CHELONIAN RESPIRATORY SYSTEM IN HEALTH AND DISEASE

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Introduction

Respiratory disease is among the commonest presenting clinical problems in chelonia and yet can be one of the most frustrating to try to diagnose the exact cause and then treat successfully. An understanding of the basic anatomy and physiology is essential to allow a correct understanding of normal and abnormal breathing, investigation, assessment and treatment. The chelonian respiratory system varies quite considerably compared with that found in birds and mammals and indeed, other reptiles.

As with all respiratory tracts in vertebrates, it can be divided into an Upper and Lower Respiratory Tract. The cause and effect of infections in these two parts are also quite different.

Upper respiratory tract

There are paired nostrils at the tip of the head leading to internal nares opening in the roof of the mouth. There is no soft palate, which allows for a direct communication between the nares and the mouth, and may, on occasions, allow excessive saliva to bubble out of the nostrils as chewing is undertaken. This is important to remember, especially in tortoises, as not all fluid from the nostril is an indication of runny nose syndrome (RNS), but may just be associated with the eating of particularly tasty food (Fig. 1), or even mouth infection (stomatitis) and build-up of fluids in the mouth.

In all chelonia there is a glottis protecting the opening to the trachea that is situated on the base of the fleshy tongue in the back of the pharynx. There is no epiglottis (unlike mammals) as the glottis can close up extremely tight when needed, to prevent food or fluid entering the trachea. The trachea is very short and divides immediately behind the head into paired bronchi that remain separate and run down along the sides of the neck. This configuration allows normal breathing when the head is withdrawn into the shell and a wide range of movement without the potential of compression of the trachea. Each bronchus enters at about the middle of the respective lung and then branches. The cranial branch runs the length of the cranial chambers of each lung, the caudal branch through the caudal chambers. The branches are perforated along their entire length within the lungs.

Lower respiratory tract

The lungs of reptiles developed as outgrowths of the oesophagus. On comparing like sizes, the reptilian lung volume is greater than that of mammals but with a lower surface area. Typically each lung is in effect a large semi-ridged sac with a central air space and peripherally arranged alveoli or saccules. The lungs are separated into major lobes by vertical membranous plates forming the saccules. Irregular meshworks of fibres between the vertical membranous plates (Fig. 2) divide up the lung tissue to give the 'bunch of grapes' appearance of the smaller chambers.

The chelonian lungs are semi-rigid because they are attached dorsally onto the inside of the carapace and ventrally to a fibrous horizontal membrane that is incorrectly referred to as the 'diaphragm'. The 'diaphragm' is just a membranous division between the dorsal cavity, the pericardial cavity and the ventral cavities within the coelomic cavity (Fig. 3). The 'diaphragm' does not have muscular activity nor assists in the action of breathing other than as a passive structure attached to the ventral aspect of the lungs. It is unlike the similarly named structure in mammals because of the passive nature of its part in breathing. There is no pleural cavity because of the direct attachment of the lungs dorsally to the ventral aspect of the carapace and ventrally to the membranous 'diaphragm'.

Fig. 1. Saliva coming from nose associated with eating.

Fig. 2. Lungs attached to carapace and divided up by a meshwork of fibres between vertical membranous plates.

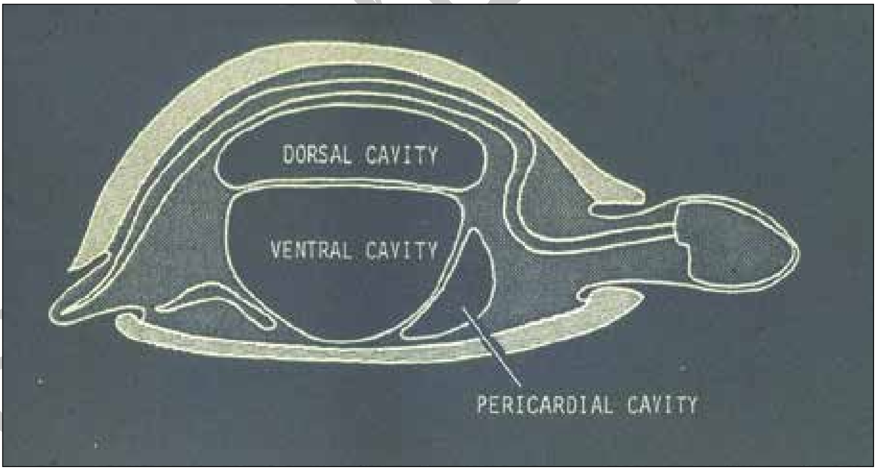

Fig. 3. Diaphragmatic membrane dividing body into dorsal and ventral cavities.

At the cranial and caudal ends of the coelomic cavity, the lungs fit tightly against the muscles covering the limb girdles. The lungs extend from pelvic to pectoral girdles. The lungs, which are spongy and elastic, do not collapse when punctured because of their semi-ridged structure and lack of a pleural cavity. The large lungs of chelonia with the large central air space also act as buoyancy chambers for aquatic species.

Respiration

Chelonia mainly breathe through the nostrils, but can also mouth breathe. The gular movements (under the jaw and the upper neck) that may be noted are associated with olfactory and not respiratory actions. Increased or obvious gular activity is never a sign of respiratory distress; however, stretching out of the neck and open mouth breathing (the majority of the time) is.

The lungs are attached on all sides but one to rigid structures, which means that there is only one side that has the possibility of movement. The ventral side of the lungs is mobile because it is attached to the membranous 'diaphragm'. Viscera other than lungs lie ventral to this 'diaphragm' and some are also actually attached to this membrane. When the 'diaphragm' moves this causes the ventral surfaces of the lungs to move with it resulting in either an increase or decrease of the lung volume.

The paired, spongy lungs of chelonia occupy the dorsal half of the body cavity when the animal is in the resting position, but this is reduced to a fifth of its volume when the head and limbs are fully retracted into the shell. The movement of the limbs has a marked effect on the position, size and therefore the capacity of the lungs. This is entirely to do with pressure changes within the coelomic cavity. When the cranial and caudal ends of the ventral cavity are moved outwards (e.g. the head and legs are withdrawn fully from within the shell) they are followed by the viscera. This action pulls the 'diaphragm' ventrally which, in turn, pulls on the attached ventral surface of the lungs. The resulting expansion of the lungs causes air to be drawn in via the trachea and bronchi. Expiration is achieved mainly by rotating the forelimbs into the shell and by pulling the caudal limiting membrane forward. The squeeze on the ventral viscera pushes the 'diaphragm' dorsally and compresses the lung volume which expels gases out of the lungs (Fig. 4).

During hibernation, although there is a reduced metabolism and therefore a reduced requirement for respiration, the beat of the heart is sufficient to cause some movement of the 'diaphragm' up and down resulting in movement of the ventral surface of the lungs up and down to allow some movement of air in and out of the lungs. This small degree of breathing together with anaerobiosis (see later) allows the survival of hibernating species despite the non-movement of the limbs, which is normally an important component of breathing.

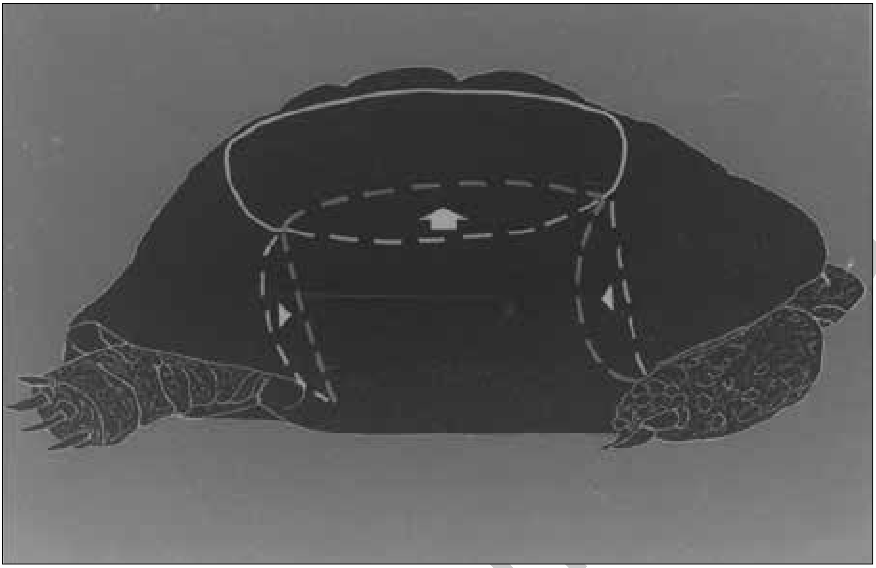

Fig. 4. Effects of changing intracoelomic pressure by legs being with drawn into shell on lung volume.

Breathing is noted as respiratory cycles, but is not continuous as is the norm for mammals and birds. In general, respiration has been described as 'apnoeic' consisting of episodes of diaphasic air flow separated by breath holding of variable duration. Terrestrial species do breathe faster and more regularly than aquatic species, where the apnoeic periods tend to be longer and in diving chelonia can be quite prolonged.

It is this ability to enter periods of apnoea and anaerobiosis (see later) that can be so protective to tortoises if they were to fall into a pond and not be able to get out. The survival period, which could be up to two days, does depend upon their core body temperature falling whilst in the water thus lowering metabolism and the tortoise reverting to breath holding (apnoea) with associated anaerobiosis to avoid drowning until they can be rescued.

Both inspiration and expiration are active processes that can be fully controlled. During the periods of apnoea, carbon dioxide builds up in the lungs (especially following activity) as oxygen is extracted from the contained air. Aquatic species can be very efficient in their ability to extract oxygen from the previously inspired air within the lungs. Some investigations have found that in terrestrial reptiles 14–30% of oxygen is extracted from the inspired air, whereas in aquatic species it is usually 35–52%. This ability is mainly due to the alteration of the pulmonary perfusion (particularly assisted by the Bohr effect[1]) and changes to cardiac distribution of blood through the body. Pulmonary blood flow increases with ventilation even when there is low oxygen content of inspired air. In *Pseudemys scripta elegans* stretch receptors have been found in the lungs, allowing the state of lung capacity to be monitored.

Although there is good evidence for a high degree of separation of the oxygenated and deoxygenated intraventricular blood (chelonia, in common with all reptiles, only have a single ventricle) and reasonably equal flow of blood between the systemic and pulmonary circulations during periods of normal breathing, this is very much affected by the shunting cycles in apnoeic periods. During ventilation there is mainly a left to right shunting which results in some oxygenated blood being recirculated to the lungs. During apnoea there is a corresponding right to left shunting, bypassing the pulmonary circulation. The changes in shunt pattern are often more pronounced in the aquatic chelonia especially at times of being submerged. This variable shunting of blood allows increased removal of oxygen from the lungs and distribution to the body.

There is also a degree of gas exchange by non-pulmonary means, involving aquatic gas exchange across the skin (when it is thin and permeable enough as occurs in aquatic species). *Geochelone* spp may only lose 2.9% of carbon dioxide production to water, while *Trionyx* spp loses 64%. Cutaneous oxygen uptake is affected by the partial pressure of oxygen in the blood. In addition the pharynx and cloaca also play parts in respiration, especially in aquatic species or during hibernation. The presence of cloacal bursae (such as found in turtles) aids respiration and in some species is shown to have synchronised movement with ventilation.

Anaerobiosis

Anaerobic respiration is protective and not just required for diving chelonia, but is also required for terrestrial tortoises following strenuous activity or during hibernation. The low metabolic rate of reptiles allows them to undergo long periods of breath holding. Hibernating reptiles are able to undergo anaerobic metabolism. During these times, there is a slow progressive build-up of body lactate to extents that are well tolerated in reptiles, unlike mammals. This is particularly noted in terrapins where it can increase from 1mmol/kg to 62mmol/kg without harmful effects. It is only when normal aerobic respiration reoccurs that there will be a slow reversal and lowering of the lactic acid that has built up.

1 Bohr Effect – an effect by which an increase of carbon dioxide and a decrease in pH in the blood results in a reduction of the affinity of haemoglobin for oxygen, thus releasing more oxygen from the blood (haemoglobin) into tissues – After Christian Bohr (1855-1911), Danish physiologist.

Anaerobic respiration is supported by glycolysis with the conversion of glycogen into glucose. The stores of glycogen in the heart and liver of reptiles is usually higher than that found in mammals. Following periods of anaerobic respiration, the lactic acid is mainly stored in muscles, although there will be spill over into the blood, contributing to changes in the pH and contributing to the Bohr effect. Recovery will take several hours to reduce the levels of the lactic acid in the muscles. Gluconogenesis is thought to result in the lactic acid being converted back into glucose within the liver hepatocytes, where it is then transported back into the muscles and stored as glycogen until next needed.

Breathing stimuli

Chelonia are sensitive to oxygen and carbon dioxide concentrations and it is not known which of these gases is primarily responsible for stimulating breathing. The body temperature and blood pH (which have an inverse and linear relationship) also act as stimuli to breathing. The ability of reptiles to tolerate relatively low pH blood concentrations associated with hypercapnoea is advantageous at times of submergence or anaerobic respiration as is the Bohr shift (effect), where the carbon dioxide tension is allowed to increase with tolerance.

Clinical history and examination

The importance of obtaining a thorough clinical history cannot be understated. It is essential to be able to assess the environmental temperature and humidity as these are commonly implicated in non-infectious respiratory disease. The details of diet and supplementation are important as some vitamins may influence susceptibility to disease and the health status of the mucosa of the respiratory tract. Hygiene is a major factor as the majority of the bacterial infections are associated with opportunistic pathogens. A history of aquatic chelonia swimming to one side suggests a buoyancy problem that may be associated with pneumonic lesions.

Respiratory disease may be noted as a variety of clinical signs from a mild whistling to gasping noises and open mouth breathing. There may be a nasal discharge, which, although more commonly associated with an Upper Respiratory Tract Infection (URTI), can also be associated with more widespread infection involving the lungs or mouth. Posture will also indicate the extent of the respiratory disease; tortoises with severe lung pathology will adopt a position with the head as high up as possible and mouth wide open.

The examination of the reptile with a respiratory infection should be systematic and thorough, starting with the external nares, then the internal nares, mouth, glottis and finally lungs. Auscultation is possible in chelonia despite the shell, but is far less rewarding than the same procedure being

Investigation	Assessment of	Comments
Blood sampling	PCV/ RBCC	Anaemia can be a cause of respiratory disease.
	WBCC	A low WBCC may be indicative of viral infection and a high count indicative of septicaemia or abscess formation.
	Serology	Tests now available for some viruses (such as Herpes virus).
Parasitology	Faeces	Many parasites have a migratory stage which may involve the lungs.
	Oral mucus	The eggs of pulmonary parasites or larvae of migratory parasites are often found in the buccal cavity.
Cytology	Nasal flushes	Useful for assessment of RNS.
	Lung washings	Allows assessment of bacterial infections or parasitic involvement.
Radiography (horizontal beam needed)	Anterio-posterior	Often allows comparison of left and right lung fields.
	Lateral	Assessment of length of lung and localisation of lesion, together with anterio-posterior view.
	Dorsal	Less useful than the other two views unless there is consolidation or systemic problems (e.g. egg binding).
Endoscopy	Via glottis	Assessment of upper respiratory airways and possibly lungs.
	Via lung	More rewarding. Requires drilling through the shell and into the lung (which cannot collapse) but allows the direct assessment of lung and direct taking of samples.
Computerised Tomography		3D radiography which provides the most detailed evaluation of the lung fields and is superior to radiography in its ability to detect subtle changes in the lungs.
Culture and sensitivity	Tracheal washes	Very easy to do due to lack of cough reflex and access to forward placed glottis. Up to 1% of body weight can be put into the lungs.
	Lung washes	Requires a very long catheter or can be performed during endoscopy. It can also be performed 'blind' by percutaneous injection.
	Direct swabs	Requires drilling a hole into the pulmonary area of the carapace.
Histopathology	Endoscopic	An ideal time to collect samples.
	Surgical	Any abnormal areas should be biopsied.
Post Mortem	Any and all samples possible	Invaluable in collections, where euthanasia and post mortem of an individual may allow diagnosis and treatment of the others (herd).

undertaken in mammals. The technique requires the use of a wet towel placed over the carapace and use of the bell of the stethoscope. The wet towel reduces the extraneous noises that would otherwise be heard should the stethoscope be placed directly onto the shell.

Investigation

It is often necessary to undertake further investigation into reptiles with respiratory disease to establish a diagnosis. It should also be remembered that respiratory disease may be a manifestation of a septicaemia condition and not an isolated condition. These should include all, most or just some of the procedures detailed on the preceding page.

Further reading and references

Boyer, T.H. & Boyer, D.M. (1996). Turtles, Tortoises and Terrapins. In: Reptile Medicine and Surgery (Ed. D.R. Mader). W.B. Saunders, Philadelphia.

Chitty, J. (2008). Respiratory Disease of Chelonia. *Testudo* 6(5): 11-24.

Davies, P.M.C. (1981). Anatomy and Physiology. In: Disease of the Reptilia (Eds J.E. Cooper & O.F. Jackson) Vol. 1. Academic press, London.

Frye, F.L. & Himsel, C.A. (1988). The Proper Method for Stethoscopy in Reptiles. *Pet Practice Veterinary Medicine* 83:1250-1252.

Murray, M.J. (1996). Pneumonia and Normal Respiratory Function. In: Reptile Medicine and Surgery (Ed. D.R. Mader). W.B. Saunders, Philadelphia.

Murray, M.J. (2006). Pneumonia and Lower Respiratory Tract Disease. In: Reptile Medicine and Surgery (2nd Edition, Ed. D.R. Mader). Saunders Elsevier, Missouri.

Murray, M.J. (2006). Cardiopulmonary Anatomy and Physiology. In: Reptile Medicine and Surgery (2nd Edition, Ed. D.R. Mader). Saunders Elsevier, Missouri.

Schumacher, J. (1997). Respiratory Disease of Reptiles. In: *Seminars in Avian and Exotic Pet Medicine* (Eds A.M. Fudge & R.A. Bennett) 6(4): 209-215.

Seymour, R.S. (1982). Physiological Adaptations to Aquatic Life. In: Biology of the Reptilia (Eds C. Gans & F.H. Pough), Vol. 13, Physiology: D Physiological Ecology. Academic Press, London.

Stoakes, L.C. (1992). Respiratory System. In: Manual of Reptiles (Eds P.H. Benyon, M.P.C. Lawton & J.E. Cooper). BSAVA, Cheltenham.