Received: 8 September 2022 | Revised: 8 January 2023 | Accepted: 10 January 2023

DOI: 10.1111/vru.13218

ORIGINAL INVESTIGATION

WILEY

Prevalence and clinical correlations of olfactory recess dilatation in MRI studies of the feline brain

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Abstract

The ability to differentiate clinical ventriculomegaly from incidental ventricular enlargement remains a challenge in veterinary radiology. Dilatation of one or both olfactory lobe recesses is occasionally seen on MRI of the brain in otherwise normal cats. The purpose of this study was therefore to determine the prevalence of this finding within a population of neurologically normal and neurologically abnormal cats, and to investigate associations with signalment, clinical and neurological examination findings, and MRI features. An observational retrospective cohort study was performed, and archived records were searched for cats that had undergone MRI of the head, including the olfactory lobes. Medical data and MRI parameters were recorded. One hundred fifty-one cats were included, with olfactory recess dilatation present in 56 cats. In 16 neurologically normal cats, olfactory recess dilatation was the only MRI finding. Olfactory recess dilatation was not associated with age, sex, breed, or with the presence of nasal disease. A significant association was found between generalized ventriculomegaly ($P = 0.001$) and the presence of CSF abnormalities ($P = 0.036$). Eleven percent of our cohort (16/151) demonstrated olfactory recess dilatation in the absence of other neurological or structural intracranial disease, suggesting that this may be seen as a normal variation in some cats.

KEYWORDS
cat, olfactory bulb cavity, olfactory lobe, olfactory ventricle, ventriculomegaly

1 | INTRODUCTION

Magnetic resonance imaging (MRI) of the brain is routinely performed to investigate suspected intracranial disease in cats. The ability to differentiate clinically significant ventriculomegaly from incidental ventricular enlargement remains an ongoing challenge in veterinary radiology.[1–4] Olfactory recess dilatation has been reported in both dogs and cats with developmental and acquired obstructive hydrocephalus[2,5–8] and in one cat with epilepsy.[9]

In the authors' experience, olfactory recess dilatation is occasionally seen as the only MRI feature in cats which are neurologically normal. In one previous report, eight out of thirty-three neurologically normal adult cats demonstrated olfactory recess dilatation on MRI.[1] In the human literature, persistence of the olfactory recesses is a subject of debate and has been reported in between 5.5% and 59% of clinically and neurologically normal individuals.[10,11] Based on our review of the literature, the prevalence and clinical significance of olfactory recess dilatation in cats have not yet been reported.

Abbreviations: CNS, central nervous system; CSF, cerebrospinal fluid analysis; DPA, dual-phase array.

The purposes of this study were as follows: to compare the prevalence of olfactory recess dilatation in cats with neurological abnormalities and cats considered neurologically normal (such as those being investigated for nasal disease or ear disease); to determine associations between olfactory recess dilatation and other MRI features, including the presence of space-occupying intracranial disease, generalized ventriculomegaly, and nasal disease; to determine associations with abnormalities on cerebrospinal fluid (CSF) analysis; and finally to determine associations with patient signalment characteristics including sex, age, and breed. Our hypotheses were that olfactory recess dilatation would be positively correlated with structural intracranial disease, ventriculomegaly, nasal disease, abnormalities on CSF analysis, and brachycephalic breed conformation. We also hypothesized that there would be no significant association with the presence or absence of abnormalities on neurological examination, sex, or age.

2 | MATERIALS AND METHODS

2.1 | Selection and description of subjects

The present investigation was conducted as an observational retrospective cohort study. The project was approved by the Cambridge Department of Veterinary Medicine Ethical Review Board. Medical records of the Queen's Veterinary School Hospital were searched for cats referred for MRI of the head from January 2014 to July 2021. Patients were included when an MRI of the head, including the olfactory lobes of the brain, was available for review. This included any MRI performed to investigate suspected intracranial disease, as well as any MRI performed to investigate non-intracranial disease of the head (such as nasal disease or ear disease). All identified cases were required to have available for review a brain MRI with a minimum set of sequences including T2-weighted (T2W), T2-weighted fluid-attenuated inversion recovery (FLAIR), and T1-weighted (T1W) sequences. All sequences and imaging planes acquired at the time of imaging were made available to each reviewer. Patients were excluded when the olfactory lobes of the brain were absent from, or incompletely included, in the study, or when orthogonal imaging planes including the entire brain were not available for review. Decisions regarding subject inclusion or exclusion were made by a second-year European College of Veterinary Diagnostic Imaging (ECVDI) resident (O.M.).

2.2 | Data recording and analysis

Medical records of cats meeting the inclusion criteria were retrieved, and clinical data were recorded by the second-year ECVDI resident (O.M.), including the following: age at presentation, sex, breed, clinical examination findings, presence, or absence of neurological abnormalities based on a neurological examination performed by a board-certified veterinary neurologist, and CSF analysis results when available (with CSF abnormalities defined as the presence of one or more of any of the following: pleocytosis, hyperproteinorrachia (albuminocytological dissociation), positive infectious titers or bacterial growth).

MRI findings were recorded independently by the second-year ECVDI resident (O.M.), with access to radiology reports but without access to patient clinical data at the time of recording. The following MRI findings were recorded based on radiology reports: presence or absence of olfactory recess dilatation presence or absence of space-occupying intracranial disease, presence or absence of a generalized ventriculomegaly, and presence or absence of nasal disease. When olfactory recess dilatation was present, the following MRI parameters were additionally recorded: unilateral or bilateral dilatation (and when unilateral, whether right or left-sided), and T1W, T2W, and FLAIR signal characteristics of the olfactory recess contents.

2.3 | Statistics

Statistical analyses were performed by the second-year ECVDI resident (O.M.) under the supervision of a European College of Veterinary Clinical Pathology (ECVCP)-certified clinical pathologist with over 10 years of experience in statistics (T.L.W.), using a commercial software (SPSS 27.0, SPSS Inc., Chicago, IL, USA). A Mann–Whitney *U* test was used to compare continuous data between groups. Repeated Chi-square or Fisher's exact tests were performed, where appropriate, to determine the association between categorical variables, including dilatation of the olfactory recesses on MRI and immature age (<1 year or >1 year), geriatric age (>10 years or <10 years), sex (male or female), breed (purebred or non-purebred), brachycephalic breed conformation (brachycephalic or non-brachycephalic), neurological abnormalities (present or absent), space-occupying intracranial disease (present or absent), generalized ventriculomegaly (present or absent), CSF abnormalities (present or absent) and nasal disease (present or absent). Backward stepwise logistic regression analysis was finally performed to determine if variables found to be associated with or tending toward an association with ($P < 0.2$) the presence of olfactory recess dilatation in univariable analyses were independently associated with olfactory recess dilatation. Statistical significance for all tests was defined as $P < 0.05$.

3 | RESULTS

Results are summarized in Table 1. One hundred fifty-one cats in total met the inclusion criteria. Fifty-six of these cats (37%) were found to have evidence of olfactory recess dilatation, being bilateral in twenty-one cats (38%) (Figure 1), and unilateral in thirty-five cats (62%; Figure 2). Of those cats with unilateral dilatation, 23 were right-sided (66%) and 12 were left-sided (34%). The median age of all cats at the time of MRI was 9 years (range 6 months to 17 years). There was no significant association between age and the presence of olfactory recess dilatation ($P = 0.754$), nor was any association found between immature age or geriatric age and the presence of olfactory

TABLE 1 Results of prevalence and correlation analyses of 151 cats presenting for MRI of the head.

Variable	Prevalence in all 151 cats	Prevalence in the 56 cats with olfactory recess dilatation	Significant correlation Yes / No	*P*-value
Immature age	13/151 (9%)	6/56 (1%)	No	$P = 0.550$
Geriatric age	63/151 (42%)	24/56 (43%)	No	$P = 0.809$
Sex	Female: 59/151 (39%)	Female: 23/56 (41%)	No	$p = 0.680$
	Male: 87/151 (58%)	Male: 31/56 (55%)		
Pure breed	35/151 (23%)	13/56 (23%)	No	$P = 0.950$
Brachycephalic breed	10/151 (7%)	4/56 (7%)	No	$P = 0.954$
Neurological abnormalities	90/151 (60%)	36/56 (64%)	No	$P = 0.499$
Space-occupying intracranial disease	27/151 (18%)	16/56 (50%)	Yes—univariable analysis	$P = 0.008$
			No- multivariable analysis	$P = 0.907$
Ventriculomegaly	11/151 (7%)	11/56 (20%)	Yes	$P = 0.001$
			More likely bilateral dilatation	$P = 0.046$
Nasal disease	38/151 (25%)	14/56 (25%)	No	$P = 0.971$
Abnormalities on CSF analysis	12/151 (8%)	7/56 (13%)	Yes—univariable analysis	$P = 0.036$
			Yes—multivariable analysis	$P = 0.031$
			More likely bilateral dilatation	$P = 0.006$

Abbreviations: CSF, cerebrospinal fluid.; MRI, magnetic resonance imaging.

recess dilatation ($P = 0.550$ and $P = 0.809$, respectively). Sex (male or female) was not significantly associated with olfactory recess dilatation ($P = 0.68$).

Of all cats included, twenty-one breeds were represented, of which the most common was the domestic shorthair (67%), followed by the domestic longhair (4.6%), Maine Coon (3.3%) and Persian (2.6%). There were three of each of the following (2%): Bengal, British Shorthair, Devon Rex, Ragdoll, and Russian Blue; two of each of the following (1.3%): Ocicat, Siamese, Siberian Forest; and one of each of the other breeds represented (0.7%): Birman, British Longhair, Burmese, European Shorthair, Exotic Shorthair, Korat, Norwegian Forest, Oriental Longhair, and Tonkinese. Four patients were of unknown breed. Of the cats with evidence of olfactory recess dilatation, twelve breeds were represented, with the most common being the domestic shorthair (68%, 38/56). Three (5.4%) were Devon Rex cats, there were two each of the following breeds (3.6%): Persian, domestic longhair, Maine Coon, and one of each of the following (1.8%): Ragdoll, Russian Blue, Siberian Forest, Tonkinese, British Shorthair, Exotic Shorthair, Ocicat. Two cats were of unknown breed. Breeds were further subdivided into purebred and non-purebred as well as brachycephalic and non-brachycephalic. Breeds considered purebred (35/151) included all breeds other than the following: Domestic Shorthair, Domestic Longhair, British Longhair, European Shorthair, Exotic Shorthair. Breeds considered brachycephalic (10/151) included the following: Persian, British Shorthair, Exotic Shorthair, Burmese, and British Longhair.[12] There was no association found between pure breed or brachycephalic breed and olfactory recess dilatation ($P = 0.95$ and $P = 0.954$, respectively). The presence of abnormalities on neurological examination was not significantly associated with the presence of olfactory recess dilatation ($P = 0.499$).

Magnetic resonance imaging of the head was performed using either a 0.27 Tesla MRI scanner (Vet MR Grande, Esaote S.p.A, St Neots, UK), or a 1.5 Tesla MRI scanner (Achieva, Phillips Electronics UK Limited Ascent, Farnborough, UK). Patients were positioned in sternal recumbency, and images were obtained in the Esaote scanner using a dual phased array (DPA) ankle/foot coil or DPA wrist coil (Esaote S.p.A, St Neots, UK), dependent on patient size, and in the Phillips scanner using a small flex coil. While extra sequences were occasionally included on an individual basis, all studies included a sagittal and transverse T2W fast spin echo (FSE), a transverse and a dorsal T1W spin echo (SE), and a transverse T2W FLAIR. Acquisition parameters for the 0.27 Tesla MRI scanner were as follows: T2W sequences were acquired with an echo time (TE) ranging from 90 to 120 ms and a repetition time (TR) ranging from 3750 to 6560 ms; T1W sequences were acquired with a TE of 26 ms and a TR ranging from 350 to 700 ms; FLAIR sequences acquired with a TE of 90 ms, a TR ranging from 7000 to 7260 ms and a time to inversion (TI) of 1800 ms. Acquisition parameters for the 1.5 Tesla MRI scanner were as follows: T2W sequences were acquired with a TE of 100 ms and a TR ranging from 4031 to 6448 ms; T1W sequences were acquired with a TE of 10 ms, and a TR ranging from 921 to 1045 ms; FLAIR sequences were acquired with a TE ranging from 125 to 150 ms, a TR of 6000 ms, and a TI of 2000 ms. Transverse and dorsal T1W sequences were also acquired 1–10 min after manual intravenous administration of paramagnetic contrast medium

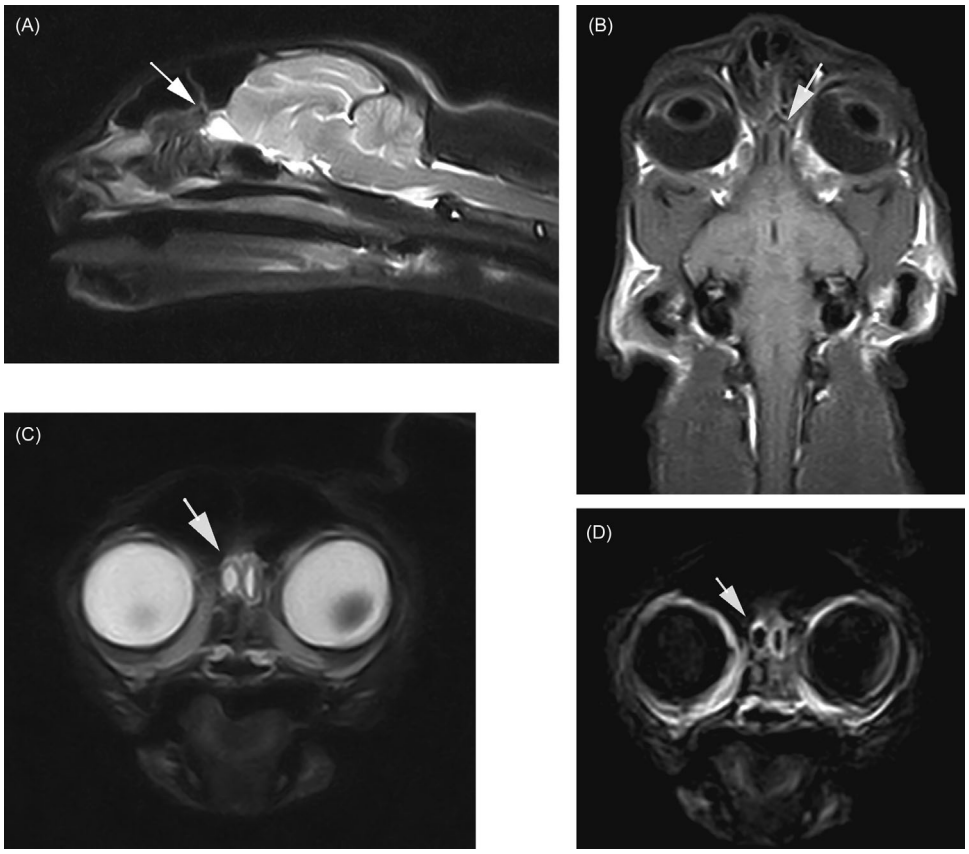

FIGURE 1 Six-year-old male neutered Devon Rex who presented with a history of paroxysmal abnormal ocular movements, a normal neurological examination, and an MRI diagnosis of left-sided otitis media (without evidence of otitis interna), right-sided chronic rhinitis and bilateral dilatation of the olfactory recesses (white arrows). A, T2W sagittal (TR: 3750 ms, TE: 90 ms). B, pre-contrast T1W dorsal (TR:450 ms, TE:26 ms). C, T2W transverse (TR: 4900 ms, TE: 90 ms). D, FLAIR (TR: 7000, TE:90, TI; 1800). Patient positioned in sternal recumbency; field strength 0.27T; slice thickness 3 mm. In the transverse and dorsal images, the cat's right side is displayed on the left.

(Gadovist 1.0 mmol/L, Bayer UK Ltd. Reading, Berkshire, UK) at a dose of 0.1 mL/kg. For all sequences, slice thickness was 3 mm, with an interslice gap of 0.3 mm. Orthogonal sequences (sagittal and dorsal) including the entire brain were obtained in all patients, even when being investigated for extracranial disease. Magnetic resonance images were analyzed using a DICOM image viewer (Visbion 64, Visbion Ltd, Chertsey, United Kingdom).

The dilated olfactory recesses, when present, were seen as well-defined, smoothly-marginated regions that were rounded to ovoid in the transverse plane, elongated in the dorsal and sagittal plane, and demonstrated an intensity pattern consistent with that of normal CSF, being markedly T2W hyperintense, FLAIR suppressing and T1W hypointense in all cats. On MRI, of all 151 cats included in the study, 108 were found to have abnormalities other than dilatation of the olfactory recesses. Twenty-seven were found to have space-occupying intracranial disease (18%), and of these 27 cats, 11 were found to have evidence of a generalized ventriculomegaly (40%). Twenty-seven cats were found to have non-space-occupying intracranial disease (18%), 38 were found to have a nasal disease (25%), 37 were found to have an extracranial disease (including ear disease) (25%), and 43 were deemed to have a normal MRI (28%). Of the cats with olfactory recess dilatation, 16 (of 56) were found to have space-occupying intracranial disease (50%), and of these 16 cats, eleven were found to have a generalized ventriculomegaly (69%). Twenty cats had evidence of other non-intracranial disease (36%), 14 had evidence of nasal disease (25%), and seven were deemed to have a normal MRI (13%). The overlap seen in both groups is due to some cats having a combination of findings (such as nasal disease or ear disease as well as intracranial disease for example). Cats with space-occupying intracranial disease were more likely to have olfactory recess dilatation than those without space-occupying lesions ($P = 0.008$).

Eleven patients were found to have generalized ventriculomegaly, of which all 11 (100%) demonstrated dilatation of the olfactory recesses (Figure 3). Those with generalized ventriculomegaly were more likely to have olfactory recess dilatation than those without ventriculomegaly ($P = 0.001$). Cats with generalized ventriculomegaly were also more likely to have bilateral rather than unilateral dilatation of the olfactory recesses ($P = 0.046$).

When considering all cats included in the study, CSF analysis was normal in 38 (25%), abnormal in 12 (8%), and was not performed in 101 (67%) cats. Of those cats with olfactory recess dilatation, CSF analysis was normal in nine (16%), abnormal in seven (13%), and was not performed in 40 (71%) cats. Cats with abnormal CSF were more likely to have olfactory recess dilatation than those with normal CSF

FIGURE 2 Twelve-year-old male neutered Domestic Shorthair with left-sided vestibular signs on presentation and an MRI diagnosis of left-sided otitis media/interna without intracranial extension and unilateral, right-sided olfactory recess dilatation (white arrows). A, T2W right parasagittal (TR: 3750 ms, TE:90 ms). B, T2W transverse (TR: 5480 ms, TE:90 ms). C, pre-contrast T1W dorsal (TR: 650 ms, TE:26 ms). Patient positioned in sternal recumbency; field strength: 0.27T; slice thickness: 3 mm. In the transverse and dorsal images, the cat's right side is displayed on the left.

findings ($P = 0.036$). Cats with CSF abnormalities were also more likely to have bilateral rather than unilateral dilatation of the olfactory recesses ($P = 0.006$). Cats with nasal disease were not more likely to have olfactory recess dilatation than those without nasal disease ($P = 0.971$).

Multivariable logistic regression analysis included CSF abnormalities and presence of space-occupying lesions only. The association between ventriculomegaly and olfactory dilatation could not be assessed using logistic regression analysis because 100% of patients with ventriculomegaly had dilatation of the olfactory recesses. In the multivariable model, only abnormalities on CSF analysis remained independently associated with increased odds of olfactory recess dilatation (odds ratio [OR] = 4.411; 95% confidence interval for OR = 1.147–17.749 $P = 0.031$). The presence of space-occupying intracranial disease was no longer significantly associated with the presence of olfactory recess dilatation in the multivariable model ($P = 0.907$). In our study population as a whole, the prevalence of olfactory recess dilatation was 37%, and of the 56 patients with olfactory recess dilatation, 16 (or 11% of the total population) were considered both neurologically normal on neurological examination and structurally normal on MRI.

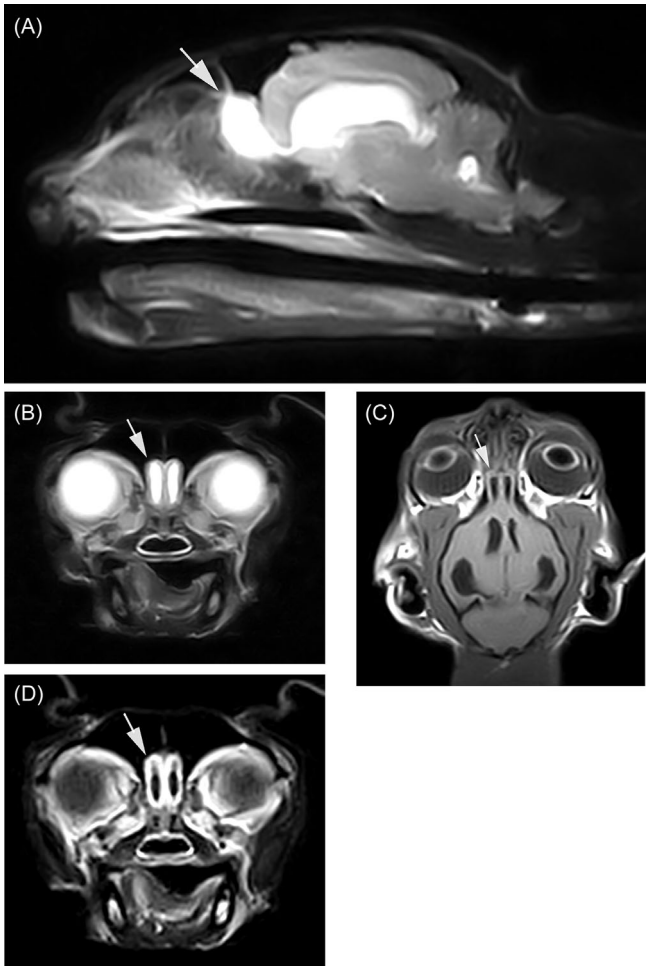

FIGURE 3 One-year-old female neutered Domestic Shorthair with a history of progressive multifocal neurological disease with a final diagnosis of marked generalized ventriculomegaly including both olfactory recesses (white arrows), secondary to Feline Infectious Peritonitis (FIP). A, T2W left parasagittal (TR:5500 ms, TE:90 ms). B, T2W transverse (TR: 6050 ms, TE:90 ms). C, Pre-contrast T1W dorsal (TR: 350 ms, TE: 26 ms). D, FLAIR (TR: 7260 ms, TE:90 ms, TI: 1800 ms). Patient positioned in sternal recumbency; field strength 0.27T; slice thickness 3 mm. In the transverse and dorsal images, the cat's right side is displayed on the left.

4 | DISCUSSION

This is the first published study to describe the prevalence and clinical correlations of olfactory recess dilatation on MRI examination of the brain in cats. As hypothesized, dilatation of the olfactory recesses was found to be correlated with generalized ventriculomegaly, and with abnormalities on CSF analysis, the dilatation being most commonly bilateral in both groups of patients. No obvious association was found with patient sex or age, nor with the presence or absence of abnormalities on neurological examination. Contrary to our hypotheses, nasal disease, structural intracranial disease, and brachycephalic breed were not found to be significantly associated with the presence of olfactory recess dilatation in our patients. Furthermore, eleven percent of our

study population were found to have olfactory recess dilatation in the absence of any neurological signs or structural intracranial disease.

The ability to differentiate clinically significant ventriculomegaly from incidental ventricular enlargement remains an ongoing challenge in veterinary radiology. This has been a subject of great debate in dogs with brachycephalic skull conformation.[2,3,4] In contrast to dogs, noticeable ventricular dilatation or ventricular asymmetry in cats is generally considered abnormal, unless mild and associated with other findings supportive of age-related brain atrophy.[13–15] At our institution, dilatation of one or both olfactory recesses is seen occasionally in feline patients which are otherwise considered both neurologically normal, and structurally normal on MRI. This finding has therefore remained of unknown clinical significance for those cats.

The olfactory recesses (also termed olfactory bulb ventricles, olfactory ventricles, olfactory bulb cavities, or rhinoceles) are bilateral rostroventral extensions from the rostral horn of the lateral ventricles into the olfactory lobes of the brain. In the fetus, they are continuous with the ventricular system and contain cerebrospinal fluid, while in adults the olfactory recesses are normally collapsed.[16–19] In humans, the olfactory recesses are considered to be a transient fetal structure, which slowly regresses, being generally absent at the time of birth or soon after.[20,21] Persistence of the olfactory recesses into adulthood in certain individuals remains a subject of debate in the human literature, with great variation in its reported prevalence (between 5.5% and 59% of the population).[10,11] Persistence of the olfactory recesses into adulthood has been reported as a normal anatomical finding in certain species, including the elephant,[22] fish,[23] rabbits, pigs, and sheep.[11,24,25] In dogs, reports of olfactory recess dilatation exist only in those with clinically significant hydrocephalus.[2,5] In cats, olfactory recess dilatation has been described in several case reports in association with obstructive hydrocephalus, including secondary to neuronal heterotopia,[6] a presumed non-colloidal intraventricular cyst,[7] and presumptive mucopolysaccharidosis.[8] Unilateral left olfactory recess dilatation was described in one patient with idiopathic epilepsy, where in the absence of any other abnormalities on MRI, this was considered an incidental finding.[9] One study did find olfactory recess dilatation in eight of 33 neurologically and structurally normal cats, while investigating the role of age in progressive ventricular dilation.[1] The findings of our study are overall in agreement with the literature to this date, with dilatation of the olfactory recesses present in all patients with generalized ventriculomegaly, but this finding also being present in a subset of our population (11% of the total studied population) in the absence of any other structural abnormality on MRI or any neurological abnormalities at presentation or on neurological examination.

CSF is produced continuously by capillaries throughout the central nervous system, with the rate of production being largely constant and independent from intracranial pressure.[17] Absorption of CSF is therefore the main mechanism for the maintenance of stable intracranial pressure in the face of its continuous production. Several extracranial sites of CSF absorption exist, including the passage of CSF along cranial nerves I, III, and VIII, where they pass through the skull bones. One mechanism of removal of CSF is therefore its passage through the cribriform plate of the ethmoid bone, in association with the olfactory nerves, to be drained via the nasal lymphatics.[5,17,26] One study performed in rats demonstrated that CSF absorption via the nasal lymphatics was reduced in rats with hydrocephalus, although the association between the two was not clear.[27] CSF produced within the ventricular system flows into the sub-arachnoid space via the lateral apertures of the fourth ventricle, to then be absorbed.[17] Any obstruction to the continuity of CSF flow by space-occupying intracranial disease will therefore result in obstructive hydrocephalus, and progressive dilation of the ventricular system rostral to the site of obstruction. Gradual dilation of the ventricular system has been shown to follow a pre-determined sequence, with initial dilation of the rostral horns of the lateral ventricles, followed in sequence by the lateral ventricles, the fourth ventricle, and the third ventricle, with the olfactory recesses being the last portion of the ventricular system to dilate.[2] In accordance with this, dilation of the olfactory recesses has been suggested to indicate increased intraventricular pressure,[28] and was also noted in experimentally induced hydrocephalus, where it was interpreted as the transmission of pressure from the rostral horn of the lateral ventricle to the normally non-expanded olfactory recesses in the advanced stage of elevated intraventricular pressure.[18,19] The results of our study concur with this hypothesis, as 100% of cats with a generalized ventriculomegaly demonstrated olfactory recess dilatation.

Hydrocephalus has been linked to brachycephalic skull conformation in multiple species, including cats, dogs, humans, and rats.[29] The ventricular dilatation reported in brachycephalic cats however was limited to the lateral ventricles only, without the involvement of the third or fourth ventricles, and without specific mention of dilatation of the olfactory recesses.[29] No significant correlation was found in our study between olfactory recess dilatation and brachycephalic breed.

No significant association was found with other patient signalment characteristics (age, sex, or pure breed), nor with the presence of abnormal neurological examination. Previous studies in humans,[30–32] cats,[1,14] and dogs,[33,34] have reported progressive dilation of the ventricular system with advancing age. Our study did not however find a significant association between age and the presence of dilated olfactory recesses. This is in agreement with a previous publication, which found a positive correlation between advancing age and dilation of the temporal horns of the lateral ventricles, right lateral ventricle, and third ventricle in their population of cats but not between age and the presence of dilated olfactory recesses.[1] As discussed above, the olfactory recesses in the fetus are normally filled with CSF. In humans, they then regress progressively to be generally absent at the time of birth,[20,21] while in animals they progressively collapse and are empty of CSF contents in adult individuals.[16–19] One can therefore consider an alternative hypothesis where the persistence of one or both olfactory recesses might be seen more commonly as a normal variation in some younger individuals, where the regression or collapse of these fluid-filled cavities may be conceivably delayed in some individuals when compared to the remainder of the population. This hypothesis however was not supported by our results.

The presence of a pathway for drainage of CSF via the nasal lymphatics led us to hypothesize that disruption to nasal lymphatic flow

secondary to nasal disease may result in reduced CSF drainage, with secondary progressive dilation of the ventricular system, including that of the olfactory recesses. There was however no significant association found between the presence of nasal disease on MRI, and that of olfactory recess dilatation.

All case reports describing dilatation of the olfactory recesses in dogs and a majority of those in cats have described dilatation of the olfactory recesses in association with a generalized ventriculomegaly.[2,6–8] It was therefore hypothesized that ventriculomegaly of any cause, would be significantly associated with concurrent dilation of the olfactory recesses. This hypothesis was supported by our results, with a significant correlation with the presence of ventriculomegaly other than that of the olfactory recesses identified in our population.

While Chi-square analysis demonstrated that space-occupying intracranial disease is significantly associated with dilatation of the olfactory recesses, this factor was not associated with olfactory recess dilatation in the multivariable logistic regression analysis. This suggests that those animals with space-occupying intracranial disease were only more likely to have dilatation of the olfactory recesses because they also had generalized ventriculomegaly and/or CSF abnormalities. Central nervous system (CNS) inflammation with a secondary accumulation of inflammatory exudate within the mesencephalic aqueduct and lateral apertures of the fourth ventricle will lead to obstruction of normal CSF flow leading to increased intraventricular pressure and secondary progressive ventricular distension.[5,35,36] We, therefore, hypothesized that the presence of abnormalities on CSF analysis would be significantly associated with olfactory recess dilatation, and this hypothesis was supported by our results. CSF analysis can therefore be indicated in cats that have olfactory recess dilatation.

Several limitations have arisen from the retrospective nature of our study. Magnetic resonance imaging studies were not retrieved and re-reviewed. Analyses were based on information recorded in radiology reports only. Long-term follow-up information was not available for all patients and therefore was not included in this study. The eventual development of neurological abnormalities in those cats with dilatation of the olfactory recesses but without neurological abnormalities at the time of MRI cannot thus be excluded. Magnetic resonance imaging protocols were not standardized across all patients, and while MRI studies of the brain at our institution do follow a standard protocol, with additional sequences added on an individual basis, this protocol is slightly different from that protocol used for studies of extracranial disease such as that of the nasal cavity or aural disease. Despite these differences, orthogonal sequences including the entire brain (dorsal and sagittal) were obtained in all patients, including those being investigated for extracranial disease. In addition, CSF analysis was not obtained in all patients, raising the possibility that underlying inflammatory disease may have been missed in certain cats with or without olfactory recess dilatation. The absence of neurological signs in those cats being investigated for extracranial disease in combination with a structurally normal brain on orthogonal sequences makes it less likely, however, that structural intracranial disease or inflammatory CNS disease may have been missed. Furthermore, the sequential dilation of the ventricular system, with the olfactory recesses being the last component of the ventricular system to dilate, suggests that it is unlikely that in the presence of structural CNS disease, dilatation of the olfactory recesses would be present alone.[18,19,28] While intraventricular pressure was not directly measured in any of the cats included in the study, in patients with a structurally normal brain other than olfactory recess dilatation, and in the absence of any other MRI findings supportive of elevated intraventricular pressure as previously described,[2] it is considered less likely that occult elevation in intraventricular pressure was missed. In the human literature, multiple MRI studies of the olfactory lobes of the brain describe a central region of T2W hyperintensity. The anatomical reason for this T2W hyperintensity is poorly understood and remains debated, with interpretations including bulbomalacia,[37] atrophy or small dysontogenic cysts,[38] a central fluid compartment,[39] or a persistent olfactory recess.[40] Later studies suggested however that the central T2W hyperintensity would, in most patients, simply represent the normal histological layering within the olfactory bulb.[10,41] Again, due to the retrospective nature of our study, histopathology was not available to better understand the histological features of the olfactory lobes in our patients. All patients with evidence of olfactory recess dilatation however had a visible connection between the T2W hyperintense region within the olfactory lobe and the ipsilateral lateral ventricle, this connection being most evident in the sagittal sequence. Furthermore, the intensity pattern of the dilated olfactory recesses was consistent with that of the remainder of the CSF-filled ventricular system, being markedly T2W hyperintense, T1W hypointense and suppressing on the FLAIR sequence in all patients. While one publication has described ipsilaterally reduced olfaction in one dog with hydrocephalus and unilateral olfactory recess dilatation,[1] this remains a single report and olfaction is in fact not routinely tested in small animals, due to the difficulty in evaluating this objectively, especially when olfaction is incomplete.[17] Furthermore, in the human literature, the presence of olfactory recess dilatation has not been found to be associated with any reduction in olfaction.[11]

In conclusion, findings indicated that dilatation of the olfactory recesses in this sample of cats was associated with generalized ventriculomegaly, and with the presence of abnormalities on CSF analysis, with the dilatation being most commonly bilateral in these groups of patients. There was not a significant association between olfactory recess dilatation and the presence of nasal disease, nor with patient signalment characteristics including sex, breed, or age. Eleven percent of our study population were found to have olfactory recess dilatation in the absence of any neurological signs or structural intracranial disease. Future studies with long-term outcome assessments are needed to further assess the clinical relevance of this MRI finding.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and Design: McGregor, Genain, Alves
(b) Acquisition of Data: McGregor, Genain, Alves
(c) Analysis and Interpretation of Data: McGregor, Genain, Alves, Williams

Category 2

(a) Drafting the Article: McGregor

(b) Revising Article for Intellectual Content: Genain, Alves, Williams

Category 3

(a) Final Approval of the Completed Article: McGregor, Genain, Alves, Williams

Category 4

(a) Agreement to be accountable for all aspects of the work ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: McGregor, Genain, Alves, Williams

CONFLICT OF INTEREST STATEMENT

The authors have declared no conflict of interest.

PREVIOUS PRESENTATION OR PUBLICATION DISCLOSURE

Previous presentation as an abstract at the EAVDI-BID pre-BSAVA conference in Manchester, 23rd March 2022.

EQUATOR NETWORK DISCLOSURE

An EQUATOR network checklist was not used

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How to cite this article: McGregor O, Genain M-A, Williams TL, Alves L. Prevalence and clinical correlations of olfactory recess dilatation in MRI studies of the feline brain. *Vet Radiol Ultrasound*. 2023;1-9. https://doi.org/10.1111/vru.13218