for comparison. In addition, the ECG can be influenced by various environmental factors. For example, the heart rate is dependent on the body temperature, and the intervals such as the P-R and Q-T segments are influenced by the heart rate. To reduce the likelihood of misclassifying the results of an ECG, it is important to perform these tests under optimal conditions. In addition, performing routine ECGs on clinically normal reptiles can be helpful in establishing a baseline for comparison. The ECG should be used in addition to other diagnostic tests to confirm the presence of cardiac disease.[16] Rishni and Carmel used an ECG to support a diagnosis of atrioventricular valve insufficiency and congestive heart failure in a carpet python (*Morelia spilota variegata*). The ECG demonstrated tall, wide QRS complexes, and a heart rate of 50 beats/min. Additional diagnostic tests, including survey radiographs and a color doppler echocardiogram, were used to confirm the diagnosis.

Survey radiographs may be used to evaluate heart size in snakes and crocodilians. Unfortunately, the heart cannot be appreciated in most chelonian and lizard patients because the heart is the same density as the surrounding tissues or is lost because of the bone density of the carapace and plastron. Varanids are an exception to this, as their heart is located more caudally in the coelomic cavity. Although there are no standard references for radiographic measurements of "normal" heart size in reptiles, routine review of heart size in patients without cardiac disease can be used to develop a standard for the practitioner. Likewise, comparing radiographs of similar sized species may be useful when evaluating heart size in an abnormal case. The second author has used survey radiographs to confirm the presence of cardiomegaly in two geriatric corn snakes (*Elaphe guttata guttata*) (Figs 4 and 5).

Mineralization of the great vessels is a common finding in captive reptiles at necropsy. Tissue mineralization has been associated with dystrophic calcification resulting from renal failure, tissue trauma, hypervitaminosis D, and other metabolic disturbances. Survey radiographs have been used to identify aortic mineralization in clinical cases.

Figure 4. Dorsoventral survey radiograph of a corn snake (*Elaphe guttata guttata*). Note the cardiomegaly.

Echocardiography and color doppler echocardiography can provide an accurate, noninvasive ante mortem diagnosis of cardiac disease in reptiles.[17] Snake and lizard hearts can easily be identified using cardiac ultrasound. In snakes, the ultrasound probe should be placed on the ventral surface of the skin overlying the heart. A lateral approach is not feasible because of the interference associated with the ribs. It is important to place copious amounts of ultrasound gel on the skin and probe surface to avoid the visual artifacts associated with air trapped between the scales. In lizards, the probe can be placed in the axillary region and directed medially because the heart is located within the pectoral girdle. For those species where the heart is located behind the pectoral girdle, the probe can be placed on the ventral surface of skin and directed dorsally and cranially. The chelonian shell represents a barrier to ultrasound, though the heart can be readily visualized through the cervicobrachial window.[18] The probe should be directed caudally and medially. Echocardiography can provide important insight into cardiac motion and function, structural defects, heart valve motion, pericardial effusion, cardiomegaly, and intracardiac masses.[19] A probable case of primary cardiac failure in a spur-thighed tortoise (*Testudo graeca*) with pericardial effusion and atrial dilation was diagnosed with the aid of echocardiography.[20] A color doppler echocardiograph can be used to determine blood flow within the heart, which enables the clinician to better ascertain each cardiac structure and look for anomalies.

A doppler ultrasonic crystal may be used to monitor the arterial pulse and the heart beat. The benefit of this monitoring device is that it provides an audible signal, which allows a surgeon to focus their vision on the surgical site without being distracted to look at other monitoring devices, such as an ECG or pulse oximetry. In snakes, the doppler crystal should be positioned directly over the surface of the heart. The probe can be taped into position during presurgical preparation and surgical procedures. In lizards, the probe can also be placed over the general vicinity of the heart. For those species where the heart is located within the pectoral girdle, the crystal should be placed in the axillary region and directed medially. For those species where the heart is more caudal, the probe can be placed on the lateral or ventral body wall. In chelonians, the crystal can be placed at the base of the neck and directed caudally and medially for acceptable monitoring.

Pulse oximetry has been used in mammals to characterize the oxygen saturation of hemoglobin. Diethelm and coworkers[21] found that the absorbencies for oxyhemoglobin (660 nm) and deoxyhemoglobin (990 nm) in iguanas were in agreement with human standards, and that pulse oximetry may prove a useful tool for measuring oxygen saturation in reptiles. One concern has been that the probes used to capture the readings in mammals were not consistent in reptiles. Newer technologies, such as rectal and esophageal probes, were thought to make the measurement of arterial oxygen saturation possible. However, in a study on the cardiovascular effects of isoflurane in the green iguana, a rectal probe was placed into the esophagus against the carotid complex to monitor functional hemoglobin saturation and was found to be inconsistent.[22] When using pulse oximetry in reptiles, it is best to look at the trends in measurements, rather than abso-

Figure 5. Lateral survey radiograph of a corn snake (*Elaphe guttata guttata*): note the cardiomegaly.

lute measurements. Additional validation of pulse oximetry in reptiles is necessary to fully determine its benefits in monitoring this group of animals.[22]

Computed tomography (CT) and magnetic resonance imaging (MRI) are both techniques that may be used to perform reptile cardiac examinations. Due to the short scan times, CT can be used for all anatomic regions, including those susceptible to patient motion and breathing. Because of the higher resolution with CT, compared with classic radiography, calcification of vessels may be visualized. Imaging with MRI may be disturbed by the low frequency of the heart rhythm. Recently, new techniques have been developed that use electronic gating to acquire images. This allows heart chambers, valves and myocardial thickness, contractility, pericardial effusion, and tumors in and around the great vessels to be observed. CT and MRI are especially valuable in chelonians, where the shell limits the access for a thorough ultrasonic or radiographic cardiac examination.

The primary disadvantages associated with these diagnostic imaging techniques are the need for anesthesia and the expense associated with the procedure. Although survey radiographs can be taken without anesthesia in some cases, the poor quality images resulting from motion are unacceptable. Unfortunately, reptiles presenting with cardiac disease are generally not the best anesthetic candidates. Most veterinary practitioners will not have "in-house" access to advanced imaging techniques, such as CT scans and MRI, and even if they have access at a local human or veterinary referral hospital the expense associated with these techniques are often cost prohibitive.

Cardiovascular Diseases

Cardiac disease is not a common finding in captive reptiles. When cases are presented, it is important to characterize whether the cardiac disease is the primary cause of the illness or the secondary result of other systemic illness. In the authors' experience, the majority of the cases presented are secondary to systemic illness.

Primary cardiac disease may be due to congenital defects of atrioventricular valves, stenosis of vessels, or masses in the lumen. A young boa constrictor (*Constrictor constrictor*) was presented to the lead author for clinical examination. A swelling was noted at the site of the heart (Fig 2), and the heart rate was 30 beats/min. Placement of the surface electrodes for the ECG was done as previously described. The P-R interval was 0.64 s, the Q-T interval was 1.44 s, and the QRS complex was low. The ECG of a healthy clutch mate was also performed. In the normal snake, the heart rate was 42 beats/min, the P-R interval was 0.32 s, and the Q-T interval 0.8 s. An echocardiograph of the clinically abnormal animal revealed that the atrioventricular valves did not close during systole. The animal was euthanized. The postmortem examination revealed congestion of all the major vessels and ascites with the pathologist's disease diagnosis being poorly developed atrioventricular valves.

Endocarditis and congestive heart failure have been described in a Burmese python (*Python molurus bivittatus*).[19] The heart was evaluated ultrasonographically and showed dilation of the right atrium and thickening of the ventricular wall with an irregular endocardial surface. A large, irregular mass was identified in the area of the right atrioventricular valve obstructing blood flow into the right side of the heart. The ultrasonographical and angiographic findings were confirmed at necropsy.

Aortic aneurysm, with subsequent shock and death, has been described in a Burmese python.[23] This animal was presented with an acute onset of respiratory arrest after constricting a rabbit. On microscopic examination, a large, dissecting aortic aneurysm with separation of the muscular medial layer from the intima was observed. Multiple organized thrombi were present in the intimal wall, with thromboemboli in the heart muscle.[23]

Nutritional diseases remain a common problem in herpetoculture. Although our knowledge base regarding the care of these animals has increased dramatically over the past decade, there remains a great deal to learn. The mineralization of the tunica media and tunica intima of the great vessels is one of the most common findings attributed to nutritional imbalances (Fig 6). Although the pathogenesis of metastatic mineralization is not well understood, research suggests that these vessel changes may reflect Vitamin D deficiency rather than vitamin D toxicity.[24] Vascular calcification in human patients with chronic renal disease is related to cardiovascular mortality, cardiovascular hospitalization, and fatal or nonfatal cardiovascular events.[25]

A 3-year-old Chinese water dragon (*Physignathus cocincinus*) with secondary nutritional hyperparathyroidism was presented for the removal of an abscess from the mandible. The mass was removed successfully and the animal uneventfully
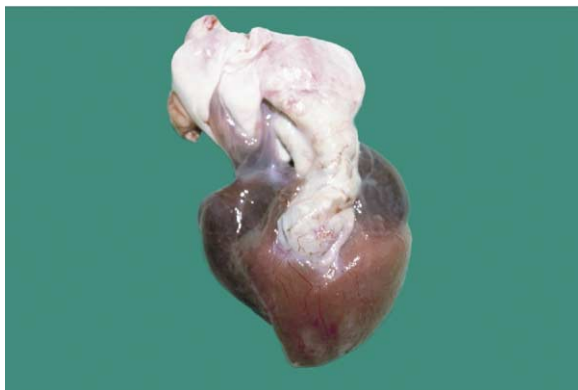
Figure 6. Heart of an iguana (*Iguana iguana*): note the thickened vessels.

recovered from anesthesia. Three months after the operation, the animal was found dead. A large volume of blood was found in the coelomic cavity at necropsy. The hemorrhage originated from a tear in the calcified right aortic wall. On histopathology, multifocal calcium aggregates were observed in the tunica intima and media. It is likely that necrosis of the tunica intima and media led to the rupture of the vessel and subsequent hemorrhage and death.

Secondary nutritional hyperparathyroidism is one of the most common diseases reported in captive herbivorous and insectivorous reptiles offered a calcium-deficient diet. Affected animals routinely present with generalized muscle fasiculations and tremors. Although most of the focus is on the changes in the skeletal muscles, the direct affect the hypocalcemia has on the cardiac muscle should also be considered. If an animal is stable, an ECG should be performed to evaluate the heart with affected animals likely exhibiting increased repolarization times.

Infectious diseases are occasionally associated with cardiac disease in captive reptiles. Aerobic, Gram-negative bacteria are the most common isolates from secondary endocarditis. Jacobson and coworkers[19] isolated *Salmonella arizona* and *Corynebacterium* spp. from a septic endocarditis in a Burmese python. The organisms were cultured from the atrial thrombus, pericardial space, and spleen.[19] Granulomatous myocarditis also has been associated with chlamydiosis in puff adders (*Bitis arietans*).[26]

Two cases of cardiomyopathy have been described in reptiles. In a mole king snake (*Lampropeltis calligaster rhombomaculata*), the lesions were characterized by fibroblast proliferation, and the replacement of myocardial fibrils by fibrocollagen

and osteoid-like seams.[27] The pathological changes in the heart of the Deckert's rat snake (*Elaphe obsoleta deckerti*) consisted of degeneration and necrosis of the myocardial fibers.[28] Furthermore, mineralized lesions of different vessel walls and of the atrioventricular valves, and focal aggregates of lymphocytes were present. In both cases the changes lead to congestive heart failure. Both animals showed signs of generalized disease; however, the etiological agents were not determined.[27,28]

Helminths are a routine finding in wild-caught reptiles. Filarid nematodes appear to have little host specificity, and have been identified in different species of reptiles. Adult nematodes may live in subcutaneous tissue, coelomic cavity, or in the vascular system. These female parasites can release large numbers of microfilaria into the circulation. Blood-sucking arthropods serve as an intermediate host and can transmit the infective larva to other reptiles. Most infections are asymptomatic; however, heavy infestations with adult nematodes in the circulation can lead to thrombosis, edema and necrosis. Diagnosis of filarid infestations can be done by demonstrating the microfilaria in a wet or stained peripheral blood smear. Surgical removal of the adult nematodes from subcutaneous tissue or the coelomic cavity is still the treatment of choice in chameleons. Because these parasites require an intermediate host vector, it is possible to break the life cycle in captivity.

Digenetic spirorchid flukes are described in the vascular system of different reptiles, but the majority of cases are associated with aquatic turtles. Because the life cycle of the flukes requires a gastropod intermediate host, infestations are generally reported in wild-caught animals or animals living in an outdoor enclosure. The adult flukes can be found in the heart and the great vessels. When the eggs from the adult flukes are released into the circulation, terminal vessels may be occluded. Cardiovascular lesions may include mural endocarditis, arteritis, and thrombosis, and are frequently associated with aneurism formation. Gordon and coworkers[29] have speculated that the thrombi are initiated by the spirorchids, but are then propagated by the adherence of circulating bacteria that create a septic thrombus. Diagnosis of fluke infestation is difficult; however an indirect ELISA for detection of antibodies in *Chelonia mydas* against three species of spirorchids has been developed. Historically, praziquantel has been recommended as a treatment; however, its effectiveness is unknown.[30]

Conclusions

Reptilian clinical cardiology is in its infancy. In the near future, it will be important for veterinarians to continue to collect and publish baseline reference material for the different diagnostic tests considered in this article, including ECG, echocardiology, CT scans, and MRI. Once this information is readily available, the practical usage of these tests for reptile cardiac case management should increase.

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