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Contents

Diagnostic Imaging of the Respiratory System in Exotic Companion Mammals

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KEYWORDS

• Respiratory system • Thoracic imaging • Rabbit • Guinea pig
• Chinchilla • Prairie dog • Rat • Ferret • Skunk

The level of care for smaller companion mammals has increased significantly during the past few years. Although not truly exotic, rabbits, rodents, ferrets, and other less common mammal species, including artiodactyls and marsupials, were grouped as undefined, and separate from traditional mammalian pets (dogs and cats). Today, exotic companion mammals represent this group and are acknowledged as a specific area of zoologic medicine. Continuing education is encouraged and supported by specific associations, such as the Association of Exotic Mammal Veterinarians and two dedicated boards of specialties: the American Board of Veterinary Practitioners and the European College of Zoologic Medicine.

Owner demands for a higher level of care is increasing dramatically. Because most of these patients are small (less than 2 kg), this represents a great challenge, in particular for the field of diagnostic imaging.

In addition to routine imaging modalities, such as radiography, oral endoscopy, and to a lesser degree ultrasonography, more diagnostic imaging, including advanced endoscopic techniques, computed tomography (CT), and magnetic resonance (MR), have become available. Many of these techniques are extrapolated from dog and cat medicine, but advances in technology also make them effective for smaller mammals.[1]

This article reviews the 5 main diagnostic imaging modalities currently available for investigation of the respiratory system of exotic companion mammals: radiography, ultrasonography, endoscopy, computed tomography, and magnetic resonance.

The authors have nothing to disclose.

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Cardiac disease is part of thoracic imaging and can affect the respiratory system. Nevertheless, cardiology is a specific branch of internal medicine and it is classified separately from thoracic imaging or respiratory disease, and for this reason it will not be discussed in detail in this article.

RADIOGRAPHY

Radiography is the mainstay of diagnostic imaging of the respiratory system, in particular of the thorax and lower respiratory tract, and should be considered the first step in an imaging diagnostic trial. Starting from the information provided by the radiographic examination, further indications for other imaging modalities can be obtained.

Because of the small size of exotic mammal patients, obtaining excellent radiographs must be considered a priority. Most standard radiographic equipment is effective for small exotic mammals. Many factors are involved in the process of taking radiographs, but the two most important are the proper combination of cassette and film, and optimal patient positioning.[2,3]

Mammography film is an ultraslow-speed film used with specific cassettes that include a low-speed intensifying screen. They provide good detail, providing a sharp, nongrainy image, and are therefore especially advantageous in small or very small mammal patients.[2] Despite the fact that low-speed screens and films require more exposure than regular screen/film (including longer exposure time for low-powered radiograph machines), they are rarely affected by patient motion caused by physiologic breathing movements.

Because of small size, behavior, and proper patient positioning, general anesthesia is often required to obtain quality radiographs useful for diagnosis.[3] Critical patients in respiratory distress for which anesthesia represents increased risk may benefit from sedation. Protocols for anesthesia and sedation have been reported elsewhere.[4,5] Manual restraint is rarely an option because of excessive stress during handling.[3] On the other hand, sedation and anesthesia might affect radiographic interpretation because of possible artifacts of pulmonary or cardiac imaging.[3]

The two standard views for radiographic study of the thorax are the latero-lateral and the ventrodorsal (or dorsoventral).[2,3,6] For the latero-lateral projection, patients are placed in right or left lateral recumbency. The thoracic limbs must be extended cranially to prevent superimposition of the brachial muscles over the mediastinal portion cranial to the heart.[2,6] This positioning is important for selected species with short chest lengths, such as prairie dogs, and less critical for other species, such as ferrets. Most common small mammal species do not have a round chest; therefore, lifting of the sternum to prevent oblique artifacts is not a special concern. Even if the radiograph will show superimposition of each hemithorax, the image of the hemithorax leaning directly over the cassette will be more detailed. For this reason, both left-to-right and right-to-left lateral projections should be obtained. This practice is important for several intrapulmonary or extrapulmonary diseases, such as lung or pleural metastasis and pleural effusion. Proper collimation of the radiographic beam is another important factor. The image of the thorax should include all the ribs; therefore, it will include the diaphragm and the cranial portion of the abdomen. More appropriately, the frame for the respiratory system should be enlarged more cranially, to include the cervical portion of the trachea.[2]

The ventrodorsal view is obtained with patients placed in dorsal recumbency.[2,6] The thoracic limbs are extended cranially to prevent superimposition of the scapulae on the lung fields. This position is more stressful for patients in respiratory distress; therefore, the sternal recumbency for the dorsoventral projection may be preferable for selected patients. Optimal symmetry is critical for the sagittal view, and in authors' experience this is easier to obtain from the ventrodorsal projection. Also, the dorsoventral projection makes cranial extension of forelimbs more difficult.

Radiographs of the nasal cavities are collected with the 5 standard projections of the skull in rabbits and selected rodent species: lateral, ventrodorsal or dorsoventral, right-to-left oblique, left-to-right oblique, and rostrocaudal.[2] They are particularly advantageous when disease of the nasal cavity is secondary to acquired dental disease. In the case of ferrets and other larger carnivore species, open-mouth projections and intraoral films can be used.[2]

Digital systems for radiographic imaging are becoming more and more popular and affordable. Basically, there are 2 digital systems: computed radiography, also named "indirect digital radiography," and direct digital radiography.[2] In the first case, digital detectors are included in the cassette and standard radiographic equipment can be adapted. The cassette is then processed by a dedicated machine and software. Direct digital systems require a specific digital radiographic unit and they send digital information directly to the computer without a reading step.

Digital systems offer several advantages and disadvantages compared with traditional films, and thorough discussion is beyond the purpose of this article. From the visual standpoint, digital radiography allows easier and more flexible adjusting of the gray scale, whereas proper contrast using mammography films depends on the exact setting. Minimal variations can affect the final image of soft-tissue intrathoracic structures, and when suboptimal, the radiograph should be repeated. Minimal variations in the gray scale are critical for visualization of lungs, bronchi, great vessels, and mediastinum, which is why digital radiography might be preferable to mammography films for thoracic imaging, especially for average-sized exotic mammals, such as rabbits, ferrets, skunks, guinea pigs, and prairie dogs. On the other hand, most digital systems do not have a specific high resolution, and the analogic view of a mammography films still remains significantly superior in regard to detail. This superiority is why, in the authors' opinion, mammography films are the best option for thoracic imaging of smaller mammals, such as chinchillas, rats, other small rodent species, hedgehogs, and sugar gliders.

No artifacts or foreign objects should hamper visualization of normal and abnormal anatomic structures; therefore, materials used for optimal positioning of patients (foam positioners, adhesive tape) should be completely radiotransparent, and other monitoring devices (electrocardiogram clips, Doppler) should be properly positioned or temporarily removed. Positioning of the endotracheal tube in patients under general anesthesia is also questionable. Ideally, thoracic radiographs should be taken immediately after induction of anesthesia while oxygen and additional inhalant anesthetic are administered through a facemask, especially in obligate nasal breather species. Endotracheal (ET) intubation should be performed immediately after radiographs are obtained, when general anesthesia must be continued for other reasons. Endotracheal intubation should be evaluated for each patient.

Common indications for collection of diagnostic radiographs of the respiratory system in single species are listed in **Table 1**, and examples of normal and abnormal patterns are shown in **Figs. 1–10**, **15–18**.

ULTRASONOGRAPHY

Conduction of ultrasound is enhanced by fluids and hampered by gas. For this reason, ultrasonography of the thorax is difficult because of the presence of air in the lungs, and does not represent the diagnostic imaging of choice. Nevertheless,

Table 1
Common indications for five diagnostic imaging modalities of respiratory system in selected exotic companion mammal species

		Rabbit	Guinea Pigs, Chinchillas, Degus	Prairie Dogs, Squirrels	Rats	Ferrets, Skunks
Radiography	Nasal cavities	Rhinitis or empyema of the nasal cavity/ maxillary recess	Rhinitis or empyema of the nasal cavity	—	—	Rhinitis
		—	—	Compressive acquired dental disease (pseudo-odontoma)	—	—
		—	Space-occupying mass (elodontoma)	—	—	—
	Esophagus	—	—	—	—	Megaesophagus
	Lungs	Bronchopneumonia, intrapulmonary abscesses	Bronchopneumonia, intrapulmonary abscesses	—	Bronchopneumonia, intrapulmonary abscesses	Bronchopneumonia
		Metastasis	—	—	—	Metastasis
	Mediastinum	Mediastinal mass (thymoma, lymphoma, thymic lymphoma)	Mediastinal mass	—	Mediastinal mass (lymphoma)	Mediastinal mass (lymphoma)
		Pleural effusion	Pleural effusion	Pleural effusion	Pleural effusion	Pleural effusion
		Pneumothorax	—	—	—	Pneumothorax
		Diaphragmatic hernia	—	—	—	Diaphragmatic hernia
		(*Cardiac disease*)	(*Cardiac disease*)	(*Cardiac disease*)	(*Cardiac disease*)	(*Cardiac disease*)
Ultrasonography	Mediastinum	Mediastinal mass (thymoma, lymphoma, thymic lymphoma)	Mediastinal mass	—	Mediastinal mass	Mediastinal mass (thymoma, lymphoma, thymic lymphoma)
		Pleural effusion	—	—	—	Pleural effusion
		Diaphragmatic hernia	—	—	—	Diaphragmatic hernia
		(*Cardiac disease*)	(*Cardiac disease*)	—	(*Cardiac disease*)	(*Cardiac disease*)

Endoscopy	Rhinoscopy	Rhinitis; empyema of the nasal cavity/maxillary recess	—	—	—	—
	Laryngoscopy	Laryngeal disease	Trauma, foreign body	—	—	Trauma, foreign body
		Aid to endotracheal intubation	Aid to endotracheal intubation	Aid to endotracheal intubation	Aid to endotracheal intubation	—
	Tracheoscopy	Tracheitis	—	—	—	Tracheitis
	Bronchoscopy	Bronchopneumonia	—	—	—	Bronchopneumonia
	Thoracoscopy	Inspection and biopsy of mediastinal mass (thymoma, lymphoma, thymic lymphoma)	—	—	—	Inspection and biopsy of mediastinal mass
Computed Tomography	Nasal cavities	Rhinitis; empyema of the nasal cavity/maxillary recess	Rhinitis; empyema of the nasal cavity/ maxillary recess	—	—	Rhinitis
		—	—	Compressive acquired dental disease (pseudo-odontoma)	—	—
		—	Space-occupying mass (elodontoma)	—	—	—
	Lungs	Intrapulmonary abscesses	Intrapulmonary abscesses	—	Intrapulmonary abscesses	—
		Metastasis	—	—	—	Metastasis
	Mediastinum	Mediastinal mass (thymoma, lymphoma, thymic lymphoma)	Mediastinal mass	—	Mediastinal mass (lymphoma)	Mediastinal mass (lymphoma)
Magnetic Resonance	Nasal cavities	Rhinitis; empyema of the nasal cavity/maxillary recess	—	—	—	—
	Lungs	Metastasis	—	—	—	Metastasis
	Mediastinum	Mediastinal mass (thymoma, lymphoma, thymic lymphoma)	Mediastinal mass	—	—	Mediastinal mass (lymphoma)

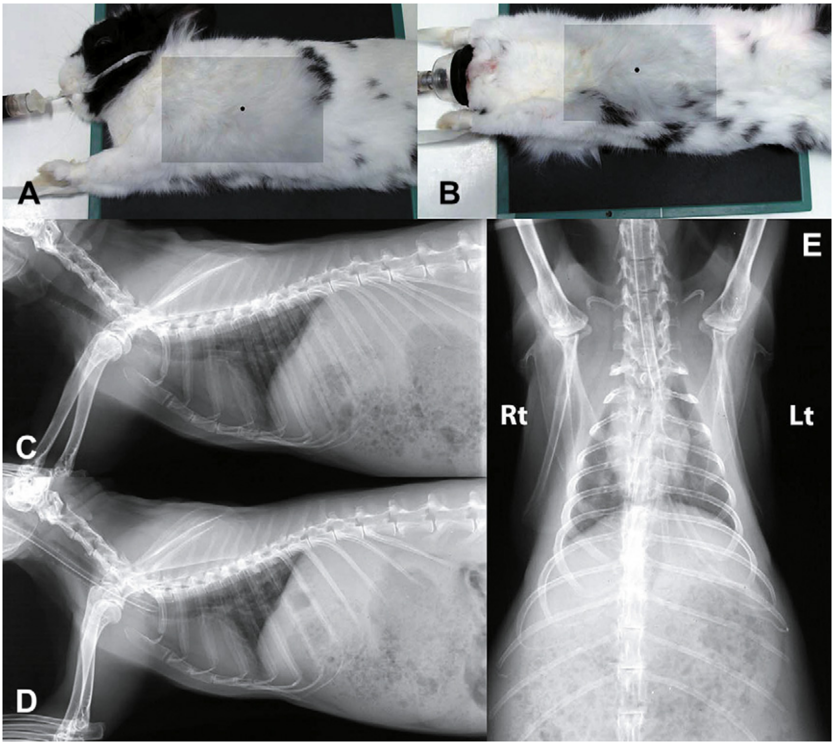

Fig. 1. (*A–E*) Radiography of the thorax in the pet rabbit. (*A*) Lateral projection. The patient is placed in lateral recumbency with the thoracic limbs extended cranially and secured with radiotransparent tape. Both lateral views should be taken. The beam (*dark area*) is collimated over the area of interest. When the cervical tract of the trachea is included in the radiograph, the frame is expanded cranially. The patient is under general anesthesia, and intubated. (*B*) Ventrodorsal projection. The patient is placed in dorsal recumbency with the thoracic limbs extended cranially. Depending on cases, the dorsoventral position can be used, with the patient placed in sternal recumbency. In this example, the patient is under general anesthesia, and oxygen is delivered by face mask. When thoracic limbs are extended, respiration can be impaired especially in dyspneic patients, even if endotracheal intubation is performed. This position should be maintened for only enough time to obtain the radiograph. (*C*) Normal thorax and cervical trachea of a 1.5 kg dwarf rabbit, without intubation. Lateral projection. (*D*) Normal thorax and cervical trachea of a 1.5 kg dwarf rabbit, with intubation. Lateral projection. (*E*) Normal thorax and cervical trachea of a 1.5 kg dwarf rabbit, with intubation. (*From* Vittorio Capello, DVM; with permission.)

ultrasonography may be useful as an adjunct to radiology when fluids or solid densities are present within the thoracic cavity.[3,7]

The use of a high-frequency (7.5–12.0 MHz) probe with a small footprint is critical for optimal results in small exotic companion mammals.[7–9] Other features, such as visualization of both B and M mode, high frame rate, and color Doppler function, are especially useful for echocardiography.

A good ultrasound device should also have a digital recording system.[8]

Fur interferes with ultrasound imaging, so furry patients must be properly shaved before examination. Because small exotic mammals are prone to hypothermia because of their high surface/volume ratio, shaving should be minimized.[7] A small

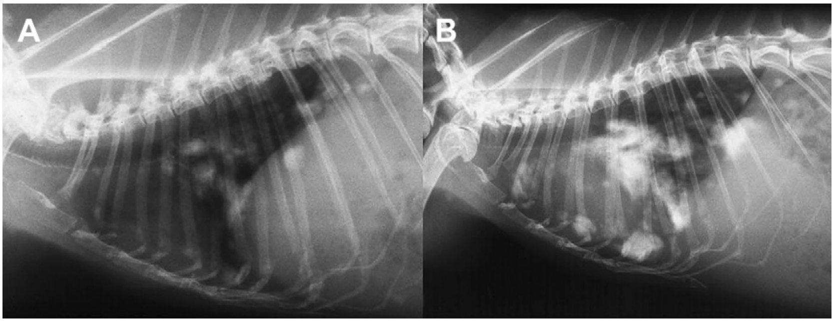

Fig. 2. (*A*, *B*) Pulmonary metastasis from uterine adenocarcinoma in a 7 year old rabbit. (*A*) At the time of diagnosis respiratory symptoms were not detectable. (*B*) Three month later, the patient is showing mild respiratory symptoms. (*From* Vittorio Capello, DVM; with permission.)

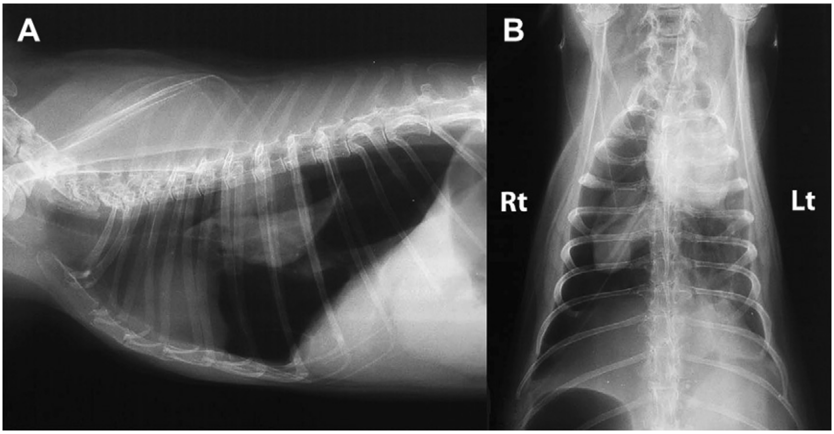

Fig. 3. (*A*, *B*) Pneumothorax in a 8 year old male, 2 kg pet rabbit. (*A*) Lateral projection. A collapsed lobe is visible, surrounded by a large amount of gas in the pleural space. (*B*) ventrodorsal projection. Pneumothorax is lateralized on the right side because radiodensity is present in the left hemithorax. History was unremarkable, and thoracocentesis was unrewarding. The owner declined esplorative thoracotomy. (*From* Vittorio Capello, DVM; with permission.)

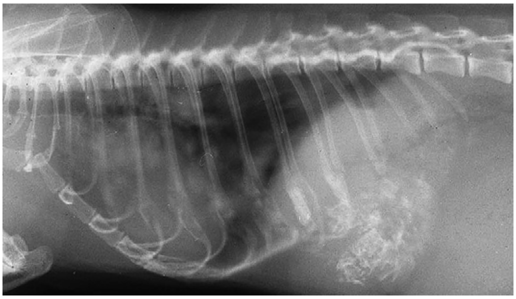

Fig. 4. Pulmonary metastasis from hepatic neoplasia in a 7-year-old female prairie dog. (*From* Angela Lennox, DVM; with permission.)

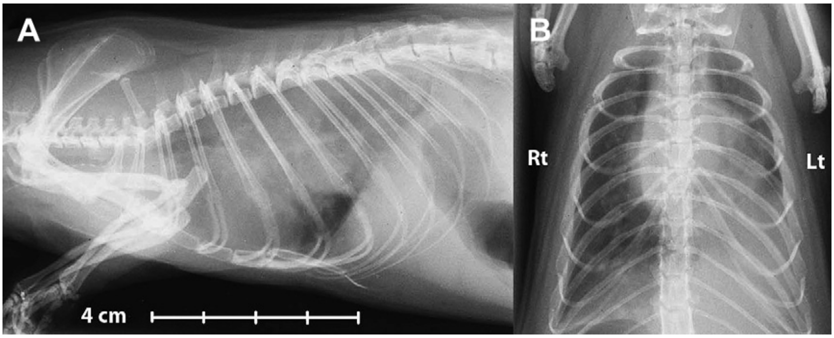

Fig. 5. (*A*, *B*) Pulmonary abscess in a 1.5-year-old female rat with moderate dyspnea. (*A*) Lateral projection. (*B*) Ventrodorsal projection. Increased radiodensity is present at the caudal portion of the left pulmonary lobe. Both standard projections are needed for a proper diagnosis because a single lateral projection might underestimate or overestimate the extent of lesions (as in this case, where disease is clearly unilateral). The left lung of rats is not divided into lobes (the right lung presents 3 lobes),[26] which explains the uniform pattern of radiodensity on the lateral projection. High-quality radiographs are necessary for proper diagnosis in small patients. (*From* Angela Lennox, DVM; with permission.)

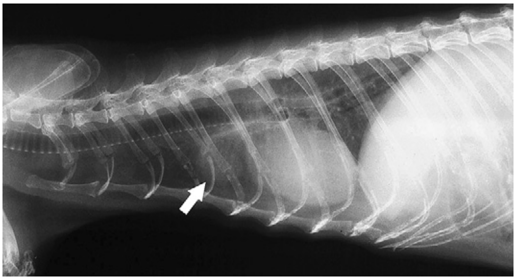

Fig. 6. Enlarged mediastinal lymph node (*arrow*) in a 7-year-old male ferret affected by lymphoma; lateral projection. Normal radiographic appearance of the heart can be evaluated in this radiography. The ferret heart is located more caudally than in the cat or dog, between T5-T8, and between the fifth the seventh intercostal space. The heart shadow is slightly globoid and is normally slightly elevated from the sternum because of the presence of fat in the pericardial ligament.[9] (*From* Vittorio Capello, DVM; with permission.)

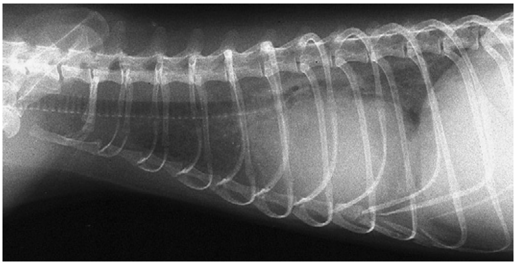

Fig. 7. Dilated cardiomyopathy in a male ferret; lateral projection. Radiographic abnormalities are represented by cardiomegaly, rounding of the cardiac apex, and narrowing of the pericardial space between the heart and the sternum. (*Reprinted from* Capello V, Lennox AM. Radiology of exotic companion mammals. Wiley-Blackwell Publishing, 2008; with permission.)

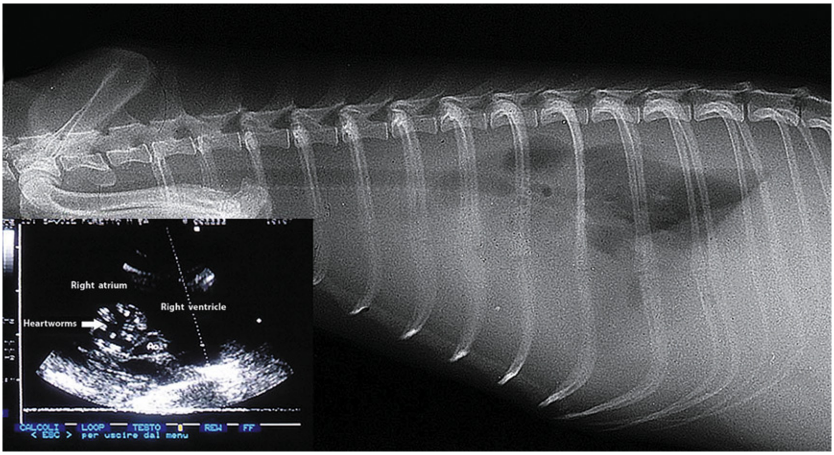

Fig. 8. Pleural effusion in a female ferret, lateral projection. The caudal lung lobes are surrounded by fluid opacity and are partially collapsed. The ventrodorsal projection (not presented here) confirmed bilateralism. Pleural effusion was secondary to heartworm disease, suspected at ultrasonography (*insert*) and confirmed at necropsy. (*Reprinted from* Capello V, Lennox AM. Radiology of exotic companion mammals. Wiley-Blackwell Publishing; 2008; with permission.)

area on both lateral sides of the thorax is usually enough for proper scanning. Water-soluble conduction acoustic gel should be warmed before application to reduce sensitivity and possible hypothermia, and should be dried off after the examination to prevent excessive self-licking.[8] Alcohol should be avoided for conduction or used in minimal amount and carefully washed.

Manual restraint is possible for most rabbits, ferrets, and tame rodents, such as guinea pigs and rats. The technique for restraint differs depending on the species

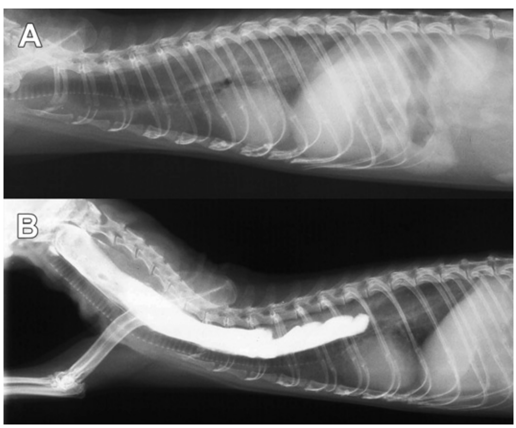

Fig. 9. (*A*, *B*) Megaesophagus in a female ferret. (*A*) Survery radiograph, lateral projection. Radiotransparency of the craniodorsal mediastinum, severe radiopacity of the lungs and deflection of the trachea are radiographic abnormalities suggestive of megaesophagus. Chronic weight loss and regurgitation were also present. (*B*) Lateral projection, after administration of positive contrast medium (barium sulfate). Megaesophagus is confirmed. (*Reprinted from* Capello V, Lennox AM. Radiology of exotic companion mammals. Wiley-Blackwell Publishing; 2008; with permission.)

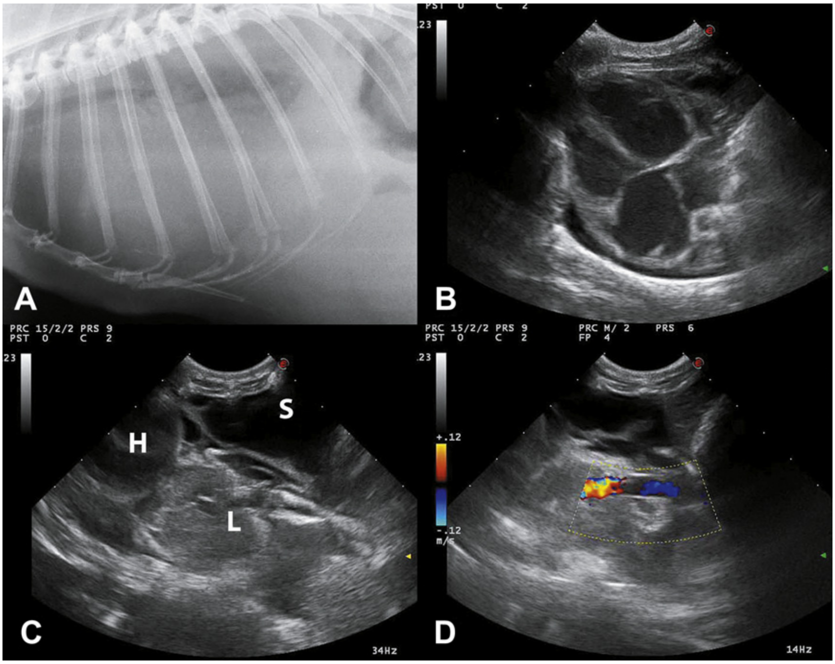

Fig. 10. (*A–D*) Diaphragmatic hernia of liver lobes in a 9 year old male lop rabbit. (*A*) Survery radiograph of the thorax, lateral projection. The caudal margin of the cardiac shadow and the diaphragmatic line are not visible. Diffuse pleural effusion covers the lung lobes. (*B*) Short axis "four chamber" view. Both pericardial and pleural effusion are present. (*C*) A liver lobe (L) is present just caudal the heart (H). Dorsal to the liver is the fluid filled stomach (S). Ultrasonographic abnormalities were diagnostic for diaphragmatic hernia. (*D*) Color Doppler ultrasonography demonstrated the presence of large vessels, confirming herniation of part of the liver. ((*A*) *From* Vittorio Capello, DVM; with permission; and (*B–D*) Oriol Domenech, DVM; with permission.)

and should be performed with extreme care by an experienced technician, especially when imaging patients who are dyspneic. Recumbency is preferably dorsal for ferrets and lateral for rabbits, considering that significant respiratory compromise may occur if a rabbit is placed in dorsal recumbency when the stomach or cecum is full.[7] Positioning patients on a slanted table or elevating the thorax while holding patients can significantly reduce the risk of respiratory compromise during imaging.

When manual restraint is not safe, or not feasible for smaller species, ultrasonography can be performed with sedation or with general anesthesia if required. Scanning planes are longitudinal and transverse. The most useful scanning planes for echocardiography are right and left parasternal long-axis 4-chamber view. B mode is used mostly to examine the mediastinum.[8]

Common indications for ultrasonography of the thorax in single species are listed in **Table 1**, and examples of abnormal patterns are shown in **Figs. 8, 10**, **17–18**.

ENDOSCOPY

Unlike other diagnostic imaging, endoscopy (meaning *to view inside*) provides direct visualization of internal anatomic structures directly or indirectly related to a real or

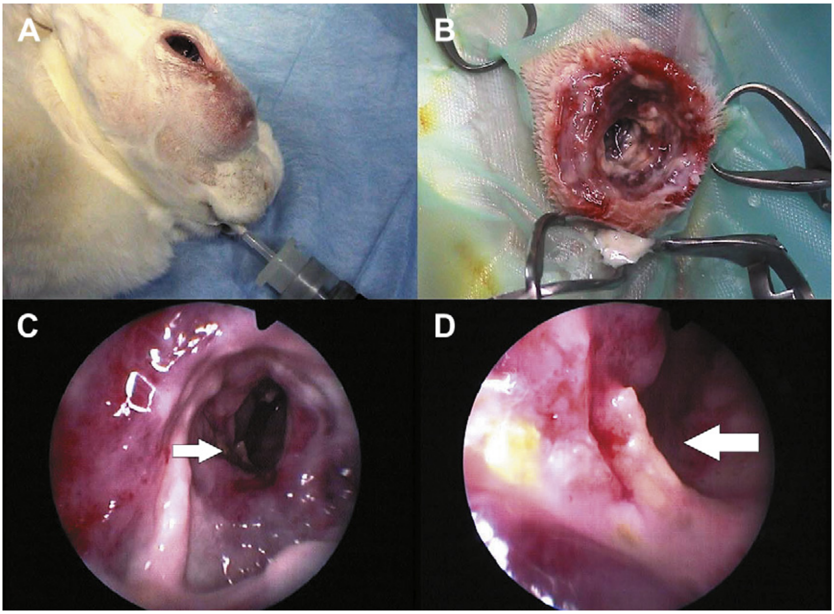

Fig. 11. (*A–D*) Rhinoscopy of the maxillary recess from a lateral approach in a pet rabbit. (*A*) A large facial abscess in a female dwarf rabbit prepared for surgery. The abscess originated from maxillary cheek teeth, and cause empyema of the alveolar bulla and the maxillary recess. (*B*) Intraoperative excision and debridement of the abscess. This surgical aprroach is actually a lateral rhinostomy, entering the maxillary recess through the perforated surface (*facies cribrosa*)[26] of the maxillary bone. (*C*) Rhinoscopy of the maxillary recess. The cavity in the background is the alveolar bulla. An ankylotic fragment of maxillary cheek tooth is till present after intraoral extraction (*arrow*). (*D*) The fragment of reserve crown, at the borderline between alveolar bulla and maxillary recess. This fragment had been missed during stomatoscopy, because inspection of the alveolar bulla is particularly difficult using a rigid endoscope. (*From* Vittorio Capello, DVM; with permission.)

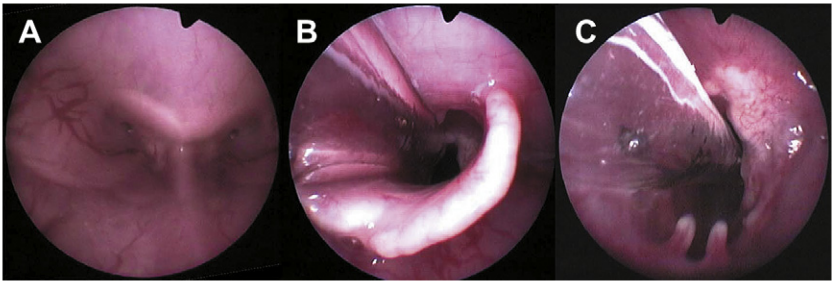

Fig. 12. (*A–C*) Endoscopic-guided orotracheal intubation in a 1.5-kg pet rabbit. (*A*) Normal appearance of the caudal portion of the oropharynx. The physiologic position of the epyglottis in obligate nasal breather species is beneath the caudal margin of the soft palate. The rhinopharynx is separated by the oropharynx. (*B*) Appearance of the epiglottis after the margin has disengaged from the caudal margin of the soft palate. the tip of a transparent, 2 mm uncuffed endotracheal tube is directed to the laryngeal opening. The aritenoid cartilages are visible in the background. (*C*) The endotracheal tube tube has been introduced in between the two arytenoid cartilages, and deeper inside the trachea. The corniculate processes are visible ventrally. (*From* Vittorio Capello, DVM; with permission.)

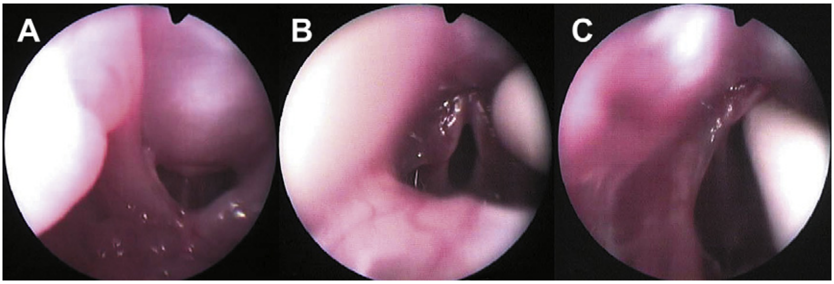

Fig. 13. (*A–C*) Endoscopic-guided orotracheal intubation in a 1-kg prairie dog. (*A*) Orotracheal intubation of intubation of obligate nasal breather rodent species (Guinea pig, Chinchilla, Degus, Prarie dog) is even more challenging than rabbits because of smaller size and because of the presence of the oropharyngeal ostium. The epiglottis is visible in the background behind the ostium. (*B*) The tip of the 2.7 mm, 30° view endoscope passed beyond the oropharingeal ostium, and the disengaged epiglottis. The white tip of a 1.5 mm uncuffed endotracheal tube is visible facing the arytenoids. (*C*) The endotracheal tube has been inserted between the arytenoids and inside the trachea. When feasible, the over-the-endoscope technique is another option for orotracheal intubation, using a larger tracheal tube and a semiflexible endoscope.[13,14] (*From* Vittorio Capello, DVM; with permission.)

virtual body cavity.[10] For this reason, the number of organs that can be evaluated is more limited.

Still, endoscopy carries several diagnostic and therapeutic advantages compared with other methods of diagnostic imaging: the possibility of great magnification of internal structures, the ability to collect biopsies, and the chance for minimally invasive endosurgery in selected cases.[10]

Detailed features of endoscopic instrumentations are reported.[10] The most common used in exotic mammal medicine and surgery are the 2.7-mm system and the 1.9-mm telescope. Both have dedicated sheaths, many with ports and instrument channels. The 1-mm semirigid miniscope is a useful adjunct for smaller exotic mammals.

Indications for the use of endoscopy for the respiratory system of exotic companion mammals are represented by rhinoscopy, tracheoscopy, and bronchoscopy. The endoscope also provides a critical aid for intubation.[11–14] Last, but not least, the use of thoracoscopy has been reported in smaller companion mammals, such as rabbits and ferrets.

Rhinoscopy is mostly performed in rabbits because rhinitis is common in this species. Patients are intubated and placed in sternal recumbency with the head slightly flexed.[11] Position of the head is critical to facilitate reflux of saline used for flushing and to reduce the possibility of inhalation of fluids from around the uncuffed ET tube. Depending on rabbit size, the 2.7-mm rigid endoscope may be used (for rabbits more than 2.0–2.5 kg), otherwise the 1.9-mm is needed for smaller patients. Entering the ventral meatus, the ventral and middle nasal conchae can be scoped. In larger rabbits, it is possible to visualize the rhinopharynx more caudally.[11] Rhinoscopy can also be performed from sites other than the natural nasal openings. Rhinotomy (ie, minimal, temporary rhinostomy) allows inspection, collections of biopsy specimen, and even debridement from a dorsal approach.[11,15] Another possible application is when chronic, septic rhinitis is secondary to advanced dental disease of maxillary cheek teeth. Facial swelling in the zygomatic area can be secondary to empyema of the maxillary recess[16] (in other sources termed the maxillary sinus[17,18]

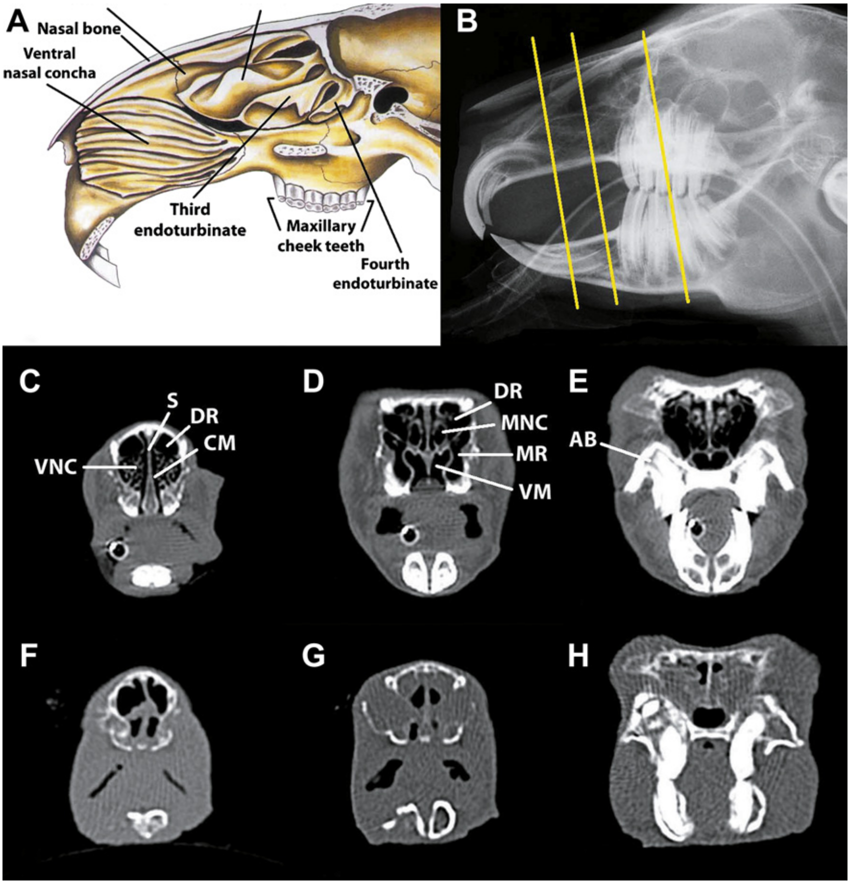

Fig. 14. (*A–H*) Computed tomography of normal and abnormal nasal cavities of the pet rabbit. (*A*) Anatomy of the nasal cavities and nasal conchae, sagittal view (*modified from* Popesko). (*B*) Radiograph of the skull of a normal rabbit, lateral projection, adapted as a scout view for CT axial views. (*C–E*) Normal nasal cavities. AB, alveolar bulla; CM, common meatus; DR, dorsal recess (otherwise named conchal sinus)[17]; MNC, middle nasal concha; MR, maxillary recess[16]; S, nasal septum; VM, ventral meatus; VNC, ventral nasal concha. (*F–H*) Empyema of the nasal cavities (including empyema of the maxillary and other recesses) following end-stage acquired dental disease. Nasal cavities are almost completely filled by radiodense, thick pus. The alveolar bullae are deformed. General bone lysis is present because of underlying metabolic bone disease. ([*A, B, F–H*] *From* Vittorio Capello, DVM; with permission; and [*C–E*] Angela Lennox, DVM; with permission.)

or paranasal sinus[11]), which is part of the nasal cavity and lies just cranial to the alveolar bulla. During an extraoral approach to the abscess and the focus of osteomyelitis, the endoscope may provide critical aid in detecting fragments of reserve crowns of cheek teeth and it can be used to enter the maxillary recess.

Inspection of the larynx and the first portion of the trachea can be performed using a rigid 2.7-mm telescope with the intraoral approach while keeping the head of the rabbit extended. Small, flexible endoscopes must be used for examination of the entire trachea and main bronchi.

Few preliminary experiences have been reported regarding thoracoscopy of exotic companion mammals.[11] Indications are related to inspection and biopsy of intrathoracic masses when definitive diagnosis was not achieved with other diagnostic tools. The single-entry approach can be paraxyphoid for most rabbits, and intercostal for rabbits weighing more than 2 kg and for ferrets.[11]

Common indications for endoscopy of the respiratory system in single species are listed in **Table 1**, and examples of normal and abnormal patterns are shown in **Figs. 11–13**.

COMPUTED TOMOGRAPHY

The basic principles of computed tomography as an advanced radiology technique make it ideal for both the upper and lower respiratory tract. In fact, the most important advantage of CT when compared with traditional radiography is the capability to

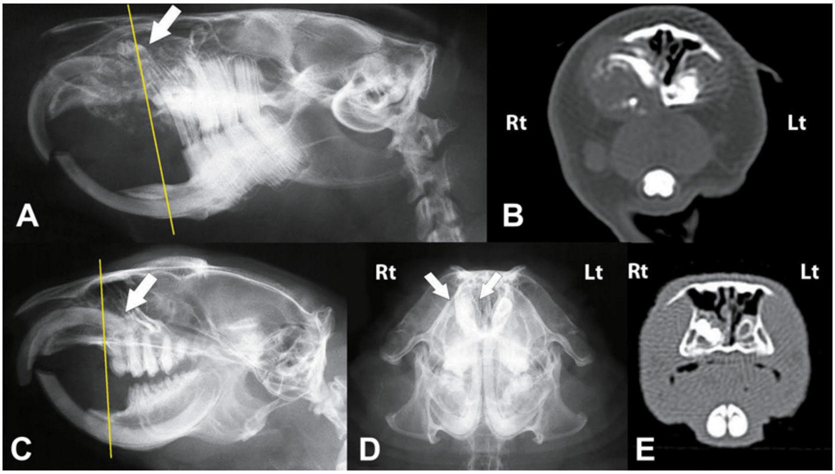

Fig. 15. (*A–E*) Diagnosis of odontomas in rodent species. (*A, B*) Elodontoma of a maxillary cheek tooth in a guinea pig. (*C–E*) Pseudo-odontoma of a maxillary incisor tooth in a prairie dog. (*A*) Skull radiograph, lateral projection. Abnormal and irregular radiodensity of the infraorbital area is present surrounding the apex and the reserve crown of a maxillary CT1 (*arrow*). Periosteal soft radiodensity is also visible ventrally to the palatine bone. The lateral radiograph has been used as scout view for the CT axial view (*yellow line*). (*B*) Computed tomography of the skull, axial view. Abnormal radiodensity, bone lysis, deformed reserve crown of maxillary CT1, and involvement of the nasal cavity with deviation of the nasal septum are present on the right side. Elodontoma (invasive odontogenic neoplasia) was ultimately diagnosed at necropsy. (*C*) Skull radiograph, lateral projection. Malocclusion of incisor teeth and apical deformity of one of them are visible (*arrow*). The other projection demonstrated unilateral pseudo-odontoma (space-occupying odontogenic dysplasia) on the right side. Mild respiratory symptoms were present at this stage. (*D*) Skull radiograph, rostrocaudal projection. Apical deformity of the right maxillary tooth (*arrows*). The lateral radiograph has been used as scout view for the CT axial view (*yellow line*). (*E*) Computed tomography of the skull, axial view. Space occupying pseudo-odontoma is visible on the right side, and is especially evident when compared with the transverse section of the normal incisive bone and the incisor tooth. Early diagnosis is critical for treatment of pseudo-odontoma, as well as to determine if disease is unilateral or bilateral. The comparison with the rostrocaudal projection of the radiograph of the skull proves that CT is a superior imaging tool for this specific disease. (*From* Vittorio Capello, DVM; with permission; and (*E*) Alberto Cauduro, DVM; with permission.)

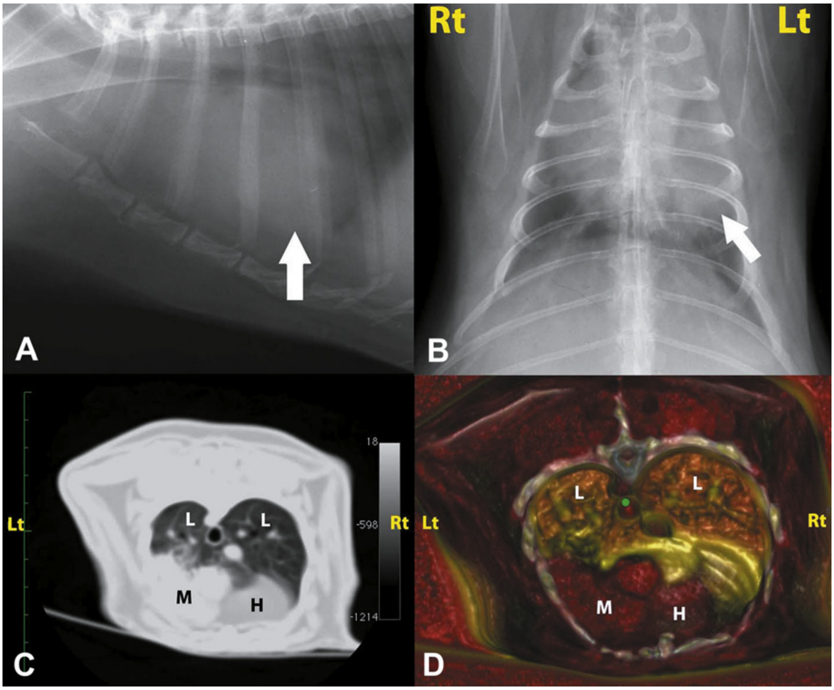

Fig. 16. (*A–D*) Pulmonary abscess in a rabbit. (*A*) Radiograph of the thorax, lateral projection. A single large nodule with moderately increased radiodensity is present (*arrow*). (*B*) Radiograph of the thorax, ventrodorsal projection. The nodule is located on the left lung (*arrow*). (*C*) Computed tomography of the thorax, axial view. It displays the abnormal mass (M), shifting heart (H) on the right side. (*D*) Computed tomography of the thorax, 3-D volume reconstruction. This special rendering provides even more detailed imaging diagnosis, especially for surgical purposes. Diagnosis was confirmed upon ultrasound-guided fine needle aspirate of the mass. (*From* Angela Lennox, DVM; with permission.)

provide images without the superimposition of adjacent anatomic structures.[1] The x-ray tube rotating around the patients and computer obtain multiple, parallel, cross-sectional image slices of the tissues of the patients.[19] Modern helical scanners (where patients are continuously moved toward the gantry) allow shorter scanning time, thin slices, and higher resolution. More help is provided by advanced software, software that is even available free of charge. Raw data can be manipulated and rendered in many different ways, including 2-dimensional multiplanar reformation for the 3 standard planes (axial, lateral, and coronal) and 3-dimensional (3-D) virtual volume and surface rendering.[1,19] All these technical features are critical for small patients.

The same axial view can be visualized adjusting different gray scales (windows). The standard windows display hard tissues, soft tissues, and air.[19] Therefore, CT images of the thorax can be examined for the 3 components, with a special emphasis on lungs and possible mediastinal masses. Contrast medium can be injected intravenously to emphasize soft-tissue abnormalities, if they are supported by sufficient blood supply.[20] CT is superior to traditional radiographs for diagnosis of intrapulmonary disease, such as abscesses in rabbits and rats, or lung metastases. They can be visualized in detail, providing higher-quality diagnosis and prognosis.

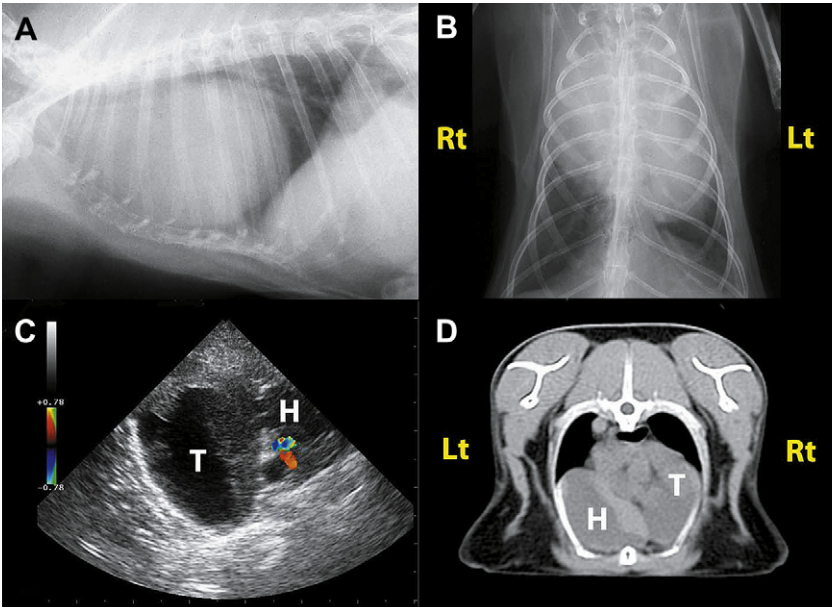

Fig. 17. (*A–D*) Thymoma in an 8-year-old female rabbit. (*A*) Radiograph of the thorax, lateral projection. Abnormal radiodensity is present in the cranial mediastinum, and the cranial margin of the cardiac silhouette is not visible. The trachea is displaced dorsally. (*B*) Radiograph of the thorax, ventrodorsal projection. (*C*) Ultrasonography of the thorax. The mediastinal thymoma (T) was partially cystic, and fluid was drained with thoracocentesis as palliative treatment. H, heart. (*D*) Computed tomography of the thorax, axial view. The thymoma (T) is twice as large as the heart (H). (*From* Vittorio Capello, DVM; with permission; and (*D*) Alberto Cauduro, DVM; with permission.)

Computed tomography of the skull is a critical diagnostic imaging tool also for the nasal cavities, especially in rabbits. Nasal meatuses, nasal septum, turbinates, and maxillary recesses can be visualized in detail; therefore, this diagnostic tool is complementary to rhinoscopy. CT is also critical for diagnosis of space-occupying masses, such as odontomas in rodent species, or for diagnosing masses that compress nasal cavities, such as pseudo-odontomas in prairie dogs.[21]

For CT scanning, patients are usually placed in ventral recumbency, under general anesthesia.[19] The endotracheal tube does not create problems of superimposition as occurs in the case of traditional radiographs.[1] When CT of the nasal cavities is performed, the head is slightly elevated in horizontal position. Proper symmetry is critical for acquisition of images. The scanning plane angle can be adjusted, but it is usually perpendicular to the palatine bone for the head and to the long axis of patients for the thorax.[19]

Common indications for computed tomography of the respiratory system in single species are listed in **Table 1**, and examples of normal and abnormal patterns are shown in **Figs. 14–17**.

MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging (MRI) is a noninvasive imaging modality because it does not use radiation for generating images. Magnetic resonance imaging relies on

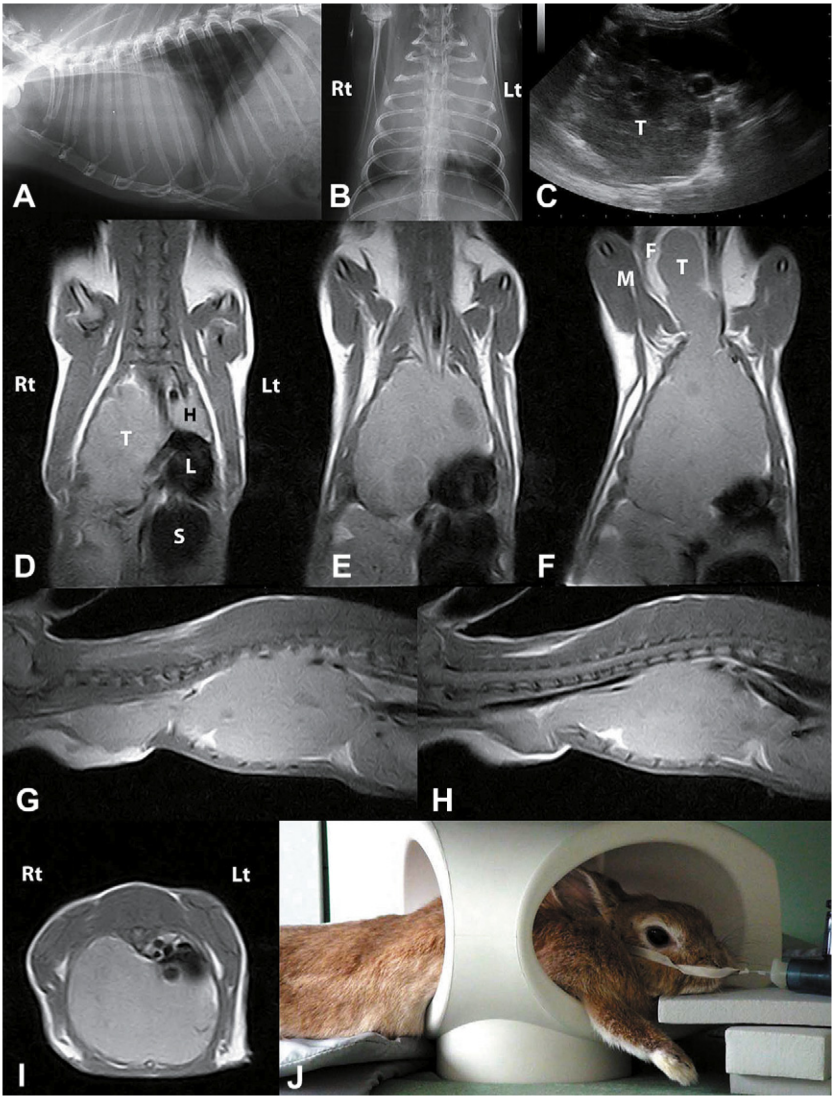

Fig. 18. (*A–J*) Thymoma in a 7-year-old female rabbit. The patient was presented with reduced food intake and mild dyspnea. (*A*, *B*) Radiograph of the thorax, lateral and ventrodorsal projection. Radiographic findings are similar to those presented in Fig. 17. Ultrasonography of the thorax displayed an enormous mass surrounding the heart (T) that occupied most of the mediastinum. (*D–F*) Magnetic resonance of the thorax, coronal views from dorsal to ventral. The heart (H) is displaced on the left side of the thorax, and a single caudal pulmonary lobe (L) is patent. Caudal to the diaphragm is the gas-filled stomach (S), distended because of aerophagy. In the second frame, the thymoma occupies almost the whole thoracic cavity. In the most ventral frame, the mass spreads outside the thorax in the extravisceral space of the neck. Note the specificity of MRI for soft tissues: neoplastic thymic tissue (T), subcutaneous fat (F), and muscles (M) are clearly distinguished. (*G*, *H*) Magnetic resonance of the thorax, lateral views from right to left. The cranial portion of the thymoma is visible cranially to the first rib. The second frame scanning the right hemithorax shows the displaced trachea and the small patent lung. (*I*) Magnetic resonance of the thorax, axial view. The section of the trachea and the small lung lobe are visible. MRI proved to be far superior for diagnosis compared with radiography and ultrasonography, which underestimated the size of the thoracic mass. In larger exotic mammal patients and if proper tesla magnet is available, MR might also be considered superior to CT. (*J*) The patient under general anesthesia and intubated is placed in sternal recumbency inside the magnetic field. (*From* Vittorio Capello, DVM; with permission; and (*D–J*) Alberto Cauduro, DVM; with permission.)

computer interpretation of the movements of hydrogen atoms in the body, in reaction to a strong magnetic field placed around patients.[20,22]

MR represents the diagnostic imaging modality of choice for soft tissues. It is most commonly used for the central nervous system, but other soft tissues can be visualized in detail with superior quality than CT.[20] Images are visualized in the 3 standard planes (dorsal, lateral or sagittal, transverse or axial), but complex manipulation and 3-D volume and surface renderings are not possible.

Patients undergoing MR examination are under general anesthesia and are usually positioned in sternal recumbency.

Two potential disadvantages of MR are resolution (especially for small mammals) and prolonged scanning time.[20] Resolution depends on the available magnet. Low-power magnets capable of field strengths of 0.2 to 0.4 T will produce lower-resolution images than magnetic fields of 1.0 T or higher. Acquisition of MR sequences depends on many technical factors that are beyond the scope of this article, but the average time for rabbit patients can range from 20 to 40 minutes, whereas acquisition time for CT scanning can be less than 1 minute. This timing might present potential risks for critical patients. Because of the long acquisition time, images might be affected by patients' respiratory and cardiac rates, which are higher in small-sized mammals.[22] Actually, this does not represent a concern because they respiratory and cardiac rates are significantly reduced under anesthesia.

The dorsal plane is superior for examination of the lungs and mediastinal structure, but the use of all 3 planes is always recommended for complete evaluation of the thorax.[22]

The lungs appear black because of the presence of air inside the parenchyma, and similar to traditional radiographs and CT, it is easy to visualize soft-tissue intrapulmonary abnormalities, but with superior quality. MR is particularly advantageous for detecting intrapulmonary abscesses of rabbits and rodents, metastasis of tumors, and mediastinal masses (lymphomas and thymomas).[18]

MR provides sufficient resolution to provide detailed diagnosis and prognosis, and to access the potential for surgical treatment. The presence of abnormalities should always be confirmed in more than one plane to avoid overinterpretation of various artifacts.[22]

Surgical excision of thymomas can be feasible if they do not envelope the vasculature of the cranial mediastinum.[22–24] In many cases, the vasculature is simply displaced in a lateral position by the mediastinal mass. In other patients, the mass includes the vasculature, making surgical excision extremely challenging to impossible.[22] Because of a specific affinity for soft tissues, MR represents the diagnostic imaging of choice for this disease.

Thick pus, typical of rabbit odontogenic abscesses, results in signal intensities similar to those from soft tissues. For this reason, MR of the skull for purposes other than central nervous system evaluation has interesting applications in pet rabbits.[16] MR provides excellent information when evaluating rabbits with multiple empyema syndrome affecting one or more cavities (nasal cavities, maxillary recess, diseased alveolar bulla, and tympanic bulla)[16] and in cases of retrobulbar and parabulbar abscesses; imaging is superior to even CT, which is less specific for lower radiodensities. CT remains superior for diagnosis of dental disease and related bone infection, and for this reason CT and MRI of the rabbit skull are best used as complementary tests.[16] Because complementary imaging is not feasible in most cases for practical and financial reasons, the clinical examination and survey radiographs are generally used to guide the clinician in selecting the most appropriate diagnostic imaging test.

Common indications for magnetic resonance of the thorax are listed in **Table 1** and examples of abnormal patterns are shown in **Figs. 18**, **19**.

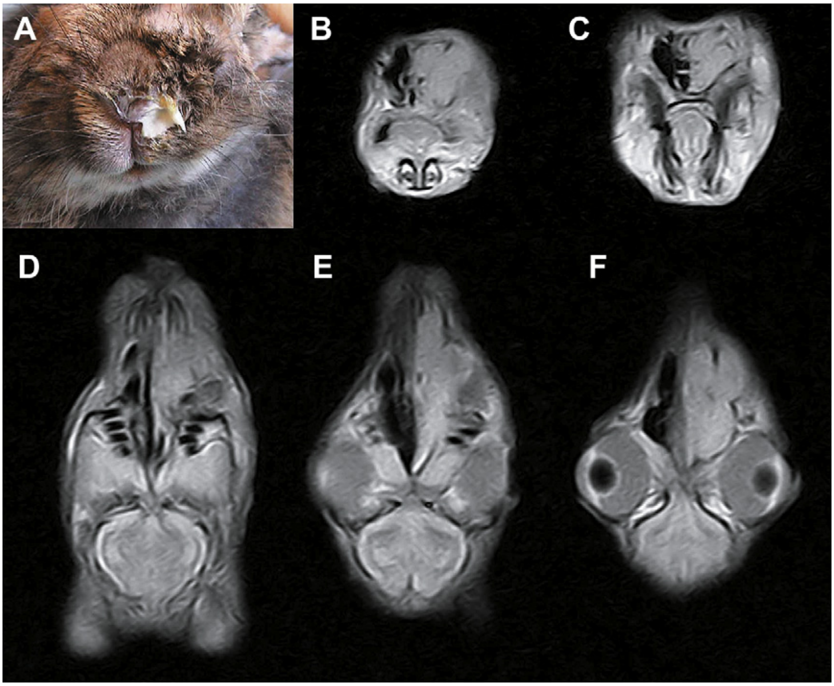

Fig. 19. (*A–F*) Rhinitis and empyema of the nasal cavity in a 2-year-old lop rabbit. (*A*) The rabbit was presented with unilateral thick nasal discharge. (*B*, *C*) Magnetic resonance of the skull, axial view, from rostral to caudal. The left nasal cavity, including the maxillary recess, is filled with pus with a signal intensity similar to that of soft tissues. (*D–F*) Magnetic resonance of the skull, coronal view, from ventral to dorsal. (*From* Vittorio Capello, DVM; with permission; and Alberto Cauduro, DVM; with permission.)

THE FUTURE OF DIAGNOSTIC IMAGING IN EXOTIC COMPANION MAMMALS

Other advanced imaging modalities, already in use in human medicine, may eventually prove beneficial in exotic mammal medicine.[20]

Fluoroscopy may be useful in selected cases for imaging of the intrathoracic tract of the esophagus, when used in conjunction with contrast medium. Fluoroscopy as an aid for surgical removal of heartworms from the ferret cranial vena cava, like in dogs, may not be an option because of patient size.

Nuclear diagnostic imaging involving injection of radioactive isotope includes scintigraphy and positron emission tomography (PET). This imaging modality provides functional information, rather than morphologic information, and should be used in addition to other standard modalities.[20]

Scintigraphy generates an image by detecting the emission of gamma rays from patients. The use of scintigraphy has been reported in a guinea pig affected by hyperthyroidism, but this technique may provide critical information in cases of neoplasia and aid in the detection of metastases.[25,26]

PET combines CT and MR with the use of radioactive nucleotides.[20]

Disadvantages of nuclear diagnostic imaging include the higher radiation dose administered to patients, the fact that patients remain radioactive after the study, few institutes offer this modality, and cost.[20] Diagnostic value of those modalities has yet to be assessed.

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