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ORIGINAL RESEARCH

Computed tomographic features of clinically suspected rhinitis in domestic rabbits (*Oryctolagus cuniculus*)

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Abstract

Background: The aim of this study was to characterise the computed tomographic (CT) findings in domestic rabbits with clinically suspected rhinitis and compare them with CT findings in rabbits without clinical signs of rhinitis.

Methods: CT images of rabbits that underwent a CT of the head were retrospectively reviewed and any CT abnormalities were described. Statistical analysis was performed to detect any association between the CT findings and clinical signs of rhinitis, and also to assess if there was any association between rhinitis and otitis media, otitis externa or dental disease.

Results: Thirty-three of the 133 rabbits included in the study had soft tissue-attenuating material within their nasal cavities and were therefore classified as having CT findings compatible with rhinitis. CT evidence of rhinitis was correlated with the presence of clinical signs of rhinitis and with the presence of otitis media. There was no statistical association between CT evidence of rhinitis and the presence of otitis externa or dental disease.

Limitations: The retrospective nature of the study, small sample size and lack of aetiological confirmation limit the conclusions that can be drawn from the findings.

Conclusion: Clinical signs of rhinitis were associated with CT abnormalities consistent with rhinitis and CT evidence of otitis media. The results of this study provide useful information for CT assessment of the nasal cavities of domestic rabbits and can be used as a reference for the diagnosis of rhinitis in this species.

INTRODUCTION

Upper respiratory tract disease is considered one of the most common diseases in pet rabbits and is a major cause of morbidity and mortality, second only to gastrointestinal diseases, mainly due to the fact that rabbits are obligatory nasal breathers.[1–4] Rhinitis is defined as a pattern of clinical signs resulting from inflammation of the nasal cavity and can be classified as infectious or non-infectious.[5] Infectious rhinitis may be primary or secondary. Primary infectious rhinitis is usually due to bacterial infection, but viral or fungal causes have also been described.[6] Secondary infection may be an extension of infection from other organs, including the teeth, middle ear, inner ear or lower respiratory tract.[6] Non-infectious causes of rhinitis include, but are not limited to, reactions secondary to an exposure to allergens, a foreign body, trauma or a mass. Allergic rhinitis is a diagnosis of exclusion after other causes have been ruled out.[2]

The diagnosis of rhinitis largely relies on the clinical signs, which include nasal discharge (unilateral or bilateral), sneezing, dyspnoea, respiratory distress and increased respiratory rate. Because of rabbits' regular grooming, the presence of matted fur on the medial aspect of the forepaws may be the only sign of rhinitis.[3] Less specific clinical signs have also been reported and include loss of appetite, weight loss and lethargy.[6] As the clinical signs are not always present and are not specific, bacterial culture of the nasal discharge could be performed, but this is not always conclusive. Rhinoscopy is rarely performed because

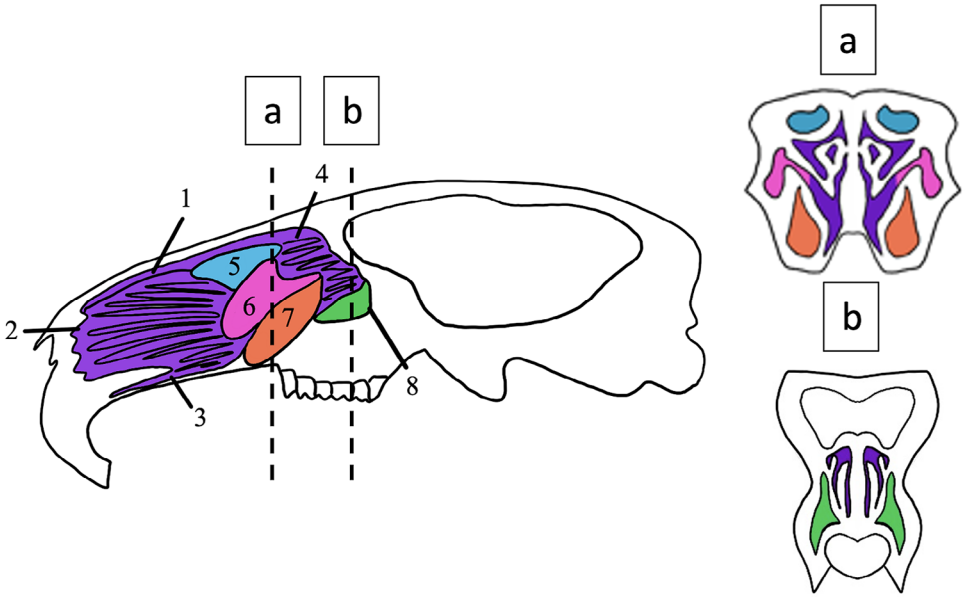

FIGURE 1 Left lateral view of the rabbit skull illustrating the nasal cavities (purple) and paranasal cavities. (1) Dorsal, (2) middle, (3) ventral and (4) ethmoidal nasal meatuses, (5) dorsal conchal sinus, (6) dorsal and (7) ventral recesses of the maxillary sinus and (8) sphenoidal sinus. (a) and (b) Correspond to the transverse views indicated by the dashed lines

very small optics are required. In addition, the complex nasal anatomy of rabbits hampers a complete exploration of the nasal cavities. Diagnostic imaging is a useful and practical tool for the diagnosis of rhinitis. Computed tomography (CT) is considered a more accurate diagnostic imaging modality than radiography in the detection, characterisation and staging of nasal diseases across most domestic species.[3,7–9]

The topography of the nasal cavities of rabbits is complex (Figure 1) and divided into the left and right nasal cavities, which are separated by the nasal septum.[10] Each nasal cavity is divided into four anatomical regions: rostrally, the dorsal, middle and ventral nasal meatuses, and caudally, the ethmoidal meatus. Rabbits also have paired paranasal sinuses that consist of the dorsal conchal sinus, the maxillary sinus and the sphenoid sinus. The dorsal conchal sinus is located caudally to the middle and ventral nasal meatuses, ventrally to the dorsal nasal meatus and rostrally to the ethmoidal meatus. The maxillary sinus is located ventrally and caudally to the dorsal conchal sinus and is divided into a dorsal and a ventral recess. The most caudal sinus is called the sphenoid sinus, which is located dorsally to the nasopharyngeal meatus.[11]

A previous study performed on canine and feline patients showed that CT images with a bone reconstruction algorithm provided the best turbinate definition.[12] Another study described the CT anatomy of the rabbit head.[7] This study highlighted that using the bone window allows identification of the endoturbinates, the nasal meatuses, the conchae and the nasal septum. These studies suggest that CT could be a useful imaging modality in the diagnosis of rhinitis in domestic rabbits because of its excellent spatial resolution even in such small animals. However, to the authors' knowledge, there is no prior study describing the CT findings associated with rhinitis in domestic rabbits.

Therefore, the aim of this study was to describe the CT characteristics of rhinitis in rabbits and determine whether CT evidence of rhinitis is associated with the presence of other diseases, such as dental disease, otitis media and otitis externa.

METHODS

Case selection

Domestic rabbits that underwent a CT examination of the head at the veterinary teaching hospital of the National Veterinary School of Alfort (France) between 1 January 2021 and 1 March 2022 were retrospectively included in the study. If a rabbit had multiple CT examinations performed, only the initial data were included. There were no exclusion criteria.

Medical records review

The rabbits' medical records were retrospectively reviewed, and data extracted included sex, ear carriage (lop-eared or straight-eared), age at the date of the CT examination and clinical signs at presentation. Rabbits were categorised as having clinical signs related to rhinitis when at least one relevant clinical sign (sneezing, nasal discharge, dyspnoea or respiratory distress) was present, regardless of the severity. A clinical sign was considered present when it was either reported by the owner or observed by the attending clinician on the day of the CT.

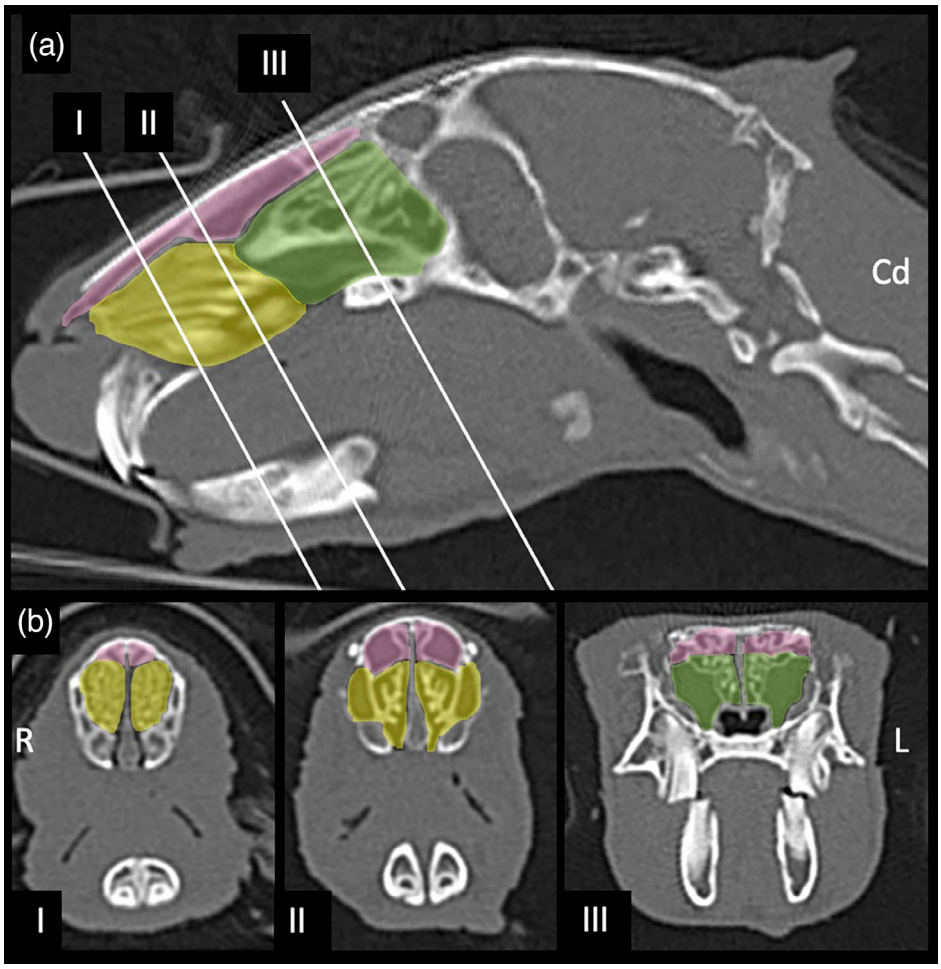

FIGURE 2 Sagittal-plane reconstructed computed tomographic (CT) image of the skull of a clinically normal adult rabbit (a), with white lines (I, II and III) indicating the level and angle of the corresponding transverse images (b). The yellow area corresponds to the ventral part of the nasal cavities, the pink area corresponds to the dorsal part of the nasal cavities and the green area corresponds to the caudal part of the nasal cavities. Window width, 3500 HU; window level, 350 HU; slice thickness, 0.5 mm. Cd: caudal; L: left; R: right

CT examinations and image review

All the images were acquired using an 80-slice CT scanner (Aquilion Lightning SP 80-slice CT scanner, Canon Medical Systems). All the rabbits were either sedated or under general anaesthesia and were positioned in sternal recumbency. The acquisition method included a scan slice thickness of 0.5 mm, 120 kV and variable mA (automatic exposure control). CT images were acquired before and after intravenous injection of non-ionic, iodinated contrast medium (Omnipaque 300 mg/mL; 2 mL/kg, Iohexol, Titolare AIC, GE Healthcare). Images were reconstructed using soft tissue and bone algorithms. A commercial image viewer (Osirix, Pixmeo) with adjustable window width and level was used by a board-certified veterinary radiologist (J.M.) and a specialised intern in diagnostic imaging (A.S.) to review the CT images in transverse, dorsal and sagittal planes using multiplanar reconstruction. The reviewers were not blinded to the final diagnosis at the time of image review.

All images were assessed for the presence or absence of any amorphous fluid or soft tissue-attenuating material within the nasal cavities on precontrast acquisitions in the bone window. The localisation of this material was classified as ventral, dorsal or caudal (Figure 2). The ventral part of the nasal cavities included the middle and ventral nasal meatuses, the dorsal part included the dorsal nasal meatus and the caudal part included the ethmoidal meatus and the maxillary sinus. The sphenoid sinus and the nasopharynx were assessed separately and were not included in this classification of the nasal cavities. Soft tissue-attenuating material was defined as any amorphous material found within the nasal cavities in a space that was normally filled with air and that had fluid or soft tissue attenuation based on subjective evaluation.

The CT criteria recorded were the laterality of the material within the nasal cavity (unilateral or bilateral), amount of abnormal material (none, mild, moderate or severe), location of the abnormalities (ventral, dorsal or caudal), turbinate lysis (none, mild, moderate or severe), cribriform plate lysis (present or absent), nasal septum lysis (present or absent), mass effect on the nasal septum (present or absent), rhinoliths (present or absent) and deformation and/or destruction of the facial bones (none, mild, moderate or severe). Rhinoliths were defined as small and well-marginated mineral-attenuating structures within the nasal cavities between the turbinates. The grading

of the lesions as mild, moderate or severe was subjective and decided after a consensus between the two reviewers. A CT diagnosis of rhinitis was made when there was any abnormal soft tissue or fluid-attenuating material present within at least one of the three parts of the nasal cavity.

The presence of CT signs of otitis media and otitis externa was also recorded using criteria described in a previous study.[13] For otitis media, the presence of tympanic bulla involvement was recorded in cases where material was observed filling the tympanic bulla, there was a distortion of its shape, or both. For otitis externa, external ear canal involvement was recorded when material was present in the external ear canal, there was an alteration in its shape, or both. Dental disease was diagnosed if at least one of the following was present for any tooth of the upper jaw: abnormal tooth curvature, abnormal tooth elongation, dental points, periodontal ligament space widening, tooth resorption.[14]

Statistical analysis

Binomial logistic regression was performed to ascertain whether ear carriage, sex, age, the presence of clinical signs compatible with rhinitis, the presence of concurrent dental disease and the presence of concurrent otitis media, otitis externa or both were associated with the presence of CT evidence of rhinitis in rabbits. The linearity of the continuous variable age with respect to the logit of the dependent variable was assessed via the Box–Tidwell procedure. All independent variables were first independently tested in a univariate model, and only variables with a *p*-value of less than 0.2 were kept in the final model. The presence of outliers was assessed by looking at standardised residuals, and animals with values of more than 3 standard deviations (SDs) were excluded from the model. The coefficient of determination adapted by Nagelkerke for logistic regression (Nagelkerke R^2) was calculated as a measure of success for predicting the dependent variable from the independent variables. The same procedure was performed to ascertain whether the location of the lesions in the nasal cavity, the presence of bilateral lesions, the presence of abnormal soft tissue attenuation, the presence of turbinate lysis, the involvement of the sphenoid sinus, maxillary recess or nasopharynx, and the presence of rhinoliths were associated with the likelihood that rabbits with CT evidence of rhinitis also presented clinical signs compatible with rhinitis. The results are given in the form of odds ratios (OR) and their respective 95% confidence intervals (CI). The significance level was set at a *p*-value of less than 0.05. Statistical analysis was performed using SPSS software (IBM Corp., SPSS Statistics for Windows, version 25.0).

RESULTS

A total of 133 domestic rabbits were included in this study, of which 55 were described as lop-eared. The ages of the rabbits at presentation ranged from 1 to 12 years (mean ± SD, 5 ± 2 years). The population included 41 females and 92 males.

Forty-one of the 133 rabbits (30%) had at least one clinical sign of rhinitis at the time of the presentation, either reported by the owner or observed by the attending clinician on the day of the CT.

Diagnostic imaging findings

Thirty-three of the 133 rabbits (24%) had soft tissue-attenuating material within the nasal cavities, either unilaterally or bilaterally and in at least one of the three areas defined previously (Figure 2). The location of the soft tissue-attenuating material found on the CT images for each of these rabbits and whether any other peripheral structure was involved is detailed in Table 1.

Twenty-one of these 33 rabbits (64%) had clinical signs of rhinitis. The remaining 12 rabbits had CT evidence of rhinitis but no clinical signs on the day of the CT (neither reported by the owner nor observed by the clinician).

Thirty-one of the 33 rabbits (93.9%) had material present in the ventral part of the nasal cavity (Figure 3), 16 (48.5%) had material present in the dorsal part (Figure 4) and 17 (51.5%) had material present in the caudal part (Figure 5). Fifteen rabbits (45.5%) had material present in only one of the three parts, five (15.2%) had material present in two parts and 13 (39.4%) had material present in all three parts. The ventral region was involved in all of the cases with material in at least two different parts. In cases that had material in two different parts, the parts involved were not always neighbouring. Turbinate lysis was observed in 16 rabbits (48%) with signs of rhinitis identified on CT. None of those cases had a space-occupying mass causing the turbinate lysis.

Statistical analysis

A logistic regression was first performed, using the data from all 133 rabbits, to ascertain whether ear carriage, sex, age, the presence of clinical signs compatible with rhinitis, the presence of concurrent dental disease and the presence of otitis media, otitis externa or both were associated with rabbits having CT evidence of rhinitis. The Box–Tidwell procedure revealed that age was linearly related to the logit of the dependent variable. Univariate analyses revealed only three variables with a *p*-value of less than 0.2, namely, ear carriage, the presence of clinical signs compatible with rhinitis and the presence of concurrent otitis media, which were therefore included in the final model. There were five standardised residuals with values above 3 SDs, which were therefore considered outliers and excluded from the model. The model explained 64.5% (Nagelkerke R^2) of the variance in the presence of rhinitis lesions on CT and correctly classified 87.5% of cases. All three covariates included in

TABLE 1 Summary of computed tomographic findings in 33 rabbits with evidence of rhinitis

	Rabbits with nasal soft tissue-attenuating material	Clinical signs of rhinitis	Location of lesions within the nasal cavity			Presence of material in both nasal cavities	Turbinate lysis	Sphenoid sinus involvement	Nasopharyngeal involvement	Presence of rhinoliths
			Ventral	Dorsal	Caudal					
No. (% of the total number of rabbits with soft tissue-attenuating material in their nasal cavity)	33 (100%)	21 (64%)	31 (94%)	16 (48%)	17 (51%)	24 (73%)	16 (48%)	12 (36%)	10 (30%)	15 (45%)

the final model were statistically significant. Straight-eared rabbits had greater odds of showing CT evidence of rhinitis than lop-eared rabbits (OR = 5.5, 95% CI 1.3–24.2, $p = 0.02$). Rabbits with clinical signs compatible with rhinitis had greater odds of showing CT evidence of rhinitis than those without clinical signs compatible with rhinitis (OR = 54.6, 95% CI 12.7–235.6, $p < 0.001$). Similarly, rabbits with CT evidence of concurrent otitis media had greater odds of showing CT evidence of rhinitis than those without concurrent otitis media (OR = 5.9, 95% CI 1.6–22.6], $p = 0.009$). The complete results of this model are presented in Appendix 1.

Another logistic regression was performed, which was restricted to the 33 rabbits with CT evidence of rhinitis, to ascertain whether the involvement of the ventral, dorsal or caudal nasal cavity, the presence of bilateral lesions, the presence of abnormal soft tissue attenuation, the presence of turbinate lysis, the involvement of sphenoid sinus, maxillary recess or nasopharynx, or the presence of rhinoliths were associated with these rabbits presenting clinical signs compatible with rhinitis. Univariate analyses revealed four variables with a p-value of less than 0.2, namely, the presence of bilateral lesions, abnormal soft tissue attenuation, turbinate lysis and involvement of the nasopharynx, which were therefore included in the final model. There was no standardised residual with a value above 3 SDs, so none of the rabbits were considered outliers in this model. The model explained 34.9% (Nagelkerke R^2) of the variance in the presence of CT evidence of rhinitis and correctly classified 72.7% of cases. None of the four covariates included in the final model were statistically significant ($p > 0.05$), although the presence of bilateral lesions on CT tended to be more predominant in rabbits presenting clinical signs compatible with rhinitis (OR = 5.61, 95% CI 0.92–34.05, $p = 0.06$). The complete results of this model are presented in Appendix 2.

DISCUSSION

Respiratory diseases are considered to be the second most common cause of morbidity and mortality in rabbits. Therefore, an early and accurate diagnosis is crucial.[4] A sample of nasal discharge can be collected for bacterial culture, but proving causality can be challenging since most of the bacteria cultured are also considered commensal organisms. For example, *Pasteurella multocida* is considered the most frequent respiratory pathogen in rabbits, and in one study, it was involved in up to 54.8% of cases with bacterial infection of the respiratory tract.[1] However, this bacterium may be a commensal organism rather than a true pathogen.[1,4] Alternatively, rhinoscopy can be performed in order to directly visualise the anatomical structures and the lesions. It also allows biopsies of the nasal mucosa to be performed for histopathological analysis and bacterial culture. However, this is a challenging procedure that requires intubation and can damage the delicate nasal conchae of the patient.[15]

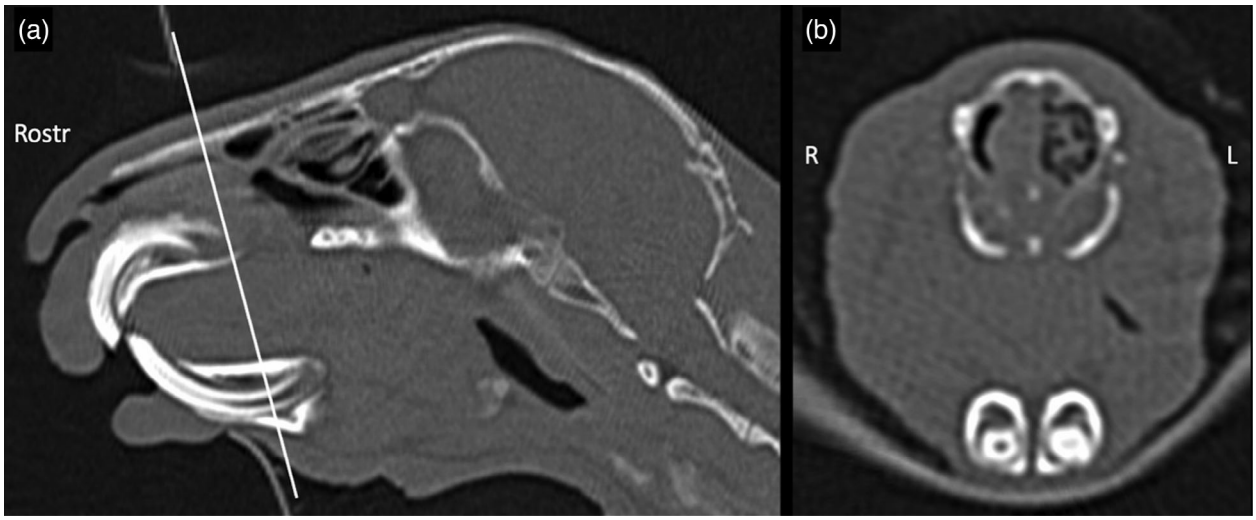

FIGURE 3 Sagittal-plane computed tomographic (CT) image of the skull of an adult rabbit with a moderate amount of abnormal material within the ventral part of the right nasal cavity (a), with the white line indicating the level and angle of the corresponding transverse image (b). Window width, 3500 HU; window level, 350 HU; slice thickness, 0.5 mm. L: left; R: right; Rostr: rostral

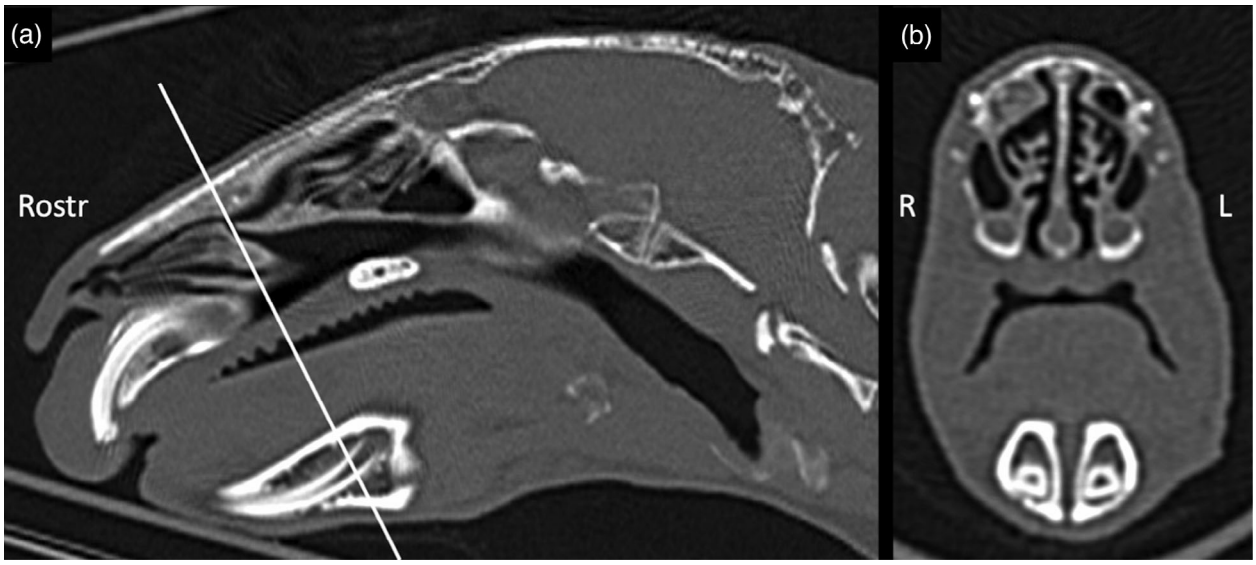

FIGURE 4 Sagittal-plane computed tomographic (CT) image of the skull of an adult rabbit with a mild amount of abnormal material in the dorsal part of the right nasal cavity (a), with the white line indicating the level and angle of the corresponding transverse image (b). Window width, 3500 HU; window level, 350 HU; slice thickness, 0.5 mm. L: left; R: right; Rostr: rostral

Radiography of the head has been described in cases of severe nasal disease in rabbits. The recommended radiographic projections are dorsoventral, right and left lateral and two lateral oblique views. An additional intraoral projection has been recommended in order to avoid superposition of the nasal cavities and the mandibles, but this projection is challenging to obtain due to the small size of rabbits and the limited opening range of their mouth.[3] The main limitations of radiography are the need for excellent positioning and technique to obtain images of diagnostic quality, and superimposition of structures that limits the diagnostic yield of this modality.[16] CT is considered a more accurate diagnostic imaging modality than radiography in the detection, characterisation and staging of nasal diseases across most domestic species.[3,7–9] CT examination of the head is commonly used to assess the nasal cavity and paranasal sinuses in cats and dogs because of its high accuracy in the diagnosis of chronic nasal disease and for the differentiation of different causes of upper respiratory tract disease.[17,18]

The use of CT in the diagnosis of rhinitis is less invasive than rhinoscopy, not limited by the size of the patient, and allows visualisation of the sinus and the caudal part of the nasal cavities. This modality also allows a concomitant CT examination of the thorax to be performed, under the same anaesthesia and without having to move the patient, to rule out diseases of the lower respiratory tract that can be associated with rhinitis. Indeed, one of the most common infectious agents affecting the upper respiratory tract is *P. multocida*, which often simultaneously affects the upper and lower respiratory tracts.[2] Lower airway infections can go undetected for a long period of time after the acute phase of infection due to the non-specific

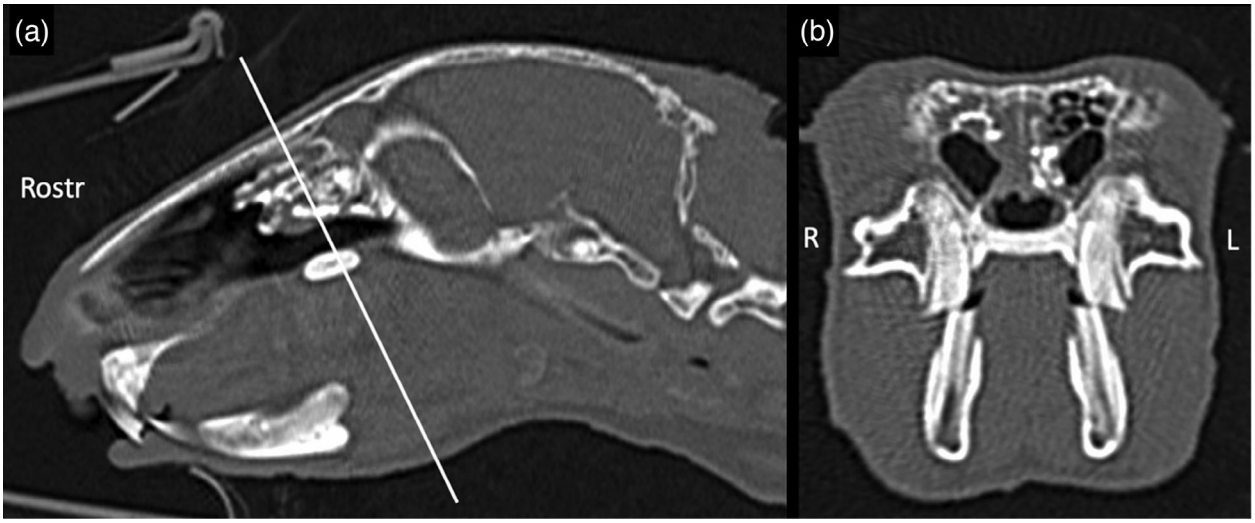

FIGURE 5 Sagittal-plane computed tomographic (CT) image of the skull of an adult rabbit with a moderate amount of abnormal material in the caudal part of the right nasal cavity, a mild amount of abnormal material in the caudal part of the left nasal cavity and bilateral rhinoliths (a), with the white line indicating the level and angle of the corresponding transverse image (b). Window width, 3500 HU; window level, 350 HU; slice thickness, 0.5 mm. L: left; R: right; Rostr: rostral

clinical signs and the small area of auscultation of the rabbit thorax.[1,8]

Another advantage of CT is the exceptional anatomical detail obtained and the possibility of multiplanar and three-dimensional reconstructions for surgical planning. Indeed, in case of treatment failure in rabbits with chronic rhinitis, a rhinotomy, rhinostomy or pararhinostomy can be performed, which consist of debridement and flushing of the affected nasal area.[19–21]

Magnetic resonance imaging (MRI) is the diagnostic imaging modality of choice for the evaluation of soft tissue structures. It has been used for the diagnosis of various nasal diseases in dogs and cats,[22–25] and the low-field MRI anatomy of the head has been described in rabbits.[26] Although the spatial resolution was limited, images obtained with a high-field MRI would probably be of diagnostic quality and a valuable tool in the evaluation of the nasal cavities in rabbits. However, the availability and cost of MRI, as well as the long scan time, ranging from 20 to 40 minutes for the head of a rabbit, limits its use in this species.[27] Moreover, there does not seem to be a superiority of MRI over CT for the diagnosis of chronic nasal disease in dogs,[28] and CT is considered a reliable tool for evaluating nasal cavities in cats.[29,30]

In our study, an association was found between the CT signs of rhinitis, defined as the presence of abnormal fluid or soft tissue-attenuating material in at least one of the three nasal areas, and the presence of clinical signs of rhinitis, which suggests that CT is a relevant imaging modality in the diagnosis of rhinitis in rabbits. However, 12 out of 33 rabbits that had CT signs of rhinitis did not show any clinical signs of rhinitis at presentation. These patients could be considered as having subclinical rhinitis. These findings mirror the results of a previous study, where nine out of 60 rabbits had incidental CT findings involving their nasal cavities.[31] One of the limitations of CT in small species is the quality of the images, especially for the assessment of small areas such as the nasal cavities. However, we found that the quality of the images was sufficient for fine assessment of the nasal and paranasal structures.

There was no statistical association between the presence of clinical signs of rhinitis and the location of the lesions on CT, but one interesting finding is that 93.9% of the patients with CT evidence of rhinitis had abnormal material present in the ventral part of the nasal cavity, which could be explained by the accumulation of nasal discharge in a dependent location due to gravity. Similarly, even if there was no statistically significant association, the presence of bilateral abnormalities on CT tended to be more frequent in rabbits presenting clinical signs compatible with rhinitis. Further studies could confirm this tendency.

The results of the present study also showed an association between CT evidence of rhinitis and CT evidence of otitis media, which was expected given the fact that one of the principal agents of rhinitis in rabbits is *P. multocida*, which can also cause otitis media by regional dissemination through the Eustachian tube.[2,16] Surprisingly, there was no association found between CT evidence of rhinitis and CT evidence of dental disease. One hypothesis is that the CT examination might have been performed before any regional dissemination occurred.[2] In addition, the diagnosis of dental disease used in our study had a wide range in terms of the types of abnormalities seen and their severity; for example, a rabbit was considered to have dental disease when one or more tooth was abnormal. Although some dental diseases, such as a maxillary tooth abscess, would be expected to induce rhinitis, others, such as mild dental points or resorption, would not.[14]

The present study also found that straight-eared rabbits had increased odds of showing CT evidence of rhinitis in comparison to lop-eared rabbits. This result is surprising as rabbits with otitis media had increased

odds of showing CT evidence of rhinitis, but lop-eared rabbits are known to be predisposed to otitis media.[13]

One of the limitations of this study is the lack of histological or cytological confirmation and the lack of information about the aetiology of rhinitis in our population of rabbits. A second limitation is the study's retrospective nature, with variability in the recording of clinical signs (either reported by the owner or recorded by the clinician), history and breed/ear carriage of the rabbit. Another limitation is the small cohort of cases; although 133 CT studies were analysed, only 33 of them showed abnormalities consistent with rhinitis, which could result in some statistical bias and lack of statistical power, especially in the second model. A final limitation is the fact that the reviewers were not blinded to the final diagnosis at the time of image review, as they did the recruitment of the cases and the analysis of the CT images at the same time.

In the future, a prospective study could be carried out with standardised grading of the clinical signs by the clinicians in order to find associations between the severity of the clinical signs, the severity of the CT signs, the response to treatment and the prognosis.

To conclude, this study described the CT findings in a population of domestic rabbits with suspected rhinitis. Clinical signs of rhinitis were associated with CT abnormalities consistent with rhinitis and CT evidence of otitis media. The CT findings presented in this study could be used as a reference in the diagnosis of rhinitis in domestic rabbits. Further prospective research with a larger population is required to correlate the aetiology of rhinitis, clinical signs, CT abnormalities and grading, treatment response and outcome.

AUTHOR CONTRIBUTIONS

Anna Slusarek contributed to the design of the study, reviewed the CT images, collected the data, analysed the results and wrote and revised the manuscript. Patricia Muffat-es-Jacques contributed to the analysis of the results and revised the manuscript. Thomas Coutant contributed to the design of the study, analysed the results and revised the manuscript. Charly Pignon contributed to the design of the study and revised the manuscript. Guillaume Léchenault collected data. Jérémy Mortier contributed to the design of the study, reviewed the CT images, analysed the results and revised the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

FUNDING INFORMATION

The authors received no specific funding for this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study retrospectively evaluated CT images obtained during routine clinical care; therefore, ethical approval was not required.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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