DIGITAL RADIOGRAPHY IN TURTLES AND TORTOISES

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INTRODUCTION

Conventional radiography has historically been the main tool for veterinary diagnostic imaging in reptiles, but performing radiographs in turtles and tortoises can be very challenging, especially because of low contrast (lack of fat tissue in the coelomic cavity, superposition of the bony shell, the pulmonary fields and the visceral organs, and skeleton less radiodense than that of domestic carnivores)[1,4,6,8].

Most radiographic units can be set to produce good quality radiographs of reptilian patients, but CR (Computed Radiography) and DR (Digital Radiography) are great equipments to enhance image quality afterwards : darkness, contrast, résolution and sharpness. It also permits to take measurements of a specific organ and easily store a great number of X-Ray snaps.

ISSUES ENCOUNTERED WHEN PERFORMING CONVENTIONAL RADIOGRAPHY IN CHELONIANS

SHELL

The chelonian shell is the main physical, acoustic and technical obstacle to obtain high quality medical images. This truly "bony armour" is derived from the integument, and composed of two parts : the upper carapace dorsally, and the lower plastron ventrally, connected together laterally by bony bridges. The shell only has two openings : one in the front, out of which emerge the fore limbs, the neck and the head, and one in the back, for the hind limbs and tail. It defines the coelomic cavity which contains all the viscera. The shell is also composed of two distinct tissue layers, one above the other: a deep dermis which is vascularised, innervated and ossified and an epidermis, on the surface, composed of large keratinized scales. The dermis is composed of about fifty bony plates called osteoderms, bound to each other by sutures. The placement of each of these corneous lamella is indicated by furrows that are clearly visible on the underlying osteoderms. The ribs and the vertebral column are adherent to the inner surface of the carapace[2,3,5,6].

INTEGUMENT

The skin of land tortoises may also be an issue. It is a scaly covering, constituted of alpha and beta keratin where thickness, rigidity and appearance vary over the body surface : on the four limbs and the tail, it is composed of thick and spiny scales. When moving proximally up the limb, the cutaneous covering scales diminish in size and in thickness until they become transformed into a thin and particularly flexible skin. It is generally at the level of the neck and of the pre-femoral fossa that it is the thinnest. Consequently, the presence of thick, highly keratinized scales can severely hinder the X-ray beam. Therefore, greater power is needed to avoid a subsequent loss of fine soft tissue detail[2,3,5,6].

ANATOMICAL FEATURES

The diaphragm, such as known in mammals and supposed to separate the thoracic cavity from the abdominal cavity, does not exist in turtles and tortoises, as in all other non-

crocodilian reptiles. These animals just have a thin membrane, called the "*Horizontal Septum*", which is not functional and adheres to the adjacent viscera ventrally[2,3,5,6].
This means that all the internal organs are close to each other in a so called “single coelomic cavity”. This can also make diagnostic imaging difficult.
Moreover, at rest, the volume occupied by the lungs corresponds to half the total volume of the shell. But this lung volume becomes considerably reduced (it is divided by five) when the four limbs are withdrawn into the shell. This explains why pulmonary radiographs must be performed on animals whose limbs are extended out of the shell.

Performing good quality radiographs on chelonians can therefore be challenging due to the following characteristics of these animals :
• they are “trapped” in a sort of “bony armour”,
• with the only “emerging” anatomic parts being covered with keratinized scales,
• their limbs, when they are retracted, push and compress the viscera in the coelomic cavity,
• and their internal organs adhere to one another due to the lack of a diaphragm.

LOW CONTRAST

From a dorso-ventral angle, you can’t avoid the superposition of bone tissue, pulmonary fields and other organs. Furthermore, in contrast to mammals, the coelomic cavity contains very little adipose tissue and, finally, the turtle skeleton is less radiodense than that of domestic carnivores. Consequently, contrast is low. To counter this problem, the selected kilovoltage should be reduced, the mAs should be increased, and the diaphragm set at its maximum. An anti-diffusing grid and a rare earth crystal reinforcing screen should also be used[7].
Mammography radiographic units provide better detail and resolution than standard radiographic equipment. Originally designed to detail very small, mineralised lesions in mammary tissue, they operate at a rather low kilovolt peak, creating images with superb contrast between bone and soft tissue structures. However, it has three drawbacks : longer exposure times, which makes it more vulnerable to patient motion, small film size, and low kiloVolt peak, which decreases the ability of the x-ray beam to penetrate through larger individuals. In conclusion, mammography films are best suited to static, anesthetized, and small reptiles (such as small lizards and snakes)[5,6].

ADVANTAGES OF DIGITAL RADIOGRAPHY IN CHELONIANS

Most radiographic units can be set to produce good quality radiographs of reptilian patients, but digital radiography is particularly well suited to help to solve some of the difficulties encountered.
Digital radiography is a kind of X-ray imaging, where digital X-ray sensors are used instead of traditional photographic films. Two different systems of digital radiography do exist so far: “computed radiography” and “digital radiography”.
The first one, so called CR, uses photo-stimulable phosphor plates instead of a film. Its major advantage is that you can still use your present X ray systems and just change your cassettes. After X-ray exposure, the sheet is placed in a special scanner where the latent formed image is retrieved point by point and digitalized, using laser light scanning. The digitalized images are stored and displayed on the computer screen. This method is halfway between old film-based technology and current direct digital imaging technology.This is not much faster than film processing.
The second one, DR, requires the use of a newer X ray system with a digital integrated detector. At the moment, this last option is still more expensive but helps by mproving the workflow (it is no longer necessary to handle the cassettes).

One of the major advantages of digital radiography is the ability to process the images after they have been recorded (rather than performing several shots before being satisfied) : you can modify the darkness, the contrast, you can change to positive, rotate it to the right, turn it around, upside down, you can also focus better on details, zoom, improve the contrast in a specific window on a specific organ, you can measure an egg, for example, and finally select the best picture you worked on.
This ability to change and optimize the contrast and to enhance visibility of detail is of great value. Moreover, it enables the viewing of images within seconds and to share them electronically with colleagues.

Immediate observation of radiographic images.
Charge-coupled devices or CCDs provide immediate viewing. However, phosphorous-plate technology requires placement of the irradiated sensor in a processing device to scan it and put the information into a computer so that the image can be viewed. Immediacy of viewing the image is a significant clinical advantage.

Ability to enhance images.
How many times have you looked at a radiographic image and thought that it needed to be lighter or darker, or that you would like the image to be somewhat larger? Digital radiography allows the clinician to change contrast (to lighter or darker), enlarge images, place color enhancements or superimpose various textures on images. All of these changes of the original image facilitate easier detection of some suspected anomalies.

Data storage.
Compared to conventional radiography, it is amazing to observe how much data can be stored in the relatively miniscule space occupied by a computer, and how easily and rapidly the data can be retrieved.

No more developing solutions.
One of the less desirable tasks in veterinary practice is maintaining and changing the radiographic developing and fixing solutions and keeping the developing devices in a functional state. In digital radiography, the tasks are eliminated, along with the dark-room. The problems of odors and stains from the developing and fixing solutions and the space occupied by the developing devices are thus eliminated.

Communication with other practitioners.
One of the most useful advantages of digital radiography is the ability it gives clinicians to send images to other practitioners in a matter of minutes. There are various ways to send an image, but the commonly used e-mail method is one of the easiest.

Less radiation.
The reduction in radiation offered by digital radiography allows multiple images for the same radiation exposure involved in a single image obtained via conventional radiography. This reduction in radiation is especially important for radioprotection.

To sum up, 3 main advantages :
- time saving because no chemical processing,
- ability to digitally transfer and enhance images,
- safety because less radiations are used to produce images of similar contrast to conventional radiography.

Table 1: Radiographic localisation of Testudines internal organs (from Frye, 1991; Hernandez-Divers, 2001; Silverman *In* Mader, 2006).

Skeleton	**The skull and the limbs are visible only if the neck is extended out of the shell and the limbs stretched out.** The scapular and pelvic girdles are covered by the shell. The vertebrae may be visualised from a latero-lateral angle. Shell osteoderms as well as possible plastron joints are clearly visible from a dorso-ventral angle.
Respiratory tract	The tracheal bifurcation and the two principal bronchi are difficult to visualise from the three angles. They can sometimes be seen in cross section from a dorso-ventral or latero-lateral angle. The lungs are attached to the inner surface of the carapace, clearly visible only from a dorso-ventral or latero-lateral angle. The pulmonary fields are visible from a dorso ventral angle only in very fat turtles or turtles with a pneumopathy that modifies the radiological opacity of the pulmonary parenchyma.
Digestive tract	The digestive tract is difficult to distinguish from other viscera. The stomach is located on the left, the intestinal loops, filled with food, tricholiths or gas may be visualised on a latero-lateral view, slightly obscured by the pulmonary fields.
Heart and large blood vessels	The heart silhouette is obscured by the pectoral girdle. The large vessels at the base of the heart are not visible unless they are mineralised.
Liver and spleen	The liver can not generally be visualised from the three angles. In the case of hepatomegaly, the lungs and intestinal loops are compressed dorsally.
Genito-urinary tract	Kidneys are in caudal position in the coelomic cavity, between the lungs, the intestines and the female genital system. Kidneys are visible only if hypertrophied. Bladder is visible only in the case of urolithiasis. The genital system cannot be visualised unless the oviducts contain calcified eggs.

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