PAPER

Vestibular disease in dogs: association between neurological examination, MRI lesion localisation and outcome

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Objectives: To determine whether the neurological examination correctly distinguishes between central and peripheral vestibular lesions in dogs.

Materials and Methods: Retrospective study on dogs with vestibular disease presenting to two referral clinics in Germany.

Results: Ninety-three dogs were included; neurological examination suggested central vestibular disease in 62 and a peripheral lesion in 31. MRI diagnosis was central vestibular disease in 68 dogs and peripheral in 25. Of the 62 dogs with a lesion localisation diagnosed as central vestibular by neurological exam, 61 were correctly identified (98.4%). Twenty-four of the 31 dogs diagnosed with a peripheral lesion by neurological exam had a consistent lesion on MRI (77.4%).

Clinical Significance: The neurological examination is efficient at identifying lesions in the central vestibular system but less so for peripheral lesions. Therefore it is prudent to recommend imaging in dogs that show signs of peripheral vestibular syndrome but do not rapidly respond to treatment.

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INTRODUCTION

Dogs with vestibular syndrome are frequently presented to veterinarians (Fluehmann *et al.* 2006). The neurological examination is a non-invasive and inexpensive test that is essential to choose the appropriate diagnostic work-up to detect the aetiology of vestibular dysfunction. The lesion can be localised to the central or the peripheral vestibular system and can be caused by a wide range of diseases (De Lahunta & Glass 2009). Various diagnostic tests such as otoscopy, radiography of the skull, CT, myringotomy and analysis of the cerebrospinal fluid can lead to non-specific or insufficient results (Garosi *et al.* 2001). MRI is a well-established diagnostic tool to detect the causative lesion and to suspect or confirm the underlying aetiology of vestibular dysfunction (Kraft *et al.* 1997, Garosi *et al.* 2001). High field MRIs provide detailed images of anatomical structures and so even small lesions in the brainstem or inner ear can be detected (Bayens-Simmonds *et al.* 1997, Kraft *et al.* 1997, Dvir *et al.* 2000). The sensitivity and specificity of MRI in the diagnosis of vestibular syndrome was evident in a recent study (Boudreau *et al.* 2018).

Determining the aetiology of the disease is essential for accurate treatment and provides owners with information regarding the likely prognosis. The current study was conducted to investigate how accurate the clinical neurological examination is in correctly localising a lesion within the vestibular system in dogs. For this purpose, MRI was used as gold standard to discriminate central *versus* peripheral vestibular disease. Additional aims were to report the most frequent aetiologies of peripheral and central vestibular disease and the outcome of affected dogs.

MATERIALS AND METHODS

Inclusion criteria

The digital patient management systems of two veterinary clinics were searched for dogs with vestibular syndrome presented between January 2009 and April 2015 to retrospectively retrieve data from

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their medical records. Keywords used for the search were "vestibular" and "head tilt." MRI of the head was mandatory for inclusion. All information about the medical history was noted, including signalment, history, clinical signs, neurological examination findings and neurolocalisation, MRI results and other diagnostic test results such as cerebrospinal fluid (CSF) analysis, otoscopy, brainstem auditory evoked potentials (BAEP) or *post mortem* examination including histopathology if available. Depending on the duration of clinical signs before presentation, onset of the disease was classified as peracute (less than 2 days), acute (up to 2 weeks) and chronic (longer than 2 weeks), respectively. In investigating the occurrence in different dog breeds, the breed distribution of the total hospital population was taken into consideration.

Neurological examination

Neurolocalisation was classified as central or peripheral vestibular. Neurological examinations were performed by either a resident-in-training or Diplomat of the European College of Veterinary Neurology (ECVN). Dogs with vestibular ataxia, head tilt and normal proprioception were defined as having a peripheral vestibular syndrome (PVS) (Troxel *et al.* 2005). In these patients, nystagmus or strabismus or other additional deficits are sometimes observed affecting cranial nerves VII, VIII or the sympathetic nerve. If proprioceptive deficits, cranial nerve deficits other than of VII, VIII or the sympathetic nerve, hypermetria, intention tremor or changes in the state of consciousness or behaviour were also observed, the localisation was designated central vestibular syndrome (CVS) (Troxel *et al.* 2005). In CVS, different types of nystagmus can be observed: if the side of the head tilt was contralateral to the side of other clinical signs, such as proprioceptive deficits, a paradoxical vestibular syndrome with involvement of the cerebellum was presumed (Troxel *et al.* 2005). A bilateral vestibular syndrome is an occasional type of PVS, although cases of bilateral vestibular syndrome due to CVS are described (Markovich *et al.* 2013).Affected animals show bilateral incoordination, swinging head movements and no physiological nystagmus (Lorenz *et al.* 2011).

Diagnostic findings

MRI was performed using a 1.0 Tesla Siemens Magnetom impact plus (Siemens, Germany) in 2009 and from February 2010 using a 3.0 Tesla Philips Achieva x-series (Philips, Netherlands) in some cases and a 1.5 Tesla Siemens Magnetom (Siemens, Germany) was used in other cases. All MRIs were analysed by an ECVN Diplomat. In all cases, at least T1- and T2-weighted images were acquired in transverse, sagittal and dorsal planes. Eighty dogs additionally received intravenous gadolinium-based medium for contrast T1-weighted images. Other MRI sequences included fluid-attenuated inversion recovery (FLAIR) sequence (n=85), T2*-weighted sequence (n=46) and short-tau inversion recovery (STIR) sequence (n=12). Detected cerebellar or brainstem lesions were defined as central lesions and lesions located in the middle and inner ear or an absence of detectable lesions in MRI were attributed to peripheral disease. Lesions located only in the middle ear with neither clinical nor imaging presumption of an inner ear involvement were valued as incidental findings.

If CSF analysis, BAEP, otoscopy or other diagnostic tests had been performed, their results were also taken into account for the final differentiation as central or peripheral vestibular lesion. As defined in the current literature, if there were no detectable lesions on MRI and a lack of other diagnostic findings on CSF analysis or other diagnostic tests, idiopathic vestibular disease was the presumed diagnosis (Garosi *et al.* 2001, Rossmeisl 2010). Detected fluid or solid material in the tympanic bulla in addition to data from myringotomy or otoscopy indicated a presumed diagnosis of otitis media/interna, a polyp or neoplasia of the middle and/or inner ear (Platt & Olby 2004).

Differentiation between inflammatory and neoplastic lesions in the brain can be difficult in individual cases. For the confirmed or presumed diagnosis of neoplasia the results of blood tests, tumour staging investigation and lesion characteristics on MRI were considered (Thomas *et al.* 1996, Kraft *et al.* 1997, Rodenas *et al.* 2011, Bentley 2015). For the identification of inflammatory lesions the characteristics of the MRI lesion, its behaviour concerning contrast enhancement, the results of CSF analysis and blood results were considered (Tipold 1995, Kitagawa *et al.* 2004, 2007, Platt & Olby 2004, Talarico & Schatzberg 2010, Coates & Jeffery 2014, Cardy & Cornelis 2018).Presumed infarcts and bleeding caused by traumatic brain injury or presumed microbleeds were differentiated using MRI characteristics, case history and other diagnostic tests (Platt & Olby 2004, Garosi *et al.* 2006, Garosi 2010, Thomsen *et al.* 2016, Kerwin *et al.* 2017). Lesions in the brain with other aetiologies such as congenital malformation, abiotrophy or hydrocephalus were also differentiated as precisely as possible (De Lahunta & Glass 2009, Bernardino *et al.* 2015, Bertalan *et al.* 2014, Kwiatkowska *et al.* 2013, Laubner *et al.* 2015).

Outcome

A minimum follow-up period of 3 months was achieved in most cases (n=81). The outcome was classified as "alive for more than 3 months," if the dog was alive for at least 3 months after the presentation or had died for reasons unrelated to the vestibular syndrome after this point. If the dog had died from the vestibular disease or was euthanised on request of the owner because of the clinical condition itself or a poor prognosis, outcome was classified as "dead." If the medical record contained no outcome information the owners were contacted by telephone.

Statistical analysis

In order to compare occurrence of the syndrome in different dog breeds and outcome of dogs with PVD and CVD, a Chi-square test was used. Differences with $P<0.05$ were considered significant.

RESULTS

Ninety-three dogs fulfilled the inclusion criteria (Table S1, Supporting Information). The most frequently presented dogs were crossbreed (14 of 93; 15.1%) followed by French bulldogs (7 of 3; 7.5%). Compared to the general hospital population French bulldogs were significantly more frequently affected with vestibu-

lar disease in this study than other dog breeds. The ratio of vestibular French bulldogs to the total French bulldog population presented at the hospitals was compared with the ratio of vestibular dogs of other breeds to the total hospital population (chi-squared test=96; P<0.0001). Other frequently affected breeds were Jack Russell terriers, German shepherd dogs, boxers, Labrador and golden retrievers and Border collies. Median age was 7 years (range 1 month to 16 years). There was no sex predilection. Thirty (32.3%) dogs were presented with a peracute onset of vestibular signs, 28 (30.1%) had an acute onset of signs and in 35 (37.6%) dogs the vestibular signs had been noticed for more than 2 weeks at time of presentation. The distribution of disease onset was not significantly different for CVD and PVD. In the neurological examination 80 of 93 dogs (86%) showed a head tilt; additional clinical signs are listed in Table 1 and Table S1. Dogs without head tilt (13 of 93) showed vestibular ataxia and other signs of vestibular disease such as strabismus or nystagmus. Horizontal or rotatory nystagmus were the most frequent forms observed in PVD, whereas in CVD vertical, horizontal and rotatory nystagmus were observed most frequently and in equal numbers of dogs (Fig 1 and Table S1). Vertical nystagmus was observed five times more frequently in CVD than in PVD. In general, nystagmus occurred more frequently in PVD (19 of 25; 76%) than in CVD (16 of 68; 23.5%). Seventeen dogs showed facial nerve palsy (CVD seven of 68: 10.3%; PVD 10 of 25: 40%). Twenty-eight of the 93 dogs received glucocorticoids, in most cases at unknown dosage and unknown route of administration, before their presentation to one of the two study centres.

Table 1. Clinical neurological signs presented by the patients

Clinical neurological sign	Number of dogs
Head tilt	80
Ataxia	60
Strabismus	52
Nystagmus	35
General proprioceptive deficits in paw positioning	35
Abnormal postural reactions (hopping, hemiwalking, wheelbarrowing)	35
Cranial nerve deficits other than from nerve VII, VIII or the sympathetic nerve	26
Paresis	21

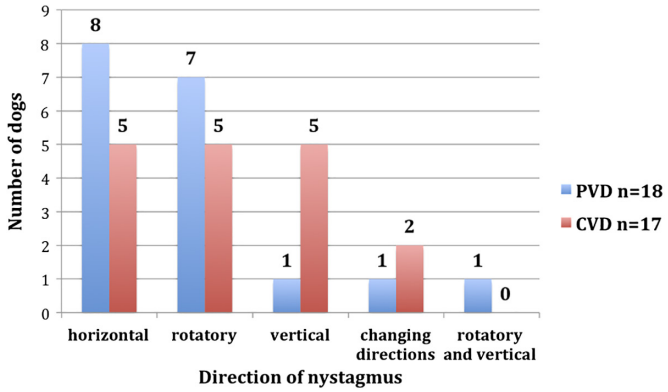

FIG 1. Different types of nystagmus in peripheral (PVD) and central vestibular disease (CVD)

Based on the neurological examination the lesion was localised to the central vestibular system in 62 dogs and to the peripheral vestibular system in 31 (Fig 2 and Table S1). According to evaluation of the MRI results, 68 dogs had a lesion in the central and 25 had a lesion in the peripheral vestibular system (Fig 2 and Table S1). Of the 25 dogs with a peripheral lesion, three had bilateral vestibular signs, all of which were diagnosed with an idiopathic bilateral vestibular syndrome. In these three patients MRI examination including administration of contrast detected no abnormalities. In two of the cases CSF analysis revealed no pathological findings. According to our distribution ratio (68:25), CVD occurred more often than PVD. Of 31 dogs with clinically presumed PVS, the localisation was confirmed by MRI in 24 (77.4%), while in seven the lesion was incorrectly localised to the peripheral vestibular system (Table 2). Of 62 dogs considered to have CVS according to the neurological examination, 61 (98.4%) had central vestibular disease confirmed by MRI. The only dog with a lesion that was incorrectly localised to the central vestibular system was diagnosed with a carcinoma of the middle ear. Therefore, the presumed clinical localisation through the neurological examination was correct in 85 of 93 cases, giving an accuracy of 91.4% (95% confidence interval: 85.7 to 97.1).

Peripheral vestibular disease

Twenty-five dogs were diagnosed as having PVD according to MRI. The majority of dogs (17 of 25; 68%) displayed characteristics of idiopathic vestibular syndrome. All of the lesions were localised to the peripheral vestibular system according to the neurological examination and had no specific findings on MRI. Three dogs with bilateral clinical signs were diagnosed with presumed bilateral idiopathic vestibular syndrome by exclusion of other differential diagnoses. The mean age of dogs with idiopathic vestibular syndrome in this study was 10 years, reflecting the commonly used term 'geriatric' or 'old dog' vestibular syndrome. Overall, 10 dogs with PVD showed facial nerve palsy, six

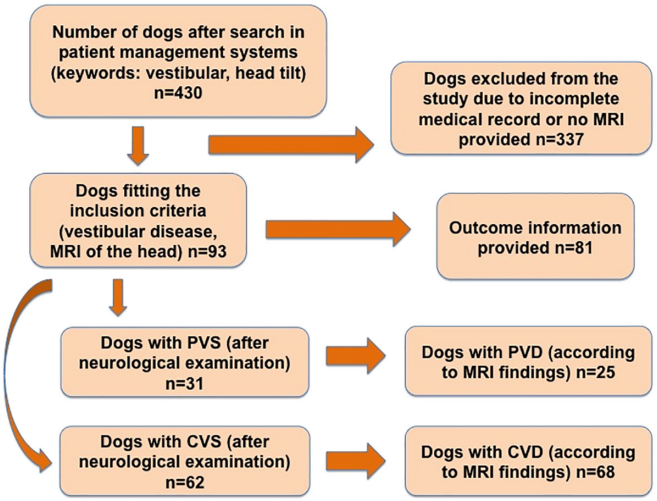

FIG 2. Flowchart describing the data search and the inclusion/exclusion of dogs with vestibular syndrome. CVD Central vestibular disease, CVS Central vestibular syndrome, PVD Peripheral vestibular disease; PVS Peripheral vestibular syndrome

Table 2. Data of dogs with central vestibular disease (CVD) localised to the peripheral vestibular system by neurological examination (n=7)

Breed	Age	Sex	Neurological examination findings	Diagnosis based on MRI	Other diagnostic test results
Shih-tzu	6 years	neutered female	Head tilt to the right, vestibular ataxia, ventral strabismus OD	Meningoencephalitis of unknown origin (MUO)	CSF – protein: 30.6 mmol/L leukocytes: 10 cells/µL segmented leukocytes: 15% lymphocytes: 77% monocytes: 8%, erythrocytes: 112 cells/µL Thyroid values within reference range
Chihuahua	6 years	male	Head tilt to the left, vestibular ataxia, left facial nerve palsy, ventral strabismus OS, horizontal nystagmus	Presumed necrotising meningoencephalitis (NME)	CSF – protein: 27.99 mmol/L leukocytes: 5 cells/µL erythrocytes: 2350 cells/µL
St. Bernard	6 months	male	Head tilt to the right, vestibular ataxia	Presumed microbleeds in the region of vestibular nuclei	CSF – protein: 19.5 mmol/L leukocytes: 0 cells/µL erythrocytes: 5 cells/µL
Golden retriever	4 months	male	Head tilt to the right, vestibular ataxia, ventral strabismus OD	MUO	CSF – protein: 10.2 mmol/L leukocytes: 0 cells/µL erythrocytes: 17 cells/µL
Crossbreed	10 years	female	Head tilt to the left, vestibular ataxia, rotatory nystagmus	Presumed neoplasia/ metastasis	CSF – leukocytes: 3 cells/µL Pandy test: negative Radiographs: thorax presumed metastasis
Labrador retriever	5 years	male	Head tilt to the right, vestibular ataxia, drifting to the right	Presumed multiple bleeding in the brain due to traumatic brain injury	CSF – protein: 42.41 mmol/l leukocytes: 5 cells/µL Radiographs: thorax unremarkable Thyroid values within reference range
French bulldog	3 years	male	Head tilt to the right, vestibular ataxia, right facial nerve palsy, horizontal nystagmus, ventral strabismus OD	Meningoencephalitis due to penetrating otitis media/ interna on the right side	CSF – leukocytes: 17 cells/µL erythrocytes: 9 cells/µL Radiographs: thorax and abdomen unremarkable, right bulla filled with solid material Thyroid values within reference range

Units and reference values – protein in cerebrospinal fluid (CSF) in mmol/L, reference interval: <25 mmol/L; Pandy test: detection of globulin in CSF; cells in CSF (leukocytes, erythrocytes) in number of cells/µL; reference interval for erythrocytes: 0/µL; reference interval for leucocytes: <5/µL; differential cell count (segmented leucocytes, lymphocytes, monocytes, eosinophilic granulocytes) in %; reference interval for thyroid values, thyroxine: 1.5 to 4.5 µmol/dL; canine thyroid stimulating hormone TSH<0.3 ng/mL; OD Oculus dexter, OS Oculus sinister.

of them had an idiopathic vestibular syndrome and no evidence of structural or inflammatory lesions responsible for facial nerve dysfunction. Therefore, facial nerve palsy was also considered to be idiopathic. Facial nerve palsy was associated with idiopathic vestibular disease in 35% cases. The remaining four dogs with peripheral vestibular disease had otitis media/interna, causing vestibular as well as facial nerve disorder. Two of these cases had obvious inner ear damage and the other two had massive lesions in the tympanic bulla with a presumptive effusion in the inner ear and were therefore designated as otitis media/interna. In cases with MRI findings of otitis media without obvious damage to the inner ear, an otitis media/interna was presumed because of clinical findings of vestibular syndrome, although otitis media as an incidental finding could not be completely ruled out. In all cases the facial nerve palsy was ipsilateral to the side of the head tilt. The second most frequent aetiology for peripheral lesions in this study was otitis media/interna (6 of 25; 24%). One dog was diagnosed with cholesteatoma and one had a carcinoma (presumably an undifferentiated squamous cell carcinoma) of the middle ear.

Central vestibular disease

According to MRI, 68 dogs were diagnosed with central vestibular disease. In 24 (35.3%) inflammatory conditions were diagnosed or presumed. Of those 24 dogs, 21 had meningoencephalitis of unknown origin (MUO). Nineteen dogs (27.9%) had a diagnosed or presumed neoplastic lesion affecting the brainstem or cerebellum. Histopathological confirmation of the tumour classification was available in seven cases and the other diagnoses were based on MRI characteristics. The confirmed or presumed diagnoses were meningioma (n=5), glioma (n=2), choroid plexus papilloma (n=2) and haemangiosarcoma, astrocytoma or malignant myoepithelioma (n=1 each). In seven dogs, neoplasia that was not further classified, was presumptively diagnosed by MRI.

Ten dogs (14.7%) had a presumed infarction in brainstem, cerebellum or thalamus. Four dogs showed intracranial lesions consistent with metabolic or degenerative disturbances of the cerebellum. In one case thiamine deficiency was proven and one dog was diagnosed with hypothyroidism, both dogs improved with adequate therapy. In the other two cases a final diagnosis for the central lesion could not be reached. Degenerative lesions of the cerebellum were suspected but further investigation, such as metabolic screening, was not permitted by the owners. Four dogs had presumed abiotrophy of the cerebellum. In three dogs, traumatic brain injury was diagnosed; one of these had bleeding only in the region of the vestibular nuclei, the other two had multiple bleeding sites in the brain. Two dogs were diagnosed with hydrocephalus and presumed increased intracranial pressure and secondary herniation of the cerebellum or atlanto-axial overlapping, respectively. Seven dogs showed facial nerve palsy. The underlying aetiology of the vestibular syndrome in those cases was neoplasia in four cases and inflammatory conditions in three. Seven dogs with central vestibular disease displayed clinical signs

suggesting a peripheral vestibular lesion according to the neurological examination. Further information concerning the diagnoses of these dogs is summarised in Table 2.

Outcome analysis

The medical records provided information for at least 3 months of follow-up for 43 dogs, the owners of 38 dogs were contacted by telephone for further information and 12 dogs were lost to follow-up. Twenty-six dogs died because of their vestibular dysfunction (Table S1). Of those 26 dogs, 23 were euthanised on request of the owner and three died spontaneously during their stay at the hospital or shortly after discharge after developing status epilepticus. Fifty-five dogs survived the disease for at least 3 month (55 of 81; 68%) and, at the time of writing, 36 dogs were still alive, 19 with residual vestibular signs such as mild ataxia or head tilt and 19 were dead for reasons other than the vestibular syndrome. More than half of all dogs survived at least 3 months after the first presentation - central vestibular disease: 41 of 62; 66.1% and peripheral vestibular disease: 14 of 19; 73.7%.

DISCUSSION

The presumed clinical localisation assessed by the neurological examination was correct in 85 of 93 cases giving an accuracy of more than 90%. Altogether this reflects a reliable result and is in agreement with another recent study (Boudreau *et al.* 2018). However, the consistency between neurological examination and MRI findings was more accurate for central than for peripheral vestibular disease, as described below.

Sixty-one of the 62 dogs (98.4%) with clinically defined central lesion localisation were correctly identified, indicating good reliability. On the other hand, for peripheral vestibular syndrome presumed lesion localisation was confirmed through MRI in only 24 of 31 dogs (77.4%). Consequently, seven dogs with peripheral vestibular signs were finally diagnosed with CVD according to MRI. This leads to the question as to whether central signs were just overlooked in these seven cases, not recognised by the examiner, or whether the progressive vestibular disease with delayed onset of central vestibular clinical signs is underestimated. As MRI was usually performed shortly after the clinical neurological examination the assumption of progressive clinical signs is unlikely. The most frequent aetiology of these lesions localised incorrectly by the neurological examination was inflammation. Inflammatory aetiologies often have a progressive course with deterioration of neurological signs (Tipold 1995, Kitagawa *et al.* 2004, 2007, Talarico & Schatzberg 2010, Coates & Jeffery 2014). Furthermore, in patients with otitis media/interna there is an increased risk of subsequent meningoencephalitis through spreading of the infection into the meninges and/or brain parenchyma (De Lahunta & Glass 2009). The second most frequent aetiology of lesions localised incorrectly as PVS by the neurological examination were diseases with a traumatic aetiology. In dogs with traumatic brain injury, oedema, bleeding or swelling of the tissue might occur (Platt & Olby 2004). These processes are not locally restricted and can expand inside the brain due to secondary tissue damage. In addition, some tumours, for example nerve sheath tumours, show a slow growth pattern. Slow tumour growth can lead to a progressive exacerbation of clinical signs and dogs might therefore be presented with progressive signs of vestibular disease with a delayed occurrence of central vestibular signs (Platt & Olby 2004). The findings are also in accordance with the study from Boudreau *et al.* (2018) stating that approximately one-third of dogs with only peripheral signs of vestibular dysfunction may have a central vestibular lesion subsequently identified by MRI. Pretreatment, especially with glucocorticoids, may attenuate or falsify neurological signs (Gomes *et al.* 2005) and potential central vestibular signs may not be recognised by the neurologist. Indeed, in the current study 28 of the 93 dogs received glucocorticosteroids before their presentation to a neurologist. However, only one of the seven dogs, with a lesion localised incorrectly in the peripheral vestibular system was pretreated with glucocorticoids and so it is unlikely that these drugs contributed to erroneous localisation in these cases. Only one dog was falsely localised to the central vestibular system. This dog had a carcinoma of the middle ear spreading into the surrounding extraneural tissue and developed behavioural changes which may have misled the examiner. Summarising all information, a clinically localised CVS is a very reliable finding. However, a peripheral localisation should be questioned, if the clinical signs of the dog are progressive or not responding to treatment. In those cases, MRI should definitely be recommended.

French bulldogs were statistically over-represented in this study. Primary brain tumours (Gough & Thomas 2004) or meningoencephalitis (Timmann *et al.* 2007, Coates & Jeffery 2014, Mayousse *et al.* 2017) are both common possible causes for vestibular dysfunction in French bulldogs and, furthermore, brachycephalic breeds are predisposed for the development of otitis media with effusion, which could also effect the inner ear (Hayes *et al.* 2010, Mayousse *et al.* 2017). In this study, only one French bulldog was diagnosed with a primary brain tumour and four were diagnosed with encephalitis, while the remaining two dogs were diagnosed with either an infarct or with otitis media/interna. Only one French bulldog was finally diagnosed with PVD due to otitis media/interna. In the study by Boudreau *et al.* (2018) the German shepherd dog was overrepresented compared to other dog breeds, central vestibular lesions occurred more frequently in Yorkshire terriers and Chihuahuas. In the present study the German shepherd dog was also a highly presented breed with vestibular disease.

The most common causes for peripheral vestibular dysfunction in this study were idiopathic vestibular syndrome and otitis media/interna. For central vestibular dysfunction inflammatory conditions, neoplasia and vascular disease were the most common aetiologies, which is in accordance with previous reports (Garosi *et al.* 2001, Negrin *et al.* 2010, Lorenz *et al.* 2011). Boudreau *et al.* (2018) diagnosed less than 40% of peripheral vestibular diseases as idiopathic vestibular syndrome. In contrast, in our current study approximately 70% of dogs with PVD were diagnosed with idiopathic vestibular disease. We also diagnosed central vestibular disease more frequently than peripheral disease and other recent reports showed similar results (Garosi *et al.* 2001,

Steenbeck 2007, Boudreau *et al*. 2018). This leads to the question as to why peripheral vestibular disease occurred less often than central vestibular disease in these study populations. Dogs with clinical signs of peripheral vestibular syndrome might not always undergo MRI and are frequently treated symptomatically. Dogs presented at the two institutions with otitis media/interna were therefore frequently not included in the current study. Only patients not responding to the first treatment attempt get a more advanced diagnostic work-up including MRI which was an inclusion criterion for this study. Dogs that responded to the first treatment attempt were excluded from the study (Fig 2), leading to bias towards cases with CVD in studies using MRI as gold standard.

Among the dogs with peripheral vestibular disease, three showed bilateral vestibular signs, all of them localised in the peripheral vestibular system according to the neurological examination. The aetiology of the disease was presumably idiopathic in these dogs, even though the most common cause for bilateral vestibular syndrome described is bilateral otitis media/interna (De Lahunta & Glass 2009).

In addition to the typical clinical vestibular signs, 17 dogs showed facial nerve palsy in the current study. Vestibular dysfunction was localised as a peripheral in 10 cases and central in the remaining seven. For peripheral facial nerve palsy the causative disease can be otitis, neoplasia, neuritis or idiopathic conditions and for central facial nerve palsy inflammatory or neoplastic conditions are the most common underlying aetiologies (Ricco 2016). Our results support these findings. PVD combined with facial nerve deficits was presumably induced by idiopathic conditions in the current study population. In other studies similar findings of concurrent facial nerve palsy with idiopathic vestibular syndrome were described and different hypotheses were discussed (Garosi *et al*. 2001, Jeandel *et al*. 2016). Underlying inner ear disease could possibly not be detected using MRI if lesions were very small (Garosi *et al*. 2001) or early stages of inflammatory disease might also be overlooked (Jeandel *et al*. 2016). A recent study including 69 dogs with facial nerve paresis considered almost half to be idiopathic and even 36% of all cases were diagnosed with idiopathic facial nerve paresis and idiopathic vestibular syndrome (Ricco 2016).

Outcome analysis was possible in 81 cases (87.1%).Other studies (De Lahunta & Glass 2009, Negrin *et al*. 2010, Lowrie 2012) consider that the outcome of animals with peripheral lesions is better than of animals with central lesions but our data does not support this assumption. The bias in our study arising from MRI examination of the head as an inclusion criterion would exclude dogs with mild peripheral vestibular signs that are most likely to recover without a complete diagnostic work-up. In addition, dogs with a more severe form of peripheral vestibular syndrome might perhaps be diagnosed with a therapy-resistant form of otitis media/interna. Such cases often require long-term and intensive therapy, sometimes additional surgical intervention and in some cases the conditions are not curable at all (Jacobson 2002, Gotthelf 2004, Lorenz *et al*. 2011). On the other hand, some diseases causing central vestibular signs such as vascular lesions or some inflammatory diseases have a good prognosis, leading to complete or partial recovery (Lowrie 2012). These considerations can explain why our study does not support previous assumptions regarding relationship of localisation with prognosis and, instead, emphasise the importance of aetiology. Therefore, every patient should be considered individually regarding aetiology and treatment options.

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Conflict of interest

None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

References

Bayens-Simmonds, J., Purcell, T. P. & Nation, N. P. (1997) Use of magnetic resonance imaging in the diagnosis of central vestibular disease. *The Canadian Veterinary Journal* **38**, 38

Bentley, R. T. (2015) Magnetic resonance imaging diagnosis of brain tumors in dogs. *Veterinary Journal* **205**, 204-216

Bernardino, F., Rentmeister, K., Schmidt, M. J., *et al*. (2015) Inferior cerebellar hypoplasia resembling a Dandy-Walker-like malformation in purebred Eurasier dogs with familial non-progressive ataxia: a retrospective and prospective clinical cohort study. *PLoS One* **10**, e0117670

Bertalan, A., Glass, E. N., Kent, M., *et al*. (2014) Late-onset cerebellar abiotrophy in a Labrador retriever. *Australian Veterinary Journal* **92**, 339-342

Boudreau, C. E., Dominguez, C. E., Levine, J. M., *et al*. (2018) Reliability of interpretation of neurologic examination findings for the localization of vestibular dysfunction in dogs. *Journal of the American Veterinary Medical Association* **252**, 830-838

Cardy, T. J. A. & Cornelis, I. (2018) Clinical presentation and magnetic resonance imaging findings in 11 dogs with eosinophilic meningoencephalitis of unknown aetiology. *The Journal of Small Animal Practice* **59**, 422-431

Coates, J. R. & Jeffery, N. D. (2014) Perspectives on meningoencephalomyelitis of unknown origin. *The Veterinary Clinics of North America. Small Animal Practice* **44**, 1157-1185

De Lahunta, A. & Glass, E. (2009) Vestibular System- Special Proprioception. *Veterinary Neuroanatomy and Clinical Neurology*. 3rd edn. Saunders Elsevier, St. Louis, MO, USA

Dvir, E., Kirberger, R. M. & Terblanche, A. G. (2000) Magnetic resonance imaging of otitis media in a dog. *Veterinary Radiology & Ultrasound* **41**, 46-49

Fluehmann, G., Doherr, M. G. & Jaggy, A. (2006) Canine neurological diseases in a referral hospital population between 1989 and 2000 in Switzerland. *The Journal of Small Animal Practice* **47**, 582-587

Garosi, L., Mcconnell, J. F., Platt, S. R., *et al*. (2006) Clinical and topographic magnetic resonance characteristics of suspected brain infarction in 40 dogs. *Journal of Veterinary Internal Medicine* **20**, 311-321

Garosi, L. S. (2010) Cerebrovascular disease in dogs and cats. *The Veterinary Clinics of North America. Small Animal Practice* **40**, 65-79

Garosi, L. S., Dennis, R., Penderis, J., *et al*. (2001) Results of magnetic resonance imaging in dogs with vestibular disorders: 85 cases (1996-1999). *Journal of the American Veterinary Medical Association* **218**, 385-391

Gomes, J. A., Stevens, R. D., 3rd Lewin, J. J., *et al*. (2005) Glucocorticoid therapy in neurologic critical care. *Critical Care Medicine* **33**, 1214-1224

Gotthelf, L. N. (2004) Diagnosis and treatment of otitis media in dogs and cats. *The Veterinary Clinics of North America. Small Animal Practice* **34**, 469-487

Gough, A. & Thomas, A. (2004) Breed Predispositions to Disease in Dogs and Cats. Blackwell Publishing, Oxford, UK

Hayes, G. M., Friend, E. J. & Jeffery, N. D. (2010) Relationship between pharyngeal conformation and otitis media with effusion in cavalier king Charles spaniels. *The Veterinary Record* **167**, 55-58

Jacobson, L. S. (2002) Diagnosis and medical treatment of otitis externa in the dog and cat. *Journal of the South African Veterinary Association* **73**, 162-170

Jeandel, A., Thibaud, J. L. & Blot, S. (2016) Facial and vestibular neuropathy of unknown origin in 16 dogs. *The Journal of Small Animal Practice* **57**, 74-78

Kerwin, S. C., Levine, J. M., Budke, C. M., *et al*. (2017) Putative cerebral microbleeds in dogs undergoing magnetic resonance imaging of the head: aretrospective study of demographics, clinical associations, and relationship to case outcome. *Journal of Veterinary Internal Medicine* **31**, 1140-1148

Kitagawa, M., Kanayama, K., Satoh, T., *et al*. (2004) Cerebellar focal granulomatous meningoencephalitis in a dog: clinical findings and MR imaging. *Journal of Veterinary Medicine. A, Physiology, Pathology, Clinical Medicine* **51**, 277-279

Kitagawa, M., Okada, M., Kanayama, K., *et al*. (2007) A canine case of necrotizing meningoencephalitis for long-term observation: clinical and MRI findings. *The Journal of Veterinary Medical Science* **69**, 1195-1198

Kraft, S. L., Gavin, P. R., Dehaan, C., *et al*. (1997) Retrospective review of 50 canine intracranial tumors evaluated by magnetic resonance imaging. *Journal of Veterinary Internal Medicine* **11**, 218-225

Kwiatkowska, M., Pomianowski, A., Adamiak, Z., *et al*. (2013) Magnetic resonance imaging and brainstem auditory evoked responses in the diagnosis of cerebellar cortical degeneration in American staffordshire terriers. *Acta Veterinaria Hungarica* **61**, 9-18

Laubner, S., Ondreka, N., Failing, K., *et al*. (2015) Magnetic resonance imaging signs of high intraventricular pressure – comparison of findings in dogs with clinically relevant internal hydrocephalus and asymptomatic dogs with ventriculomegaly. *BMC Veterinary Research* **11**, 181

Lorenz, M., Coates, J. & Kent, M. (2011) Handbook of Veterinary Neurology. Elsevier Saunders, St. Louis, MO, USA

Lowrie, M. (2012) Vestibular disease: diseases causing vestibular signs. *Compendium: Continuing Education for Veterinarian* **34**, E2

Markovich, J. E., Heinze, C. R. & Freeman, L. M. (2013) Thiamine deficiency in dogs and cats. *Journal of the American Veterinary Medical Association* **243**, 649-656

Mayousse, V., Desquilbet, L., Jeandel, A., *et al*. (2017) Prevalence of neurological disorders in French bulldog: a retrospective study of 343 cases (2002-2016). *BMC Veterinary Research* **13**, 212

Negrin, A., Cherubini, G. B., Lamb, C., *et al*. (2010) Clinical signs, magnetic resonance imaging findings and outcome in 77 cats with vestibular disease: a retrospective study. *Journal of Feline Medicine and Surgery* **12**, 291-299

Platt, S. & Olby, N. (2004) BSAVA Manual of Canine and Feline Neurology BSAVA Manual of Canine and Feline Neurology. British Small Animal Veterinary Association, Quedgeley, UK

Ricco, C. (2016) Facial nerve paralysis in dogs: a retrospective study of 69 cases. Proceedings 29th Symposium ESVN-ECVN Edinburgh, United Kingdom 16th–17th September 2016. *Journal of Veterinary Internal Medicine* **30**, 1929-1955

Rodenas, S., Pumarola, M., Gaitero, L., *et al*. (2011) Magnetic resonance imaging findings in 40 dogs with histologically confirmed intracranial tumours. *Veterinary Journal* **187**, 85-91

Rossmeisl Jr, J. H. (2010) Vestibular disease in dogs and cats. *The Veterinary Clinics of North America. Small Animal Practice* **40**, 81-100

Steenbeck, S. 2007 Retrospective analyse prognostischer faktoren beim vestibularsyndrom des hundes. Dissertation. Ludwig-Maximilian-Universität München

Talarico, L. R. & Schatzberg, S. J. (2010) Idiopathic granulomatous and necrotising inflammatory disorders of the canine central nervous system: a review and future perspectives. *The Journal of Small Animal Practice* **51**, 138-149

Thomas, W. B., Wheeler, S. J., Kramer, R., *et al*. (1996) Magnetic resonance imaging features of primary brain tumors in dogs. *Veterinary Radiology & Ultrasound* **37**, 20-27

Thomsen, B., Garosi, L., Skerritt, G., *et al*. (2016) Neurological signs in 23 dogs with suspected rostral cerebellar ischaemic stroke. *Acta Veterinaria Scandinavica* **58**, 40

Timmann, D., Konar, M., Howard, J., *et al*. (2007) Necrotising encephalitis in a French bulldog. *The Journal of Small Animal Practice* **48**, 339-342

Tipold, A. (1995) Diagnosis of inflammatory and infectious diseases of the central nervous system in dogs: a retrospective study. *Journal of Veterinary Internal Medicine* **9**, 304-314

Troxel, M. T., Drobatz, K. J. & Vite, C. H. (2005) Signs of neurologic dysfunction in dogs with central versus peripheral vestibular disease. *Journal of the American Veterinary Medical Association* **227**, 570-574

Supporting Information

The following supporting information is available for this article:

Table S1. Signalment, clinical signs, neurolocalisation, disease, outcome and lesion localisation after MRI examination.