Diagnostic Imaging of the Respiratory Tract of the Reptile Patient

Michaela Gumpenberger, DVM*

KEYWORDS

• Diagnostic imaging • Radiography • CT • Respiratory tract • Reptile • Pneumonia • Lung compression • Mass effect

KEY POINTS

- Diagnostic imaging (preferably radiography and/or computed tomography [CT]) should always be included in the clinical examination in any dyspneic reptile, especially in chelonians.
- For proper radiographic evaluation, 2 orthogonal radiographs are needed. In lizards and snakes dorsoventral and lateral views are used, whereas in chelonians an additional craniocaudal view is performed. Although the respiratory tract is less differentiable on a dorsoventral radiograph in chelonians, it can provide additional valuable informations.
- Lateral radiographs should be performed in horizontal beam technique.
- Exposure settings (for radiographs and CTs, respectively) may be adapted from protocols of the head of dogs for chelonians, whereas protocols of the thorax or abdomen of small mammals, cats or dogs may be adapted for similar-sized lizards and snakes.
- Multiple figures will demonstrate the advantages of the different imaging techniques as well as the appearance of different respiratory diseases. The focus will be laid on chelonians, as they are less accessible for clinical examination.

SHORT INTRODUCTION TO IMAGING TECHNIQUES

Radiographic Technique and Positioning

Laterolateral (LL) and craniocaudal (CC, to compare right and left side) views are the basic and most important views for evaluation of the respiratory tract, especially the lungs, in *chelonians*. The radiographs should be performed with horizontal beam technique with the patient placed on an—ideally—radiolucent, stabile device or pedestal that is able to bear the weight and movement of the reptiles (**Fig. 1**). The legs should be extended as much as possible to minimize superimposition. For the same reason,

Diagnostic Imaging, Department for Companion Animals and Horses, University of Veterinary Medicine Vienna, Austria
* Diagnostic Imaging, vetmeduni Vienna, Veterinärplatz 1, Vienna 1210, Austria.
E-mail address: Michaela.Gumpenberger@vetmeduni.ac.at

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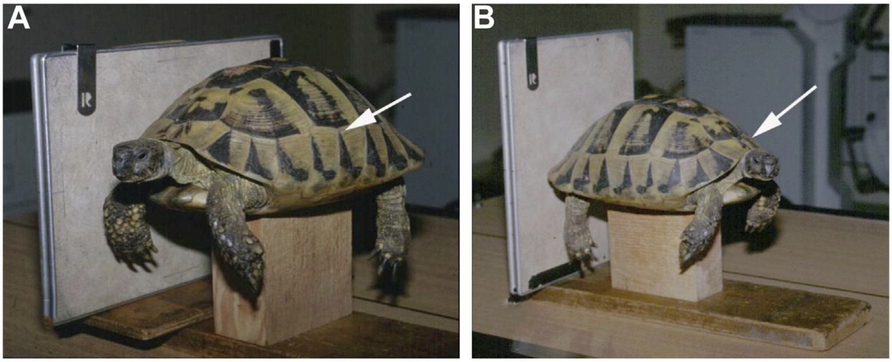

Fig. 1. Radiographic technique: lateral (*A*) and craniocaudal (*B*) views should be performed with horizontal beam technique in chelonians. The animals should retract the head and legs from the shell to reduce organ compression and superimposition. The beam is centered between the costal and marginal shields or on the nuchal shield (*arrow*), respectively. The pedestal should be high and small enough so that the patient cannot flee from the setup.

the head should be extracted and lowered for CC views. An additional dorsoventral (DV) view performed in table-top technique in perpendicular beam supports interpretation of the trachea or bronchi as well as all other organ systems that may influence lung capacity.[1] Some investigators point out the value of horizontal beam radiographs with chelonians in upright position when the benefit of gravity helps to detect larger free fluid accumulations.[2] It is not recommended to perform LL views in perpendicular beam with the animal, for example, taped to a device, as this will cause a shift of the coelomic organs and undesired superimposition of organ contours and is therefore prone to misinterpretation.[3]

Larger iguanas and *lizards* may be handled similarly to cats or dogs, whereas smaller species can be placed in a plastic box to perform standard DV and LL views

Fig. 2. Radiographic technique: lateral views may be performed with horizontal beam technique in lizards as well. Manual restraint can be avoided when using small translucent plastic boxes or tubes for positioning. Although images may be partially superimposed by the extremities, usually good to fair results are achieved. In this example a bearded dragon (*Pogona vitticeps*) was placed in a storage box. The normal lungs are clearly seen.

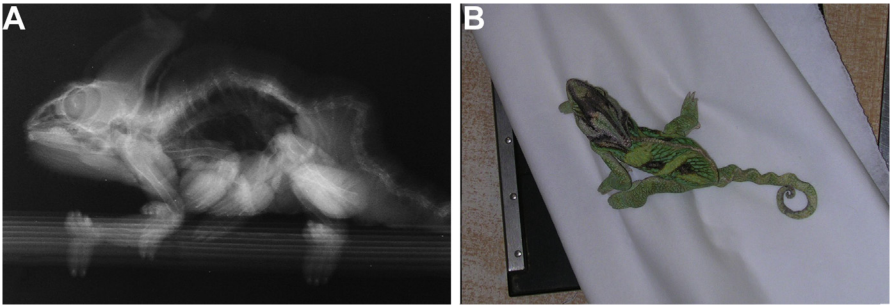

Fig. 3. Radiographic technique: lateral views (*A*) may be performed with horizontal beam technique without manual restrain in chameleons as well. A short branch or stick is used as a climbing device. For dorsoventral views (*B*) a paper towel is placed on the cassette to comfort the patient and avoid slipping.

(Fig. 2). The latter should be done in horizontal beam technique as described earlier. Smaller lizards can be manipulated with a Q-tip. Rübel and colleagues[4] used a stockinette tubing to immobilize some patients. Be aware that some species have a very delicate skin. *Chameleons* may be offered any climbing device for performing LL images in horizontal plane. These animals feel also more comfortable with some paper-towels to grab for DV radiographs (Fig. 3) in order to avoid manual restraint. However, this will result in some superimposition of the extremities. In case of disturbing superimposition, chameleons need to be stretched and positioned similarly to iguanas. Although manual restraint is done quickly and easily, it may not be allowed in all countries due to radiation safety regulations. Therefore, sedation may be needed when, for example, taping or tying the animal on the cassette or on the table. At the author's clinic alfaxalon, 7 mg/kg body weight (BW) intravenously or 10 mg/kg BW intramuscularly is used for sedation in reptiles. In chelonians intramuscular administration of midazolam (0.5 mg/kg BW) may be added.

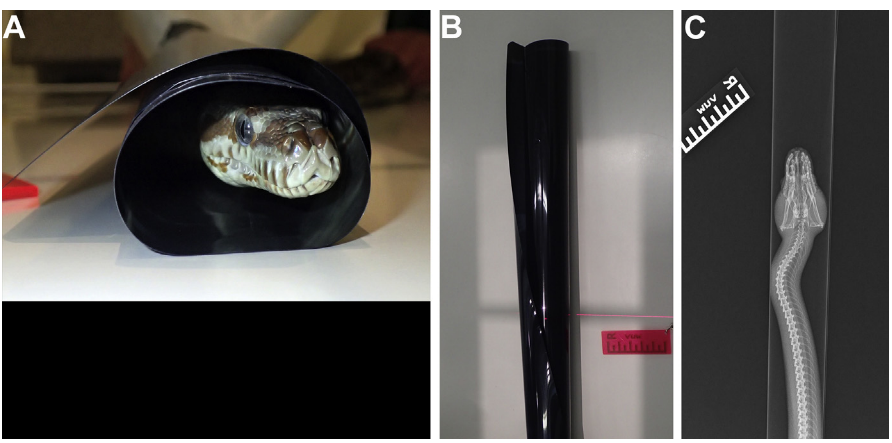

Fig. 4. Radiographic technique in snakes: although plexiglas tubes of various diameter (see Fig. 6) may act as positioning device, a cheaper tool of adaptable diameter is a rolled up old radiographic film (*A*, *B*). Exposed films have the advantage of being black, which is preferred by the snakes. The film causes no artifacts that would hinder image interpretation (*C*).

A meaningful *snake* radiograph can only be fabricated with an extended, properly positioned animal and when performing 2 orthogonal planes, namely DV and LL views. A long plastic tube (which has to be cleaned after each patient) or a coiled recycled old radiographic film (**Fig. 4**) can be used as positioning device in conscious patients. The latter is simple and cheap and can be replaced easily. In addition, dark tubes invite snakes to move in. A prewarmed table or cassette may comfort the snake or any other reptile as well. Lateral views performed in horizontal beam technique in inspiration provide better radiographs than in vertical beam in expiration. However, diagnostic value for mild-to-moderate lung changes is low in snake radiography. Furthermore, recent feeding may compromise pulmonary inflation due to distension of the gastrointestinal tract.

GENERAL TECHNICAL RECOMMENDATIONS FOR RADIOGRAPHIC EXAMINATIONS

A R/L marker should be used for any radiograph to ensure identification of the proper side affected. Usually there is rarely need for anesthesia to take overview radiographs of reptiles. Good radiographs are mostly achieved—after preparing the whole imaging setup—with quick positioning and some patience. If digital systems (cassette system, detector, or dental radiographic units) are used, increased milliampere-seconds (mAs) (in comparison to analogue settings) will prevent quantum noise and provide higher image resolution (**Fig. 5**). However, be aware of "chronic" overexposure and check the exposure index for adequate settings. Algorithm, kV, and mAs used for radiographs of the skull of cats or dogs should be adaptable for chelonians, those of the abdomen of smaller mammals for smaller lizards and smaller snakes, and those of the abdomen of cats or middle-sized dogs for larger iguanas and larger snakes, respectively. If analogue technique is used, high-resolution film-screen or even mammography and dental systems should be used, especially for smaller species. For example, at the authors clinic, a digital Fuji cassette and detector system is used when exposing 0.5 to 3 kg BW chelonians with 55 to 65 kV and 2.6 to 5.6 mAs with a film focus distance of 60 to 70 cm.

One advantage of digital radiography is the "postprocessing" opportunity on the computer. The wide range of gray scale allows altering contrast and brightness and

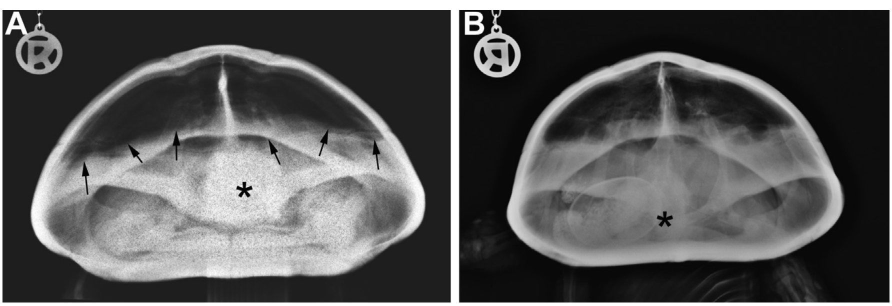

Fig. 5. Craniocaudal radiograph of 2 different Herman's tortoises (*Testudo hermanni*) in horizontal beam technique. The beam is centered on the nuchal shield. The head (*asterisk*) of the animals is lowered to hinder superimposition with the dorsally positioned lung fields (*arrows*). Note the mottled appearance of the soft tissues ventral to the lung border in (*A*). This is quantum noise due to insufficient exposure settings, usually mAs. The aerated lung is not influenced in this case. The animal in (*B*) is exposed with proper exposure setting. Note the eggs in (*B*). However, the craniocaudal view is not particularly useful in evaluating dystocia.

therefore adaption of the different soft tissues. Pathologic changes may also be highlighted by inverting the image or using high-resolution filters. Yet, one should be aware that improper positioning of the animal and poor exposure settings cannot be compensated with a computer.

Computed Tomography

Computed tomography (CT) is a cross-sectional imaging technique that provides sufficient resolution images without any superimposition for easier diagnostic and therapeutic approach (eg, carapacial osteotomy for sample taking or intrapulmonic therapy in chelonians). Depending on the mobility and temperament of the patient, CT examination can be performed in the unrestrained animal in a radiolucent box. Be aware that metallic hinges or locks of some boxes will cause beam hardening artifacts. The extremities of chelonians may be taped in physiologic position into their shell (**Fig. 6**A). However, this compromises the lung volume.[3] Otherwise, chelonians may be mounted on a box or wooden cube that is smaller than the plastron to prevent escaping from the scene (**Fig. 6**B). Depending on the indication for CT, movement of the head and extremities may not affect the diagnosis. Snakes can be placed into a tube similar as in radiographic examinations (**Fig. 6**C). Some animals can be

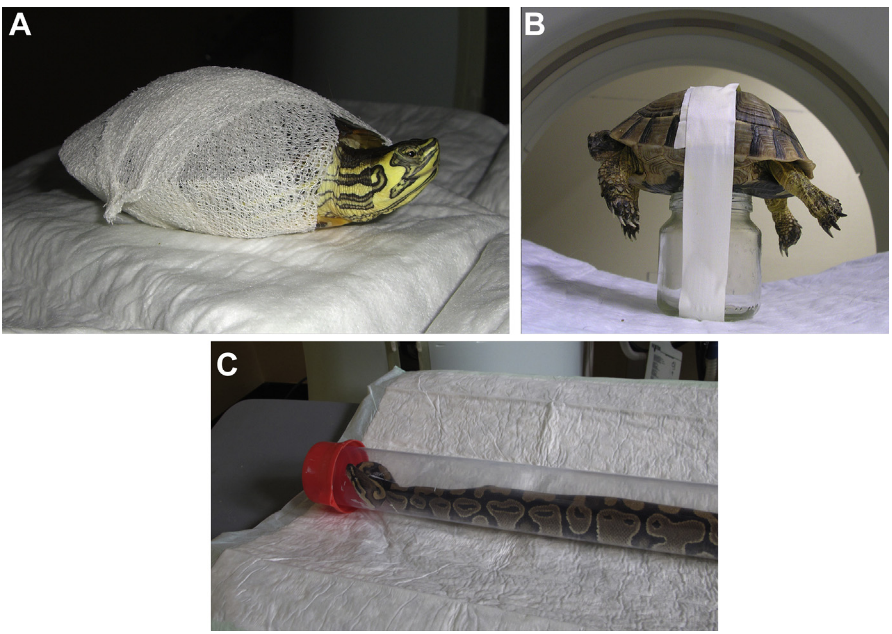

Fig. 6. CT technique: most animals are put in a box without further restraint. The legs are taped into the shell in physiologic position in some chelonians (*A*), whereas others are placed on a stabile for example, wooden block (*B*), depending on the temperament of the patient. Some snakes (C, placed in a tube) or lizards may need anesthesia to guarantee meaningful high-quality images. Symmetric images in not perfectly aligned patients are gained with multislice helical CT and modern software that allows multiplanar reconstruction (MPR) in any desired plane. Standard image interpretation includes sagittal, transversal, and coronal planes, whereas some disorders may profit from plane alignment along the trachea or bronchus.

calmed by blindfolding them. Mobile or agitated patients need to be sedated to receive images free of motion artifacts.[5]

At the authors clinic, CT scans (with a 16-slice helical CT) of chelonians and most other reptiles are performed with the following technical parameters: 100 to 130 kV, eff. 80 to 200 mAs, rotation time 0.6 sec, pitch 0.8, slice thickness 0.75 mm, and reconstruction increment 0.5 mm. As already suggested for digital radiography, processing programs can be adapted from small mammals, cats and dogs. The author prefers a high-resolution bony algorithm to interpret the respiratory tract as well as the skeleton, complemented by a soft tissue algorithm. It is essential to reconstruct various windows instead of manually shifting the window settings in a soft tissue window to mock a bony window. Good image quality depends on proper algorithms (**Fig. 7**).

Densitometry (done in Hounsfield units, HU) enables further evaluation of tissues. Zero Hounsfield unit equals water whereas 20 to 100 HU represent different soft tissues. Cancellous bone measures more than 350 HU, whereas bone cortex or corticalis reach up to 2000 HU. Fat has a density of 0 HU to minus 100 HU and air minus 1000 HU. Therefore, densitometry supports, for example, diagnosis of hepatic lipidosis or infiltrations, which indicate pneumonia.[6]

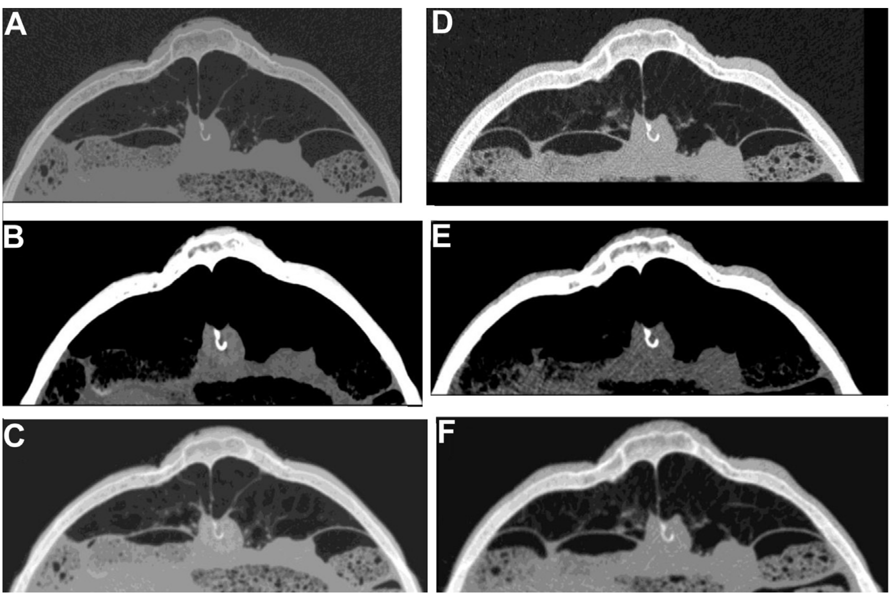

Fig. 7. Transversal sections of CT images of the normal lung of a healthy Burmese star tortoise (Geochelone platynota) demonstrating the importance of variable algorithm and exposure settings. (A) and (D) show a high detailed bony algorithm while (B) and (E) are a routine soft tissue window. Note the loss of pulmonary and bony detail in (D) and the increase of quantum noise in (D) and (E). The scans in (D), (E) and (F) were taken with only 50mAs and 80kV while (A), (B) and (C) were performed with 150mAs and 130kV. (C) and (F) demonstrate the poorer image quality of the soft tissue windows from (B) and (E) after manually shifting the window width and level to a bony window. It is important to recalculate different windows instead of pretending a bony window by adapting a soft tissue window.

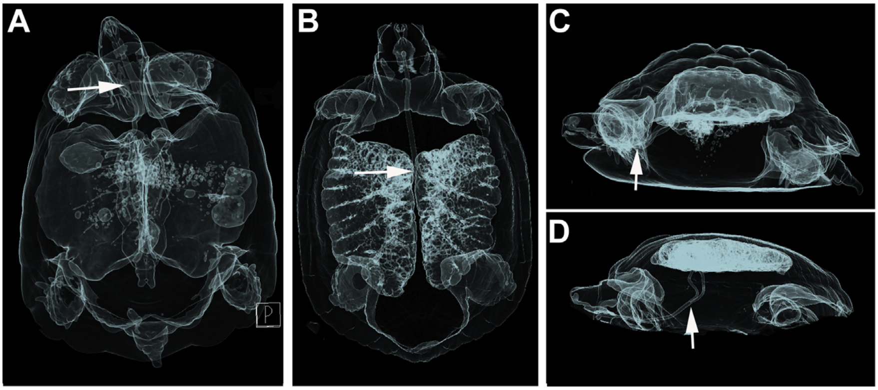

Fig. 8. A three-dimensional (3D) model of the CT of the respiratory tract (dorsoventral and lateral view) of a Herman's tortoise (*Testudo hermanni*) (*A, C*) and red-eared slider turtle (*Trachemys scripta elegans*) (*B, D*). These models demonstrate the situs of the tracheal bifurcation (*arrows*) as well as of the paired lungs. The trachea is shorter in terrestrial species and the bifurcation is therefore located more cranially than in most aquatic species.

Multiplanar reconstruction (MPR) facilitates correct interpretation due to better understanding of the spatial sense and easier illustration of pathologies. Mapping of some pathologies is only possible when viewed in at least 2 orthogonal planes, as in radiography. The imaging plane may be adapted as well, along the trachea or one bronchus for instance. Three-dimensional models are used to demonstrate anatomy as well as pathologic findings (**Figs. 8** and **9**). Curved MPR may ease interpretation in coiled snakes.[7] As a curved MPR may be hampered by artifacts and due to some lung distortion, the author prefers snakes being stretched out when possible.

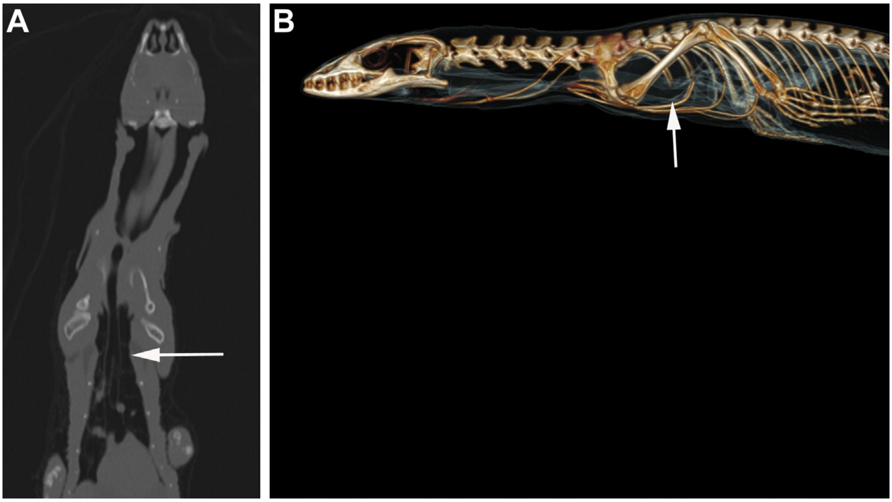

Fig. 9. Coronary CT (modified bony window [*A*] and lateral 3D model [*B*] of the cranial body and the respiratory tract of a blue spotted tree monitor (*Varanus macraei*). The position of the tracheal bifurcation (*arrow*) varies between species but is important to know especially for intubation. Note that the MPR of the coronary CT (*A*) is aligned along the trachea and bronchi.

Virtual endoscopy is often included into the software package of most CT machines and may be useful for further evaluation of trachea and bronchi.

Note that in case of a single slice CT it is important to place the animals as symmetrically as possible in the gantry. Although modern software allows MPR of any image package, the quality may not be sufficient, especially in smaller species. The author preferred sagittal scans of chelonians when no MPR was available because they corresponded to lateral radiographs. If necessary, smaller patients may be placed in each desired plane in the gantry in older machines to obtain robust diagnoses.

Magnetic Resonance Imaging

Another cross-sectional imaging technique is MRI. It is able to differentiate between various soft tissues much better than CT. However, any patient movement influences each single image of a sequence. Therefore, usually general anesthesia is mandatory. Some investigators[8] state that taping the head and limbs into the shell is sufficient to mechanically immobilize chelonians to perform MRI. In our experience, most animals, especially anxious or agile patients, will still struggle and cause artifacts that hinder adequate diagnosis.

Several sequences must be performed to gain sufficient tissue information (soft tissues—fat—fluid/liquor—blood), which means that MRI lasts much longer than CT. Given that most animals recommended to diagnostic imaging of the respiratory tract suffer from dyspnea or are in a poor condition, one would prefer a quick examination that does not require anesthesia. In addition, it has a lower resolution than CT or radiography, which may limit differentiation of tiny structures in delicate patients. Different coils are needed to support imaging of different animal's size and shape, which makes MRI even more expensive and less affordable (Fig. 10).

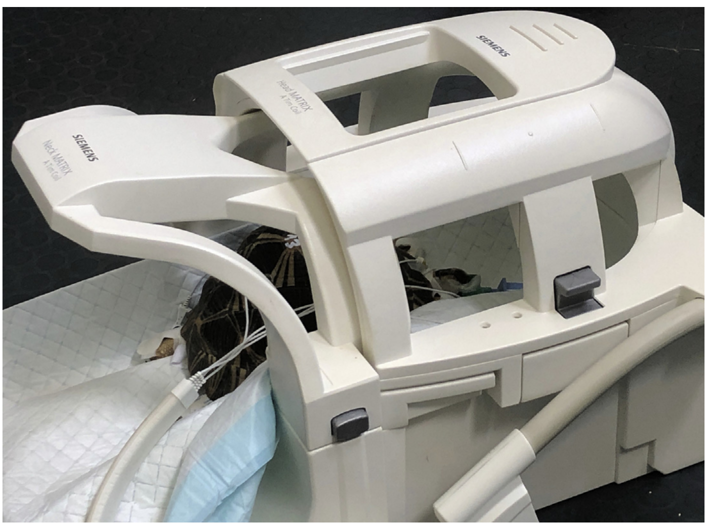

Fig. 10. Radiated tortoise (*Astrochelys radiata*) under anesthesia positioned within a combined head and neck coil to undergo an MRI. Any movement will compromise image quality and is therefore to be prevented by sedation. Although CT examinations with modern multislice helical machines take only few seconds to minutes, a basic MR lasts minimally 15 to 30 minutes, depending on the animal size and desired sequences.

Fig. 11. Magnification of a dorsoventral radiograph of the caudal left lung of a black and white tegu (*Salvator merianae*). Note the superimposing scutes throughout the whole lung. They should not be misinterpreted as pathologic lung pattern.

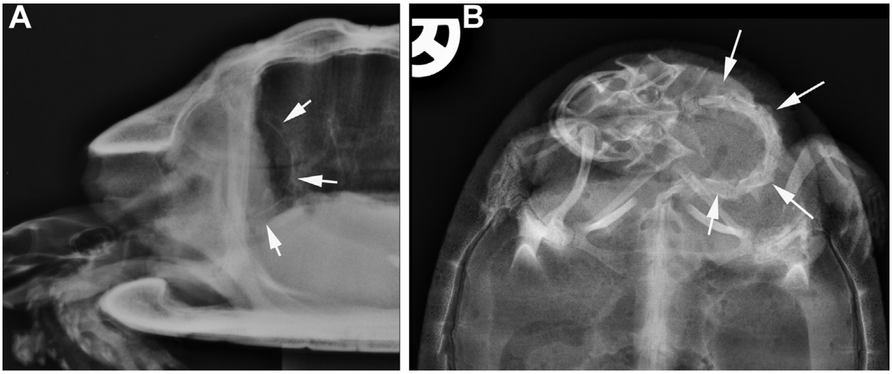

Fig. 12. Sections of lateral (*A*) and dorsoventral (*B*) radiographs of a Herman's tortoise (*Testudo hermanni*) and a Gibba turtle (*Hrynops gibbus*), respectively. The 2 images compare the situs of the cervical spine (*arrows*) and trachea of a hidden-neck turtle or Cryptodira (*A*) and side-neck turtle or Pleurodira (*B*). The retracted head of a hidden-neck turtle may be misinterpreted on lateral radiographs as a pathologic lung pattern (especially when fully retracted).

GENERAL RECOMMENDATIONS FOR IMAGE INTERPRETATION

In general, CT is the gold standard for imaging of the respiratory tract in all reptiles. In addition, reading CT images helps to improve radiographic interpretation. The various examples given later will point out the importance of especially lateral radiographs. One should not neglect or underestimate a basic set of "classic" radiographs, as

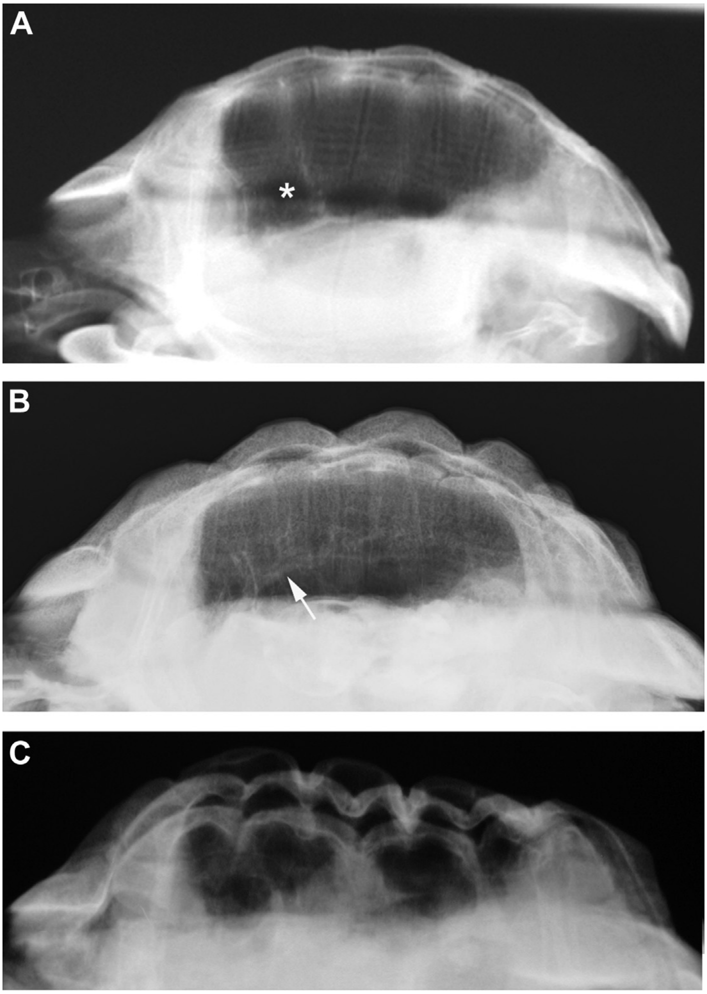

Fig. 13. Sections of lateral radiographs of 3 different Herman's tortoises (*Testudo hermanni*). Growth lines of the shell superimpose the lung fields (*A*) and may be misinterpreted as "interstitial lung pattern" by veterinarians who are not familiar with reptiles. The radiolucent line (*asterisk*) is visible in perfectly horizontally performed images and represents the suture line between costal and marginal bony plates and shields. The tortoises in (*B*) and (*C*) suffer from various grades of metabolic bone disease. The spongy bony plates (*B*) may be misinterpreted as bronchial lung pattern (although only 2 main stem bronchi exist in chelonians), whereas the sunken carapace with the pyramidal shaped bony plates may superimpose with and therefore hide pathologic lung patterns (*C*). The arrow indicates pulmonary vessels.

CT is not as globally available as radiography is. Furthermore, a CT is much more expensive and may therefore not be affordable for each owner.

In *film reading or image interpretation* of radiographs or CTs, respectively, a standard hierarchy should be maintained, independent from the requested organ or disease. First, image orientation should always follow the international standard for radiographs, CT, or MRI images because it eases identification of pathologic changes and comparison of literature: the head of the patient points to the left in lateral or sagittal views and to the top in DV/ventrodorsal (VD) radiographs or coronal planes. The right side of the animal on DV or VD views points always to the left of the image. A side marker prevents misunderstandings, especially when planning surgical procedures.

The author prefers the following *order and evaluation criteria* apart from image quality verification:

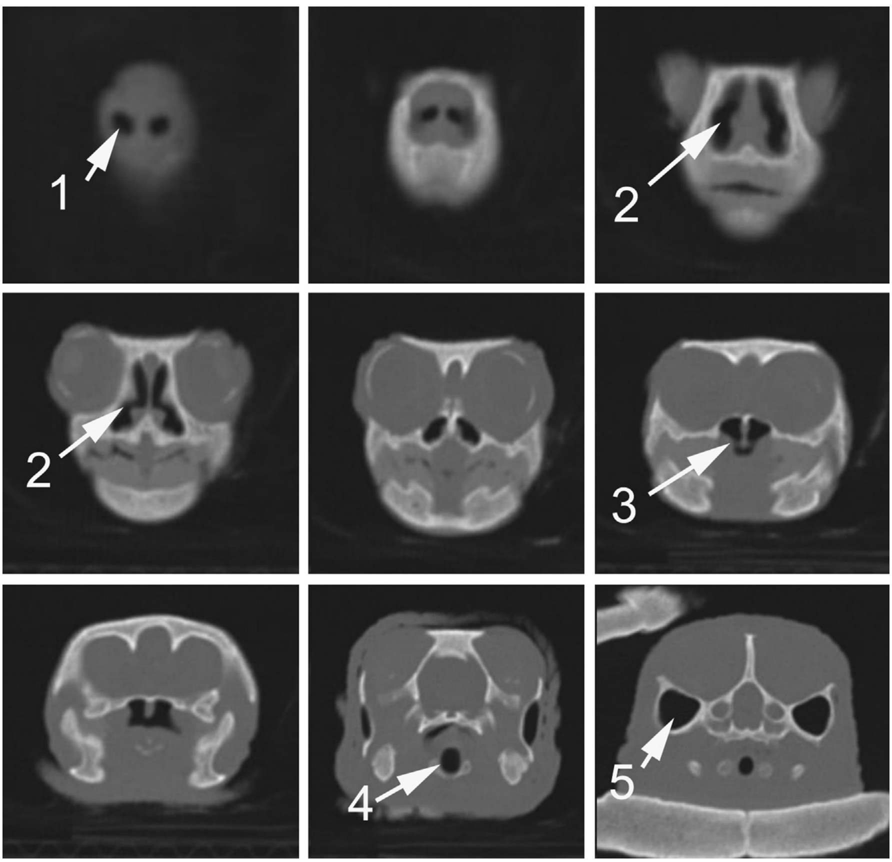

Fig. 14. Selected images of a transversal CT (bony window) of the head of a normal red-eared slider turtle (*Trachemys scripta elegans*): (1) nares/nasal cavity, (2) simple conchae, (3) choana, (4) glottis/trachea, (5) bulla tympanica. Note the simple architecture with a septum dividing the right from the left nasal chamber, although these chambers lack turbinates and sinuses.

- General body composition (obesity, cachexia)
- Skeleton: position and shape of single bones, overall density, bony plate thickness of the shell in chelonians, structure, periosteal reactions, local soft tissue swellings (especially in extremities and tail)
- *Respiratory tract:* nose, choana, glottis, larynx, trachea, mainstem bronchi, and lung as well as air sacs (if present) for position, wall thickness and density, size or diameter and shape, opacification of lumen or changes of structure. Abnormalities are categorized according to their location (uni- or bilateral, cranial, caudal, dorsal, ventral, peribronchial), extent, and density. Asymmetry of the lungs should be evaluated as well. Note that each species holds variable anatomic features (eg, a multicameral lung in chelonians or varanidae, a paucicameral type in chameleons, or a unicameral type in most lizards and snakes).
- All other coelomic organs are evaluated for position, size/diameter, shape, density (in comparison to muscles), margins, contents, wall structure and wall thickness of hollow organs, inner architecture of parenchymal organs or eggs: heart, liver and gall bladder, spleen, gastrointestinal tract, kidney, urinary bladder, gonads, follicles, and eggs (moreover the latter should be counted) if it is possible.
- Head (including eyes, ears, brain, maxilla, mandibula, teeth), thyroid

IMAGE INTERPRETATION OF THE NORMAL RESPIRATORY TRACT

Motion artifacts caused by breathing are usually barely visible due to the slow respiratory rate. *Radiographically* the nasal cavity is aerated, and glottis and trachea or bronchi appear as radiolucent tubular structures that may be bordered by a

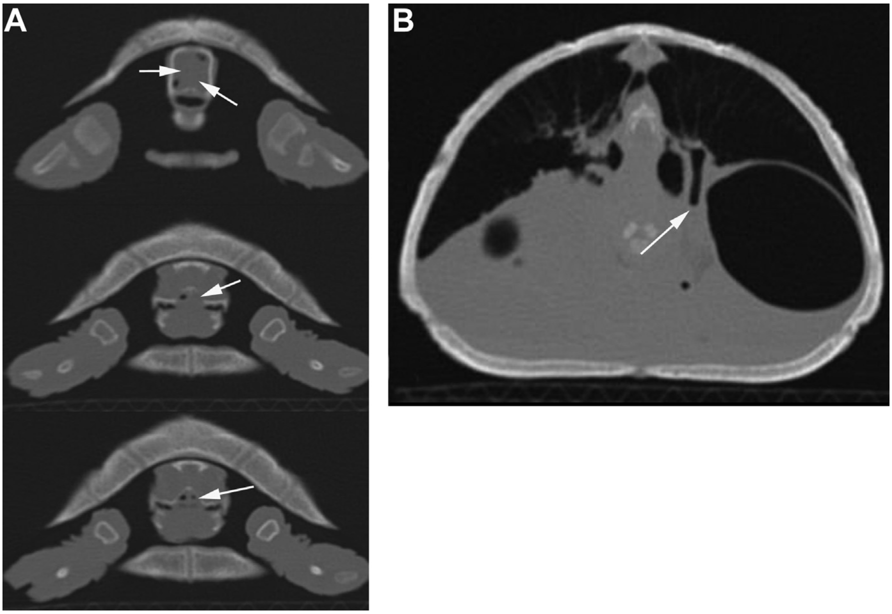

Fig. 15. Selected images of a transversal CT (bony window) of the head and cranial lung of a Leopard tortoise (*Stigmochelys pardalis*) suffering from severe rhinitis (*A*, *arrows*). The whole nasal cavity is obstructed by soft tissue dense material (compare Fig. 14). In addition, the left bronchus (*B*) shows an abrupt blunted end (*arrow*), which indicates most likely more secret accumulation.

mineralized, thin wall. Depending on the species the lung (and air sac, if present) is an elongated to oval radiolucent area. The size of the lungs depends on the status of inspiration or expiration, as the expandability is influenced by the surrounding organs, especially the digestive tract.[1,2] Positive pressure ventilation influences the lung appearance most prominently in snakes and lizards. Pulmonary artery (dorsal) and vein (ventral) bordering the primary bronchus may be differentiable within the lung field, especially in chelonians (see **Fig. 5**). The delicate honeycomb-like network of faveolae and ediculae in chelonians (note the more complex, parenchyma-rich architecture in sea turtles[1]) and more primitive lizards or the more vascularized anterior part of the lungs in snakes[9] are only seen when thickened or of increased density. Note that most coelomic organs cannot be differentiated properly on plain radiographs in reptiles due to the lack of internal fat between the coelomic organs. Nevertheless, gas and mineralized ingesta provide "natural contrast media" for gastrointestinal tract evaluation and identification. Per oral or intravenous contrast media (barium sulfate suspension or iodinated contrast media, respectively) can be used to highlight some organs further.

Be aware that bony plates, osteoderms, and scutes (especially in pine cone lizards *Tiliqua rugosa* or crocodiles; **Fig. 11**) as well as the shell, the spine, or ribs superimpose the lung fields and may be misinterpreted as pathologic lung pattern, especially in veterinarians who are less familiar with reptile anatomy (**Figs. 12** and **13**).

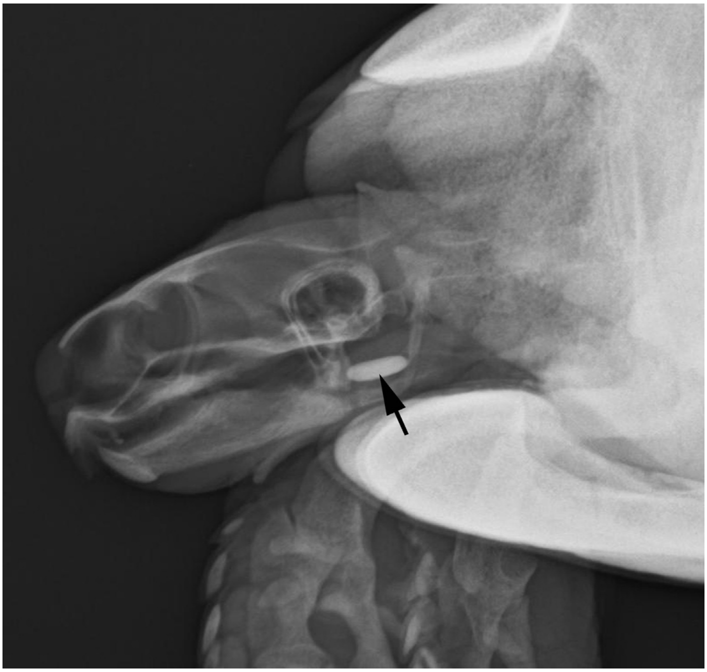

Fig. 16. Lateral radiograph of the cranial part of a Herman's tortoise (*Testudo hermanni*). A flat stone is locked immediately caudal to the glottis (*arrow*). Loud respiratory noise made a foreign body or stenosis the most likely differential diagnosis. Although a CT may provide additional information, plain radiographs are usually sufficient to localize radiodense foreign bodies in the neck region.

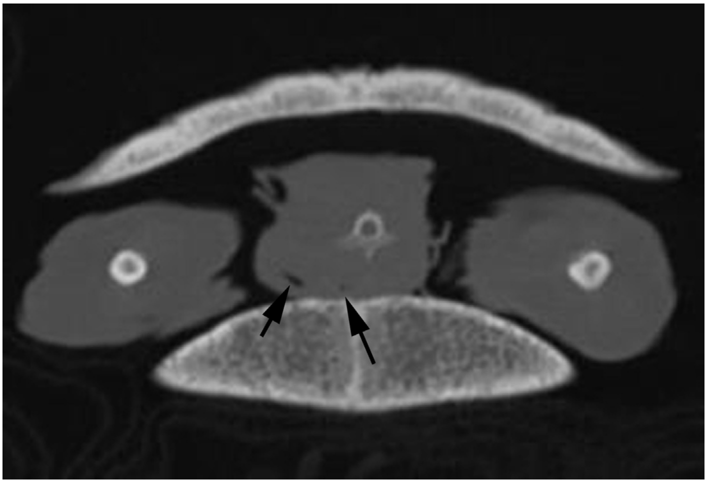

Fig. 17. Transversal CT (bony window) of a Herman's tortoise (*Testudo hermanni*) suffering from bilateral severe bronchial collapse (*arrows*, more severe on the left side). This rare disorder has only recently been described in literature[17] and can hardly be detected on radiographs. Note the thickened spongy demineralized bony plates (of the plastron) indicating metabolic bone disease that may have aggravated the collapse.

Meteorized parts of the gastrointestinal tract may further confuse proper lung differentiation, especially in chelonians.

CT on the other hand allows precise visualization not only of the upper respiratory tract[10] (**Fig. 14**) but especially of the variable delicate architecture of the lungs in the different species, especially in (adapted) lung or bony windows (see **Fig. 7**). The tracheal rings (especially when even mildly mineralized) as well as the exact location

Fig. 18. Transversal CT (lung window) of a European pond turtle (*Emys orbicularis*) suffering from unilateral (left side) bronchitis (*arrow*) and bronchial obstruction (most likely due to mucus or exudate) as well as mild pneumonia on the left side. Arrowheads indicate pulmonary vessels.

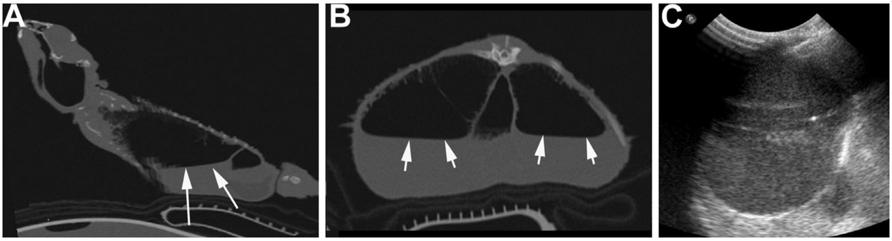

Fig. 19. Sagittal (*A*) and transversal (*B*) CT images of a Bearded dragon (*Pogona vitticeps*) suffering from severe dyspnea. The animal was placed in a plastic box to perform the CT. No restraint or anesthesia was used due to the poor clinical condition. Movement artifacts were therefore accepted. The animal sat in a very upright position to maintain breathing. The ventral half of the lung was fluid filled bilaterally. The fluid created a horizonal level (*arrows*). The dorsal half of the lung showed the typically small rim of respiratory epithelium or parenchyma, whereas most of the lung consisted of a large untextured air bubble. Although sonography (*C*) is not typically used as an imaging tool in lung disorders in reptiles, it helped to localize and aspirate the jellylike fluid. Cytology of the effusion was diagnostic for a septic, massive exudative pneumonia (Graphics by © Michi Gumpenberger). Note the more simple, peripherally situated parenchyma of this Bearded dragon, whereas the Savanna monitor in Fig. 26 has a much more complex architecture.

of the bifurcation or lumen of the bronchi are seen. In chelonians the arrangement of the air chambers, the various ridges, and septae, which create the sponge-like appearance, can be depicted easily.[5,11–13] However, the *septum horizontale* or pleuroperitoneal membrane cannot be differentiated in healthy animals. In lizards and

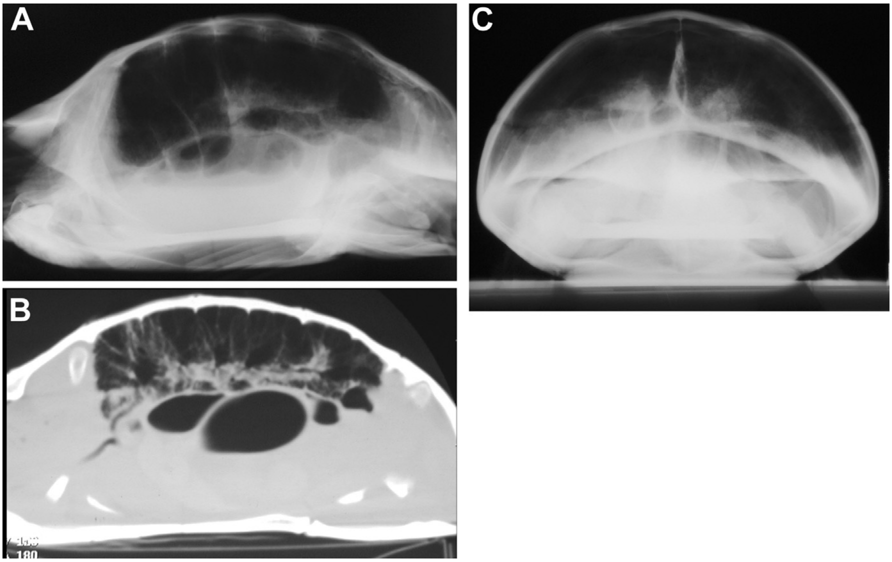

Fig. 20. Lateral (*A*) and craniocaudal radiographs (*C*) as well as a corresponding sagittal CT (modified lung window, *B*) of a Herman's tortoise (*Testudo hermanni*) suffering from bilateral moderate, exudative pneumonia. On the craniocaudal view heterogeneous opacifications are seen ventromedially in both lung fields (more severe on the right side). On lateral view the pathologic pattern is distributed in the caudoventral half of the lung. CT images reveal the full extent along the whole central bronchi bilaterally. Cranially the whole parenchyma has an increased density. The easily and quickly performed CT represents the gold standard for lung evaluation in reptiles.

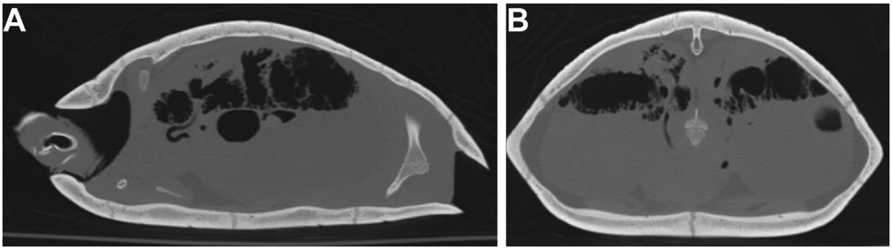

Fig. 21. Sagittal (*A*) and transversal (*B*) CT (lung window) of a Florida red-bellied cooter (*Pseudemys nelsoni*) suffering from bilateral severe bacterial pneumonia. Especially the dorsal lung parenchyma shows a massive increased density. The central air chambers seem compressed and partially opacified. The caudal half of the lung is less affected than the cranial half.

chameleons the different types of lungs (more saclike vs more complex architecture) are accessible as is the elongated, ring-like tissue with the central air chamber in snakes.[14] Even minimal mineralization can be depicted using densitometry. Recently, a detailed paper pointed out the similarity of the pulmonary anatomy of alligators and avians in CT.[15] Bronchi were identified in alligators that equal the avian entrobronchi, laterobronchi, and dorsobronchi, as well as regions of the lung hypothesized to be homologous to the avian air sacs.

Although there is no fat between the coelomic organs the slightly different soft tissue densities can be differentiated in CT. Therefore thyroid, heart, liver, gall bladder, spleen, kidney, fat body, urinary bladder, or gonads can be visualized apart from the gastrointestinal tract, even on plain images.

A private collection of radiographs and CTs of various species with an unaffected respiratory tract will serve as a kind of atlas, as the available literature is unable to document all different reptile species. Although sufficient information is provided for

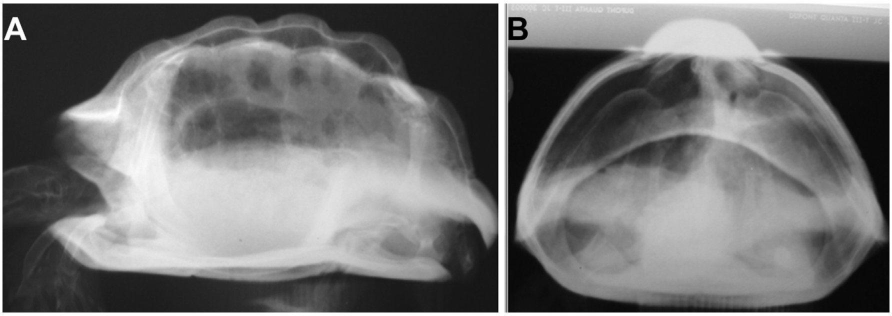

Fig. 22. Lateral (*A*) and craniocaudal radiographs (*B*) of a Herman's tortoise (*Testudo hermanni*) suffering from unilateral moderate-to-severe interstitial pneumonia (*left*). Severe heterogeneous opacification of the lung can even be seen on both views. On the craniocaudal view the unilateral lung affection (*left*) and contralateral mild emphysema (*right*), causing some midline shift to the left, is seen. Especially, the lateral view demonstrates that mostly the parenchyma seems to be affected with centrally aerated chambers. Therefore, severe fluid accumulation is less likely. Only a CT (or MRI) examination would be able to visualize mild fluid accumulations.

common species, rarer species should always receive radiographs in 2 (lizard, snake) or 3 (chelonians) views to serve as reference models.

IMAGE INTERPRETATION IN THE DISEASED REPTILE RESPIRATORY TRACT

Nasal Cavity

Rhinitis or severe epistaxis (usually caused by trauma or in context with lung hemorrhage) present as more or less homogeneous opacification of one or both *nasal cavities* (**Fig. 15**).

Trachea and Bronchi

The most common pathologic radiographical findings of the *trachea* are luminal opacifications that most likely resemble either secret accumulations, foreign bodies (**Fig. 16**), or masses, such as fungal granulomas. Recently, a rare case of a tracheal T-cell lymphoma was documented radiographically and in CT in a boa constrictor.[16]

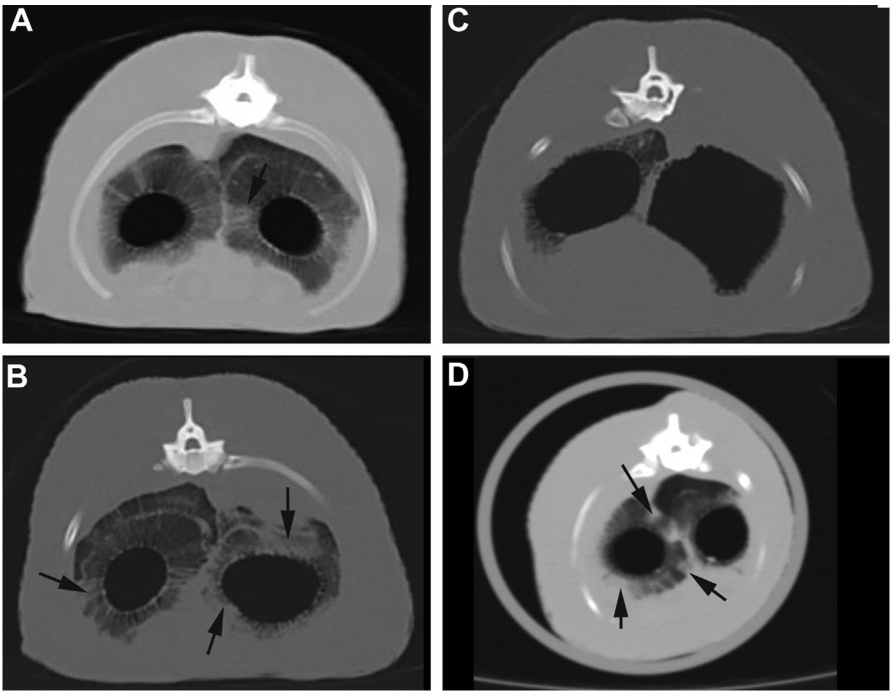

Fig. 23. Transversal CT images (modified bony window) of 2 different Indian rock pythons (*Python molurus*) suffering from bilateral pneumonia. The cranial part of the lung nearly seemed normal (*A*) in the first snake. The circular lung parenchyma looks like the iris of an eye, whereas the central chamber is airfilled and free of any structures. The increased density and patchy infiltration (exemplary *black arrows*) of the parenchyma began in the middle part of the lung and became severer the more caudally (*B*) the scan proceeded. The caudal part of the lung (*C*) in snakes is nonrespiratory and mainly functions as an air sac (left lung; at the right lung remnants of the lung parenchyma are visible). Therefore, no "irislike" structure is seen there. The second snake (*D*) was placed in a plexiglas tube. The more severe patchy infiltrates are pointed out (*arrows*). Note the more blurred images: this is due to a poor reconstruction algorithm: a soft tissue algorithm was manually adapted to fit a lung window.

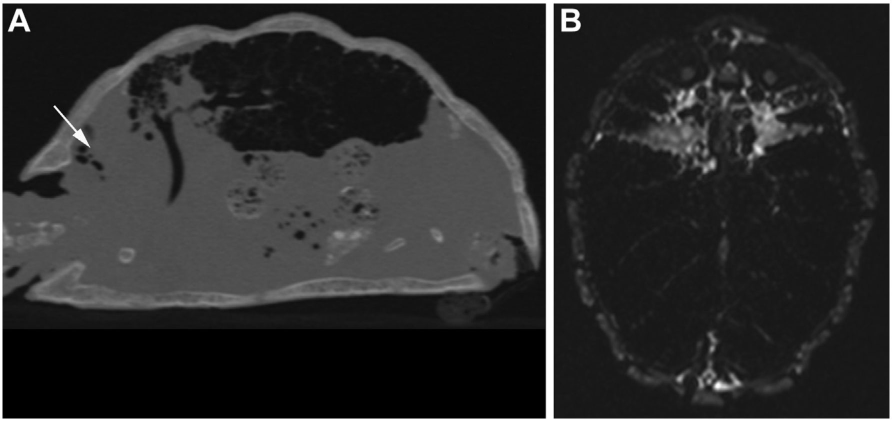

Fig. 24. Paramedian sagittal CT (*A*) and coronal T2W-MRI (*B*) of a Burmese star tortoise (*Geochelone platynota*) suffering from acute bilateral hemorrhage within the cranial lung. The clinical history (intended injection into the dorsal sinus, bloody smear from the nostrils) as well as the local emphysema (*arrow*) ventral to the nuchal shield prove that bleeding instead of pneumonia caused the increased densities/signal. However, most common cause of hemorrhage within the lung are shell fractures. T2W, T2-weighted.

Mild mucosal swelling that indicates tracheitis will not be visible radiographically. Meyer[17] illustrated a tortoise suffering from tracheal and *bronchial collapse* (**Fig. 17**) due to chondromalacia. This was first shown in a CT and then proved in pathologic examination. Bronchial obstruction and bronchial wall thickening can be easily depicted on CT as well (**Fig. 18**).

Lungs

Frye[18] listed aspiration pneumonia, bronchopneumonia, chronic granulomatous pneumonia, and verminous pneumonia as the most common respiratory disorders in reptiles. Radiographically the veterinarian is only able to differentiate increased densities that suggest pathologies within the *lung.*[19] These changes may be classified and

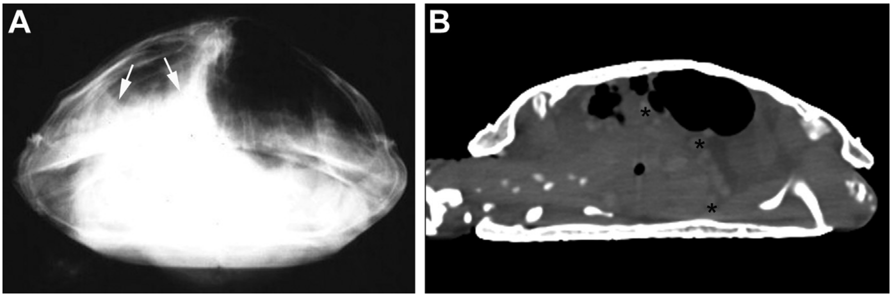

Fig. 25. Craniocaudal radiograph (*A*) of a red eared slider turtle (*Trachemys scripta elegans*). The ventrolateral part of the right lung field (*white arrows*) shows a soft tissue density, indicating a fluid filled lung suspicious for pneumonia. A sagittal CT (soft tissue window, *B*) demonstrates multiple hyperdense nodules in the cranial lung. These granulomas could not be differentiated radiographically but aggravate the diagnosis. More granulomas were outspread in the whole coelomic cavity (exemplary *black asterisk*).

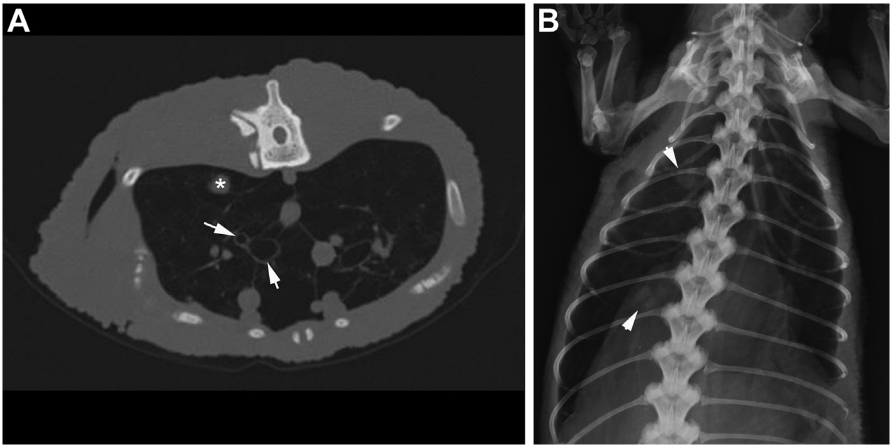

Fig. 26. Transversal CT (modified lung window) of a Savanna monitor (*Varanus exanthematicus*, *A*). The animal suffered from multiple oral abscesses as well as a sarcoma of an intestine wall. Two nodules (*asterisk*) were found in the honeycomb like parenchyma of the lung. All other round structures in this plane represent transsections of vessels. The most likely differential diagnoses were granuloma, but metastases cannot be ruled out, certainly (*arrows*—bronchi). These changes were barely visible radiographically (*arrowhead*, *B*). Nodules or masses that are localized in the periphery of the lung may be approached by ultrasound for sampling. Note the quite complex multichambered lung architecture of this animal, whereas the Bearded dragon in Fig. 19 shows the more typical, hollow, sac-like lizard lung with only a peripheral rim of respiratory tissue.

described as unilateral or bilateral, diffuse (entire lung involved), regional or local (only part of the lung affected), homogeneous or heterogeneous, and well or poorly demarcated.

Radiographically severe, more exudative *pneumonia* or lung consolidation is seen as a more or less homogeneous soft tissue opacification of the usually ventral parts of the lung.[20] Poor ciliary clearance and inability to cough aggravate disease.

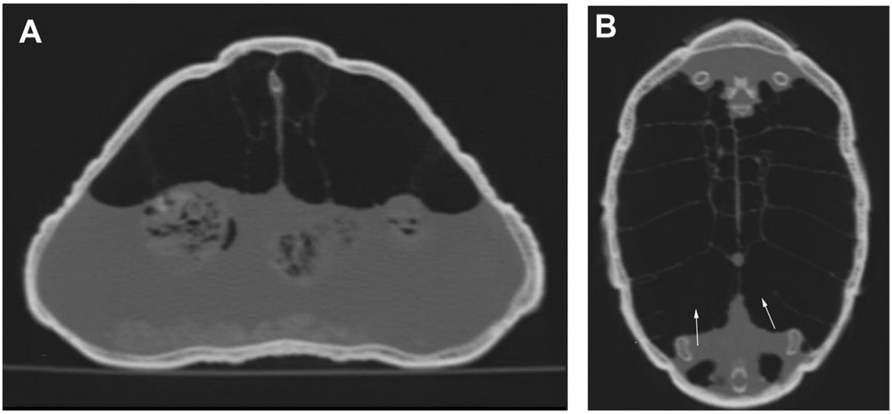

Fig. 27. Transversal (*A*) and coronal (*B*) CT (lung window) of a Herman's tortoise (*Testudo hermanni*). The faveoli are thinned and the air chambers widened. In the caudal part some septae are missing (*arrow*). These findings were interpreted as emphysema, most likely originating from an experienced and healed pneumonia.

Especially in chelonians and lizards one can follow the gravity-dependent horizontal line of fluid accumulation (Figs. 19–21; compare Fig. 25). However, this very obvious finding is missing in a more interstitial pneumonia when only the faveoli or septae become thickened and denser (Figs. 22 and 23) without massive fluid accumulation in the air chambers.[1,9] Poor definition of pulmonary vasculature helps to identify pulmonary infiltrates and enhanced reticular pattern. Depending on the severity of these infiltrates they may be superimposed and obscured on plain radiographs and therefore overlooked, whereas in CT any delicate changes will be detected. Nevertheless, some authors found it even easier to depict an interstitial or honeycomb pattern in DV instead of CC radiographs in cold-stunned sea turtles suffering from pneumonia.[1] In MRI, fluid accumulations will appear hyperintense in T2W images (Fig. 24). In case of equivocal signals, a fat suppression sequence should be performed, whereas T1W sequences demonstrate anatomic details further. Similar findings are present in marine turtles suffering from saltwater aspiration and near drowning.

Lim[21] described a generalized, diffuse unstructured interstitial lung pattern with thickened pulmonary septae on whole-body radiographs of a leopard tortoise. In CT, the lungs seemed emphysematous with irregularly thickened pulmonary septae,

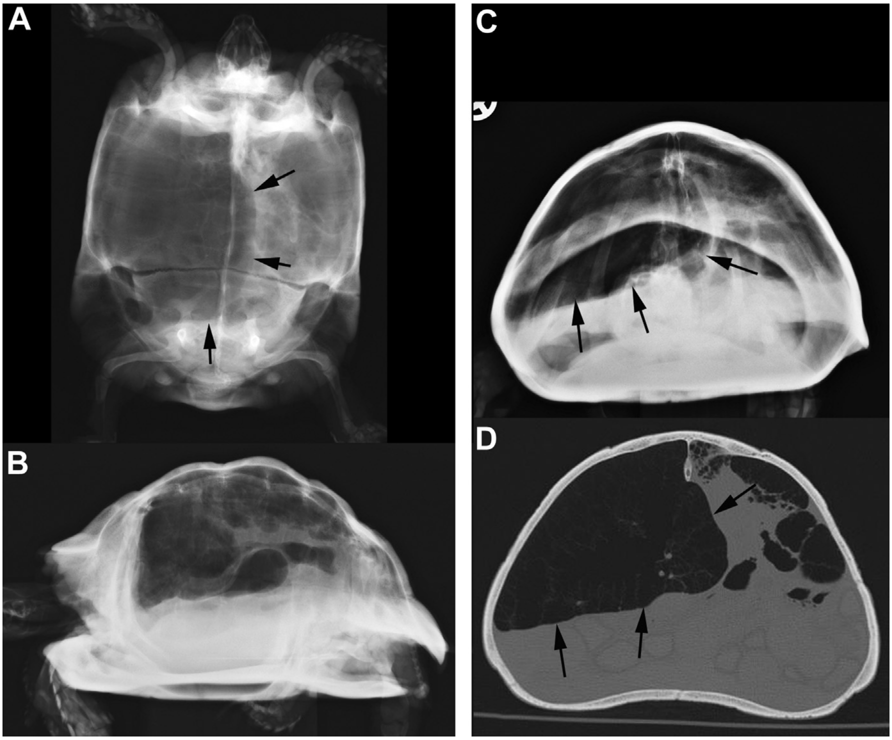

Fig. 28. Dorsoventral (*A*), lateral (*B*), and craniocaudal radiograph (*C*) of a spur-thighed tortoise (*Testudo graeca*) suffering from unilateral pneumonia (left side) and contralateral compensatory lung emphysema (*arrows*) or overinflation. Severe unilateral opacification of the lung can even be detected on dorsoventral views but should always be further investigated with additional "lung-specific" views. A corresponding transversal CT image (*D*) demonstrates the opacification of the air chambers, thickening of the septae, and reduced lung volume on the left side, whereas the normally configurated aerated right lung causes some midline shift (*arrows*) to the left.

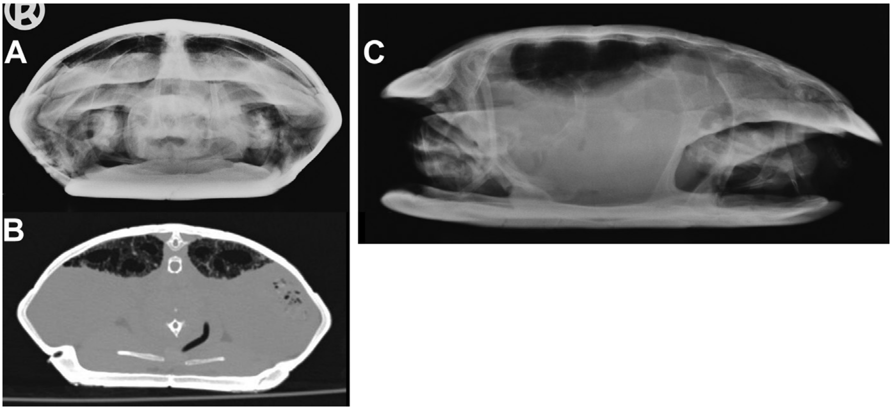

Fig. 29. Craniocaudal (*A*) and lateral (*C*) radiographs of a red-eared slider turtle (*Trachemys scripta elegans*) in horizontal beam technique. The lungs are compressed by the large opacification of the coelomic organs (sonographically identified as follicles) and the retracted head and extremities. A corresponding transversal CT (*B*) demonstrates how the faveoli and septae of the multichambered lung become thicker and denser due to compression. This pattern is homogenously distributed throughout the whole lung. There is no fluid accumulation in the air chambers. This is in contrary to pneumonia where the lung parenchyma usually increases more heterogeneously in density or the air chambers are even filled with liquid.

diffuse ground-glass opacity, and toward the periphery of the lungs several smaller areas of pulmonary honeycombing. These changes differed markedly from the reticular pattern described in normal tortoises and were compatible with chronic, extensive interstitial *pulmonary fibrosis*. Hyperattenuating lines within a quite normal lung parenchyma were interpreted as fibrosis as well.[22]

Accumulation of *granulomas* may seem similar to a less complicated exudative pneumonia radiographically (**Fig. 25**). Multiple radiopaque nodules throughout the lung that were differentiable even on DV radiography were described in cases of fibropapillomatosis and neoplasia (myxomas) in sea turtle.[23,24] Focal, more ill-defined areas of lung consolidation may be more commonly identified in other chelonians

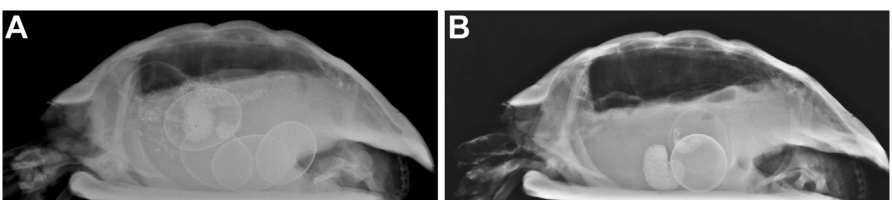

Fig. 30. Lateral radiographs of the same Herman's tortoise (*Testudo hermanni)* in horizontal beam technique in a 16-day interval. Development of multiple follicles as well as of eggs (*A*) caused physiologic compression of the lung fields. Note the change of the size of the lungs as soon as part of the eggs were disposed (*B*). Note the mineralized structure cranial to the eggs. This is feces in the caecum and transverse colon.

and lizards.[2] Most likely differential diagnoses for nodular lung pattern are granulomas, abscesses, and rarely neoplasia (**Fig. 26**).[5]

One should be aware that the different causes of pneumonia (eg, bacterial/viral/mycotic/verminous, foreign body due to force feeding, near-drowning etc.) can usually not be differentiated with imaging methods (apart from differentiable foreign bodies such as fishhooks). On the other hand, multiplanar reconstruction enables precise planning for transcarapacial sampling in chelonians or site for transcutaneous pulmoscopy in snakes, for example.

Because of the unique anatomic feature of the chelonian lung that adheres dorsally to the carapace, the chelonian lung is prone to bleeding in any cause of shell *trauma* (eg, car accidents, injuries from lawn mowers or propeller of motor boats in sea turtles[22]). Therefore, increased opacification of the lung is visible close to a shell fracture. Sometimes there is only some pleural thickening or extrapleural hemorrhage that can be evaluated with CT but barely with plain radiography.

Epistaxis and hemoptysis may be caused by fractured mineralized lung vessels originating from hypercalcemia.[25] The mineralized vessels can be easily depicted radiographically or with CT. Local hemorrhage will appear as increased density within the lungs, similar to pneumonia. It is therefore crucial to interpret any image in the light

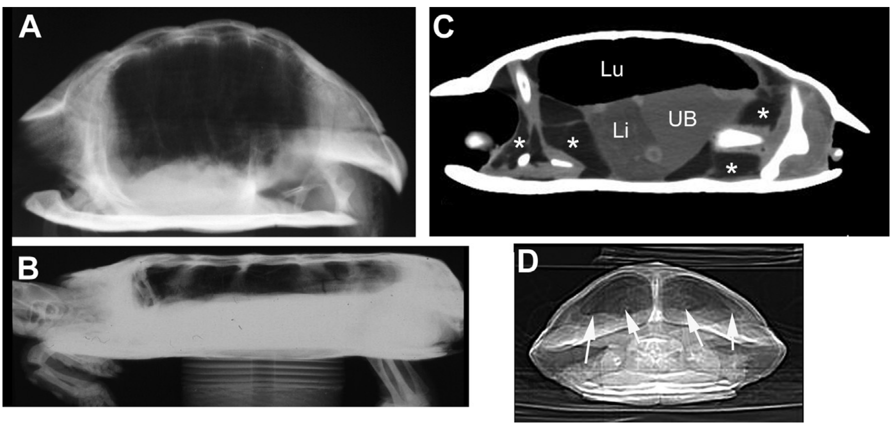

Fig. 31. Lateral radiograph of a Herman's tortoise (*Testudo hermanni, A*), a pancake tortoise (*Malacochersus tornieri, B*), and sagittal CT (*C*, soft tissue window) as well as the axial topogram of the CT (*D*) of a red-eared slider turtle (*Trachemys scripta elegans*). The radiograph of the first animal was taken after hibernation when the patient had fasted for months. The soft tissue opacification of the coelomic organs should usually occupy 50% of the height of the shell and should be leveled horizontally. This is true for most chelonians, even for a pancake tortoise (*B*). An anorectic patient or an animal with an empty GIT shows an obvious reduced shadow of coelomic organs. Controversially the red-eared slider turtle was obese with huge fat accumulations (*asterisk*) along the inner contour of the shell and around the extremities. (LU, lung; LI, hypodense liver with lipidosis; UB, urinary bladder). Although fat can be clearly differentiated on radiographs of dogs or cats due to its darker gray it is barely distinguishable in chelonians. Reptiles do not have fat in between the single coelomic organs. The lungs are compressed by those huge amounts of fat, therefore raising the horizontal border of the coelomic organs. Note that there is no lung parenchyma differentiable in this soft tissue window. Instead, the lung appears black. The topogram (in the absence of a radiograph) shows the lung compression (*arrows*) likewise.

of clinical signs and physical examination. *Pulmonary edema* from cardiac or hepatic disease may seem similar to pneumonia as well.[25]

Decompression sickness happens in marine turtles when caught in trawls and gillnets. Although the already complex lungs are partially collapsed and show increased density, gas embolism can be found in the heart, major vessels, hepatic venous system, or even nervous system.[26]

Emphysema may be more likely seen in CT than radiography and mostly results not only in overinflation and enlargement of the lung but also in disruption of septae and confluence of air chambers[21] (**Figs. 27** and **28**). It may be observed with severe unilateral pneumonia in the contralateral lung. Emphysematous pulmonary *bullae* were described in marine turtles.[22,24]

Pulmonary *parasitism* was documented in snakes with positive contrast bronchography.[2] Aerosolized tantalum powder was used as contrast medium. The pentastomides appeared as radiolucent linear structures within the contrast-enhanced lungs.

Schachner[11] provides a detailed pulmonary anatomic and CT study in a rare case of unilateral *aplasia* of the lung in a common snapping turtle (*Chelydra serpentina*).

Lung Compression

The veterinarian should not only focus on imaging the respiratory tract in dyspneic patients. Especially chelonians live in a kind of bony box, which limits the space for the inner organs. Therefore, the abnormal or even physiologic (eg, pregnancy; **Figs. 29** and **30**) enlargement of single organs will influence all others, which may lead to significant *lung compression.*[27] Lung compression due to severe adipositas (**Fig. 31**), may also result in severe respiratory distress, which can be misinterpreted as a primary lung disorder such as pneumonia. In addition, reptilian patients with pneumonia

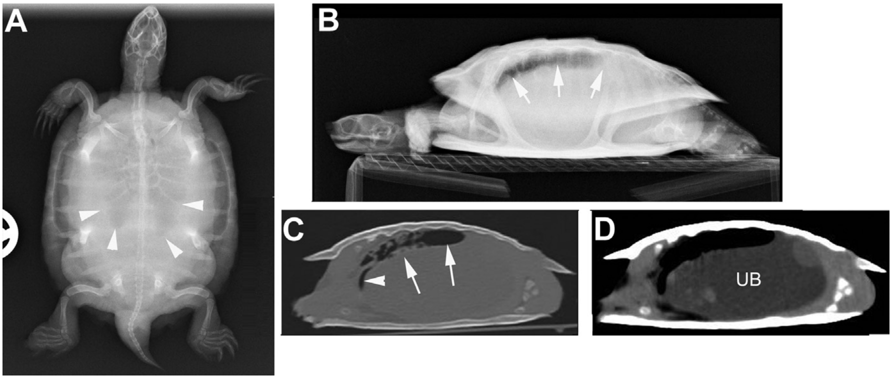

Fig. 32. Dorsoventral (*A*) and lateral radiographs (*B*) as well as corresponding sagittal CT (lung (*C*) and soft tissue window (*D*)) of a yellow-bellied slider (*Trachemys scripta scripta*) suffering from severe urinary bladder (UB) distension. The urine accumulation displaced all other coelomic organs craniodorsally and therefore caused severe lung compression (*arrows*). Even the bronchus was deviated cranially (in *C*, *arrowhead*). On the dorsoventral radiograph the compressed lungs can be seen (*arrow heads*) bilaterally. The CT images confirmed what was suspected on the radiographs: the lung compression from caudoventrally was most likely caused by severe urinary bladder distension or superovulation. In addition, this example proves again the importance of lateral radiographs. Because of open-mouth breathing this patient was treated for several weeks with antibiotics to fight the actually not existing pneumonia. To the author's opinion, a clinical examination, especially in a dyspnoeic chelonian, is incomplete without performing radiographs or ideally a CT.

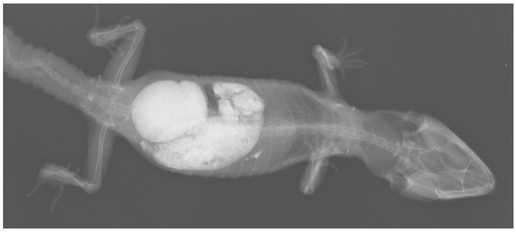

Fig. 33. A slim dyspneic leopard gecko (*Eublepharis macularius*) was suspected to suffer from dystocia on palpation. A dorsoventral radiograph revealed severe obstipation with mineralized material that caused additionally lung compression. It can be expected that on a thorough physical examination the obstipation would be palpated.

are typically systemically ill.[19] The clinical examination in a dyspneic reptile without the use of any additional imaging technique is incomplete and may lead to a wrong and even fatal diagnosis (**Figs. 32** and **33**). Besides, it is said that turtles show asymmetric swimming and floating as a typical clinical sign for pneumonia or that open-mouth breathing indicates pneumonia. However, fractures of the shoulder girdle or spine[22] as well as any unilateral mass or gas accumulation can also cause asymmetric swimming,[18,19,23] or severe pain may be responsible for open-mouth breathing. A more common reason for open-mouth breathing is severe lung compression, which may be accompanied by pale mucosal surfaces. On radiographs, organ displacement may give an indirect information for organ enlargement due to the so-called mass-effect[28] (**Figs. 34** and **35**). **Fig. 36** provides a schematic overview that may help to identify the origin of lung compression in chelonians. Severe urine retention is a common cause of lung compression and can be easily verified sonographically. In chelonians the natural shell openings or so-called windows provide an approach to visualize the coelomic organs. All other reptiles may be investigated similar to cats or dogs

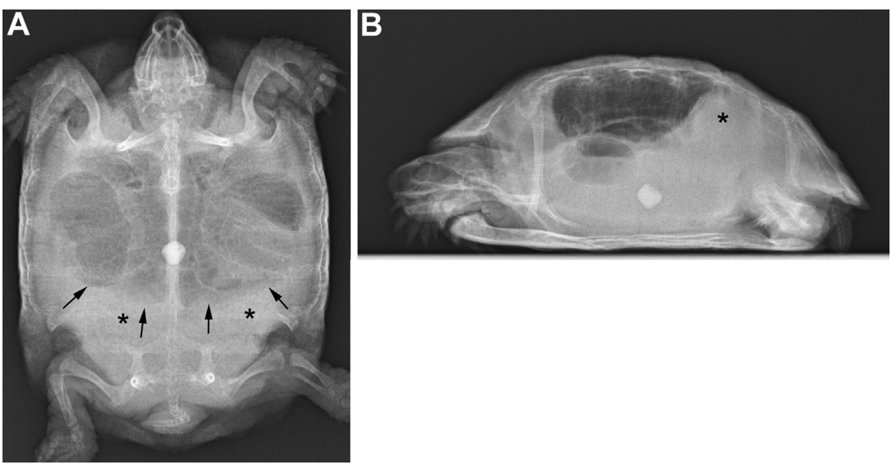

Fig. 34. Dorsoventral and lateral radiographs of a Herman's tortoise (*Testudo hermanni*) suffering from severe renomegaly (pathologically proven as gout, *asterisk*). A soft tissue dense mass is bulging into the lung fields caudoventrally (*B*). This massive lung deformation is even seen on a dorsoventral view (*arrows*, *A*). The stomach is gas-filled. A small pebble lies in a bowel loop.

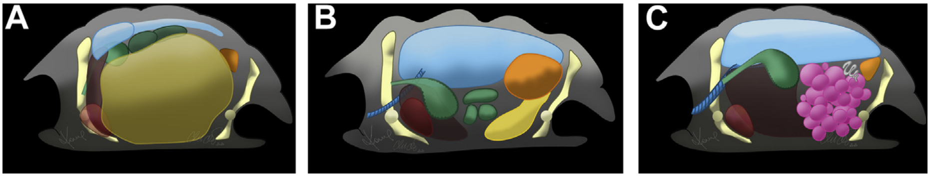

Fig. 35. Organ displacement and mass-effect in chelonians; lateral view: head is to the left. (*A*) Severe urinary retention displaces all organs to cranial and dorsal and therefore causes usually the most severe lung compression. Sonographically a severely enlarged urinary bladder may be confused with ascites. However, ascites does not displace organs. (*B*) Renomegaly results in a typical caudoventral impression or superimposition of the lung. Accompanying metabolic bone disease (as indicated here by the bumpy carapace) suggests kidney gout as the most likely reason for kidney enlargement. (*C*) A more evenly increase of the soft tissue level of the coelomic organs is caused in cases of very severe hepatomegaly or synchronous hepatomegaly and clutch development or hepatomegaly and enlarged urinary bladder, respectively. In case of obstipation or distended bowel loops the gastrointestinal tract is usually identified due to its contents. Note that the stomach is displaced (caudo-) dorsally, and the bronchi are displaced cranially by the enlarged liver. Red—heart, brown—liver, green—GIT, orange—kidney, dark yellow—urinary bladder, blue—bronchus and lung, gray—shell, bright yellow—shoulder and pelvic girdle (*circle* marks the shoulder and coxofemoral joints, respectively). (Graphics by © Michi Gumpenberger & Martina Konecny.)

with attachment of the transducer at the region of interest. This may be of great use to confirm the diagnosis or for sample collection (see **Fig. 19**).

In conclusion, each dyspneic patient should receive a thorough clinical examination in combination with appropriate diagnostic imaging. In all reptiles, at least 2 orthogonal radiographs should be performed. The lateral view should be done with horizontal

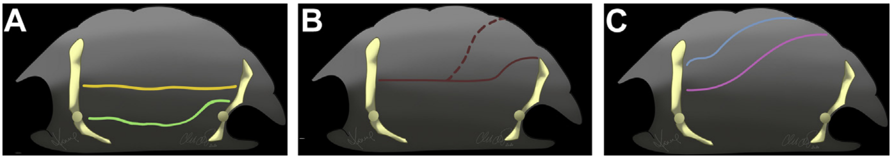

Fig. 36. The course of the usually horizontal line between lungs and coelomic organs as usually seen on lateral radiographs (head is to the left) performed in horizontal beam technique in (mediterranean) chelonians: (*A*) Normally the lungs occupy approximately 50% of the height of the shell in a healthy, feeding chelonian (*yellow line*). Chelonians after hibernation, very active males in breeding season or anorectic patients, have a relatively larger lung volume (*green line*). (*B*) Kidney enlargement creates a bump into the caudoventral lung field. The size of the indention depends on the degree of renomegaly (*broken line*—severe enlargement). (*C*) Urinary bladder enlargement or development of larger numbers of follicles or eggs (*pink line*) cause a more continuous rise of the horizontal line from cranially to caudodorsally. It seemingly tends to be more cranial convex if caused by a severely enlarged urinary bladder (*blue line*). Concurrent renomegaly will be superimposed in such cases. Simultaneous hepatomegaly will rise the cranial part of this level as well. In severe cases the lung is compressed exceptionally to craniodorsally and respiration will therefore be severely compromised. Note that performing lateral views in perpendicular beam will cause some organ shift and may therefore obscure the above-described situs! (Graphics by © Michi Gumpenberger & Martina Konecny.)

beam technique, especially in chelonians. However, CT is the gold standard to evaluate the entire respiratory tract.

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CLINICS CARE POINTS

- Severely dyspneic animals should be manipulated as quickly and carefully as possible. Therefore horizontal beam technique (if neccessary with the use of a box for restraint) should be used instead of lateral recumbency for lateral radiographs.
- Symmetric positioning is mandatory to gain meaningful radiographs. This is especially true in chelonians when the level and course of the soft tissues is interpreted in lateral views (done in horizontal beam technique).
- CT is superior to radiography in imaging the respiratory tract in reptiles. However, a properly performed full set of radiographs will support diagnosis frequently.
- Lung compression, especially in chelonians, causes dyspnea which may be misinterpreted as pneumonia without the use of diagnostic imaging tools.

DISCLOSURE

The author has nothing to disclose.

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