

Results of magnetic resonance imaging in dogs with vestibular disorders: 85 cases (1996–1999)

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Objective—To determine results of magnetic resonance (MR) imaging in dogs with vestibular disorders (VD) and correlate results of MR imaging with clinical findings.

Design—Retrospective study.

Animals—85 dogs.

Procedure—Information on signalment, clinical signs, and presumptive lesion location was obtained from the medical records, and MR images were reviewed.

Results—27 dogs had peripheral VD, 37 had central VD, and 21 had paradoxical VD. Of the 27 dogs with peripheral VD, 11 (41%) had MR imaging abnormalities involving the ipsilateral tympanic bulla compatible with otitis media (6 also had abnormalities involving the petrous portion of the ipsilateral temporal bone compatible with otitis interna), 7 (26%) had MR imaging abnormalities compatible with middle ear neoplasia, 2 (7%) had an ipsilateral cerebellopontine angle lesion, and 7 (26%) did not have MR imaging abnormalities. All dogs with central and paradoxical VD had abnormalities evident on MR images. Of the 37 dogs with central VD, 13 (35%) had an extra-axial lesion, 6 (16%) had an intra-axial lesion, and 18 (49%) had multiple intra-axial lesions. In 23 (62%) dogs with central VD, lesions on MR images corresponded with location suspected on the basis of clinical signs. Of the 21 dogs with paradoxical VD, 12 (57%) had an extra-axial lesion, 5 (24%) had an intra-axial lesion, and 4 (19%) had multiple intra-axial lesions. Location of lesions on MR images agreed with location suspected on the basis of clinical signs in 19 (90%) dogs.

Conclusions and Clinical Relevance—Results suggest that MR imaging may be helpful in the diagnosis and treatment of VD in dogs. (*J Am Vet Med Assoc* 2001;218:385–391)

Vestibular disorders (VD) are common in dogs and cats and may result in any or all of the following clinical signs: head tilt, falling, rolling, circling, abnormal nystagmus, positional strabismus, and asymmetric ataxia.^{1–3} Clinical signs may be a result of lesions involving the receptor organs in the inner ear or the vestibular portion of the eighth cranial nerve (ie, peripheral VD) or lesions involving the brainstem vestibular nuclei (ie, central VD). Less frequently, lesions affecting the caudal cerebellar peduncle, the

fastigial nucleus, or the flocculonodular lobes of the cerebellum can cause paradoxical VD.⁴ Most lesions affect a region, rather than a specific nerve or nucleus, so accompanying neurologic abnormalities can often be used to localize the lesion. Both peripheral and central VD can cause a head tilt, horizontal or rotatory nystagmus, and ataxia. However, central lesions that affect the vestibular system often involve the reticular formation as well as ascending and descending motor and sensory pathways to the ipsilateral limbs. Therefore, abnormal mental status, ipsilateral paresis, and conscious proprioceptive deficits are commonly associated with central VD. With peripheral and central VD, the head is usually tilted in the direction of the lesion. With paradoxical VD, however, the head is usually tilted opposite to the direction of the lesion.⁴

Disease processes that can cause peripheral VD include inflammation (infectious or noninfectious), neoplasia, trauma, toxicosis, hypothyroidism, and polyneuropathy.^{3,4} Idiopathic peripheral VD occur sporadically, especially in geriatric dogs.⁴ Central VD appears to most often be a result of tumors (eg, meningiomas and choroid plexus tumors) and inflammatory diseases. Other conditions such as trauma and vascular disease seem to be less common causes of central VD.³

Many of the tests used to diagnose VD in dogs and cats such as analysis of CSF, recording brainstem auditory-evoked potentials, radiography, and cerebral angiography are insensitive or yield nonspecific results.^{3–14} The use of computed tomography to evaluate middle and inner ear disease and lesions of the caudal fossa in dogs has been described.^{9,12,15,16} Computed tomography is more sensitive for detection of otitis media than is radiography,⁹ but artifacts induced by the petrous portion of the temporal bone limit examination of the caudal fossa.¹⁷ **Magnetic resonance (MR)** imaging of the inner ear and cerebellopontine angle in humans has been extensively reported,^{18–24} and the normal anatomy of the canine brain²⁵ and results of MR imaging of dogs with a variety of CNS disorders have been reviewed.^{26–32} In addition, multiple single reports of results of MR imaging in dogs with VD have been published^{17,28,29,33–37}; however, to our knowledge, results of MR imaging of a large group of dogs with VD have not been published previously. Therefore, the purposes of the study reported here were to determine results of MR imaging in a large series of dogs with VD and to correlate results of MR imaging with clinical findings.

Criteria for Selection of Cases

Medical records of all dogs examined at the Animal Health Trust, Centre for Small Animal Studies,

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Kentford, England and at the Department of Small Animal Medicine and Surgery, Royal Veterinary College, London, England between 1996 and 1999 because of VD were reviewed. Dogs that underwent MR imaging of the skull as part of the diagnostic investigation were eligible for inclusion in the study.

Procedures

Information on signalment and results of diagnostic testing was obtained from the medical records. A full neurologic examination¹ had been performed on all dogs, and results of the neurologic examination (including whether the dog had a head tilt, postural reaction deficits, or signs of upper motor neuron involvement, abnormal mentation, or cranial nerve deficits other than deficits of cranial nerve VIII) were used to classify dogs as having a peripheral, central, or paradoxical VD. When available, definitive diagnoses were reviewed, as were results of histologic examination of surgical and necropsy specimens, bacterial culture of samples obtained by means of myringotomy, analysis of CSF samples, and necropsy.

Magnetic resonance imaging—Magnetic resonance images of the skull that were obtained included transverse, dorsal, and sagittal T1-weighted images acquired before and immediately after injection of gadopentetate dimeglumine^a (0.1 mmol/kg [0.045 mmol/lb] of body weight) or gadodiamide^b and T2-weighted images. Images were reviewed retrospectively by a board-certified radiologist (CRL) who was not aware of the clinical findings, and the following information was recorded: anatomic site, location, and distribution of visible lesions; signal intensity; gadolinium-enhancement pattern; and whether there was evidence of a mass effect, edema, or ventricular enlargement. Anatomic site was classified as tympanic bulla, inner ear, brainstem, cerebellopontine angle, cerebellum, or forebrain. Location was classified as intra-axial or extra-axial. Distribution was classified as a single or multiple lesions. Signal intensity was classified as hypointense, isointense, hyperintense, or mixed, compared with normal-appearing cortical gray matter on T1- and T2-weighted images. Signal intensity within the lesion was classified as homogeneous or heterogeneous, and the border of the signal abnormality was characterized as well-defined or ill-defined. Contrast enhancement was characterized as absent, mild, or marked. If contrast enhancement was seen, it was classified as homogeneous, heterogeneous, or ring-like. Physical displacement of adjacent regions of normal brain tissue was considered evidence of a mass effect. Amount of edema was determined on the basis of the extent of abnormal hyperintensity on T2-weighted images that exceeded the area of contrast enhancement on gadolinium-enhanced T1-weighted images. Amount of edema was graded as absent, mild, or marked.

Results

Eighty-five dogs representing a large variety of breeds met the criteria for inclusion in the study. None of the breeds appeared to be overrepresented, compared with the overall hospital population. Median age

of affected dogs was 6.8 years (range, 0.2 to 16 years). Forty-two were male, and 43 were female.

Twenty-seven of the 85 (32%) dogs (15 male, 12 female) had signs consistent with a peripheral VD (median age, 6.5 years; range, 2 to 14 years), 37 (43%) dogs (17 male, 20 female) had signs consistent with a central VD (median age, 6.5 years; range, 0.2 to 11 years), and 21 (25%) dogs (11 male, 10 female) had signs consistent with a paradoxical VD (median age, 7.9 years; range, 2 to 16 years). All 27 dogs with a peripheral VD, 24 of the 37 (65%) dogs with a central VD, and 17 of the 21 (80%) dogs with a paradoxical VD had clinical signs suggestive of a focal lesion. The remaining dogs had signs suggestive of multifocal lesions.

Dogs with peripheral VD—Of the 27 dogs with a peripheral VD, 20 (74%) had MR imaging abnormalities. In 18, abnormalities consisted of a single lesion localized to the middle or inner ear. Two dogs had an extra-axial lesion affecting the ipsilateral cerebellopontine angle. The remaining 7 (26%) dogs did not have any detectable lesions on MR images.

Eleven dogs had abnormalities on MR images affecting the ipsilateral tympanic bulla that included 1 or more of the following features: gadolinium ring enhancement along the inner margin of the ipsilateral tympanic bulla (9 dogs; Fig 1), hyperintense material filling the tympanic bulla on T2-weighted images (10 dogs; Fig 2), and isointense material filling the tympanic bulla on T1-weighted images (7 dogs). No bony changes were detected, and findings were considered compatible with a diagnosis of otitis media. The diagnosis was confirmed on the basis of results of bacterial culture of material obtained by means of myringotomy in 9 dogs. For 4 other dogs with peripheral VD, bacterial culture of material obtained by means of myringotomy did not yield any growth.

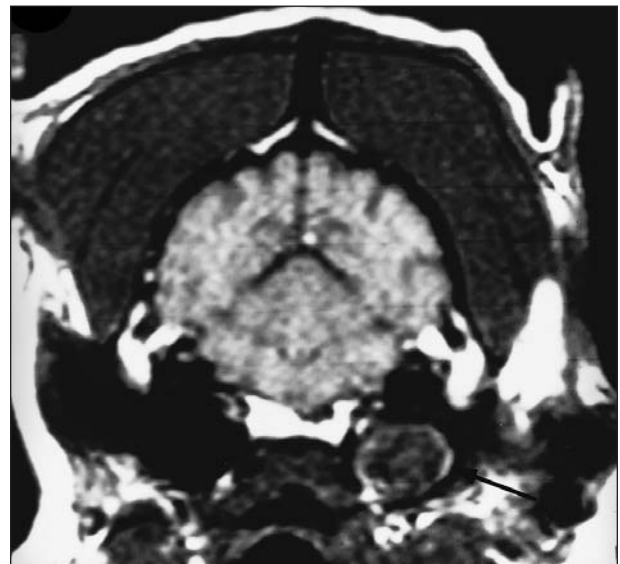


Figure 1—Transverse T1-weighted magnetic resonance image at the level of the tympanic bullae obtained following IV administration of gadopentetate dimeglumine in a 9-year-old dog with a left-sided vestibular disorder and confirmed otitis media. The normal air-filled right bulla is evident as a signal void. The affected left bulla contains material isointense to neural tissue with a narrow hyperintense rim (arrow).



Figure 2—Transverse T2-weighted magnetic resonance image at the level of the tympanic bullae in a 6-year-old dog with a right-sided vestibular disorder and confirmed otitis media. The image was obtained with the dog in dorsal recumbency. Hyperintense free fluid is visible in the right tympanic bulla (arrowhead).



Figure 3—Transverse T2-weighted fast spin-echo volume magnetic resonance image at the level of the tympanic bullae in a 7-year-old dog with a left-sided vestibular disorder that was confirmed to have otitis media and suspected to have otitis interna. The left bulla contains material that is isointense to neural tissue with a hyperintense rim compatible with surrounding fluid. Fluid within the membranous labyrinth of the normal right inner ear is visible as a curved structure with a high signal intensity (white arrow). There is a lack of a similar fluid signal from the left inner ear (open arrow). (Reproduced with permission from Garosi LS, Lamb CR, Targett MP. Magnetic resonance imaging findings in a dog with otitis media and suspected otitis interna. *Vet Rec* 2000;146:501–502.)

Six dogs with peripheral VD also had abnormalities on MR images affecting the petrous portion of the ipsilateral temporal bone characterized by gadolinium contrast enhancement on T1-weighted images and absence of the normally visible intra-labyrinthine fluid signal on T2-weighted images (Fig 3). These findings were considered compatible with a diagnosis of otitis interna. Two dogs in which results of MR imaging were

compatible with otitis media and 1 dog in which results of MR imaging were compatible with otitis interna had hyperintense foci on T2-weighted images corresponding to the site of the ipsilateral vestibular nerve.

Two dogs with peripheral VD had an extra-axial lesion affecting the ipsilateral cerebellopontine angle.

A neoplastic lesion affecting the middle or inner ear structures was suspected in 7 (26%) of the dogs with peripheral VD and confirmed histologically in 4. Histological diagnoses were carcinoma (2 dogs), sarcoma (1), and osteosarcoma (1; Fig 4). All dogs suspected or confirmed to have neoplasia had evidence of destruction of the tympanic bulla and local invasion of adjacent structures on MR images. Extension to the caudal fossa was observed in 2 dogs.

Seven (26%) of the dogs with peripheral VD had no demonstrable abnormalities on MR images. Results of CSF analyses and thyroid stimulating hormone (TSH) tests were normal in these dogs. Two of these dogs had concurrent facial paralysis, and 1 had concurrent Horner's syndrome.

Dogs with central VD—All 37 dogs with clinical signs of a central VD had abnormalities on MR images, including a single extra-axial lesion (13 dogs), a single intra-axial lesion (6), and multiple intra-axial lesions (18; Fig 5). Dogs with single lesions had lesions of the brainstem (12 dogs), cerebellopontine angle (2), cerebellum (2), or cerebrum (3). All 18 dogs with multiple lesions had lesions of the brainstem.

On the basis of side and distribution of the lesion, results of MR imaging agreed with the expected clinical localization in 23 (62%) of the dogs with a central VD. Thirty-three (89%) dogs with a central VD had lesions on MR images affecting the ipsilateral vestibular structures, and 4 had lesions affecting the contralateral structures. Of these 4 dogs, 2 had multiple intra-axial lesions with no evidence of a mass effect, and 2 had a single intra-axial lesion with evidence of a mass effect affecting the contralateral part of the cranial myelencephalon.

Fifteen of the 24 dogs with clinical signs of a focal

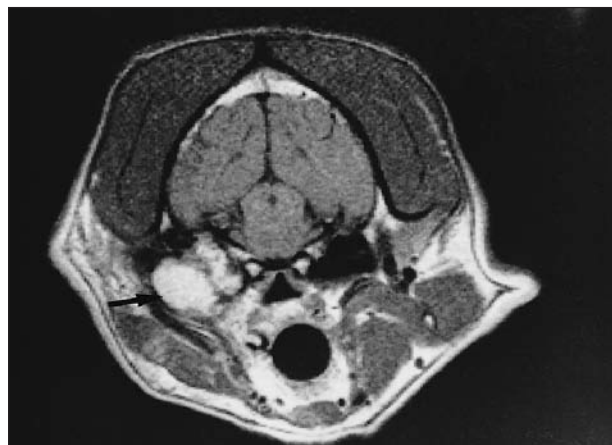


Figure 4—Transverse T1-weighted magnetic resonance image at the level of the tympanic bullae obtained after IV administration of gadolinium contrast in an 11-year-old dog with a progressive right-sided peripheral vestibular disorder, Horner's syndrome, and dysphagia. An ill-defined hyperintense mass destroying the right middle and inner ears (arrow) is evident. The histologic diagnosis was osteosarcoma.

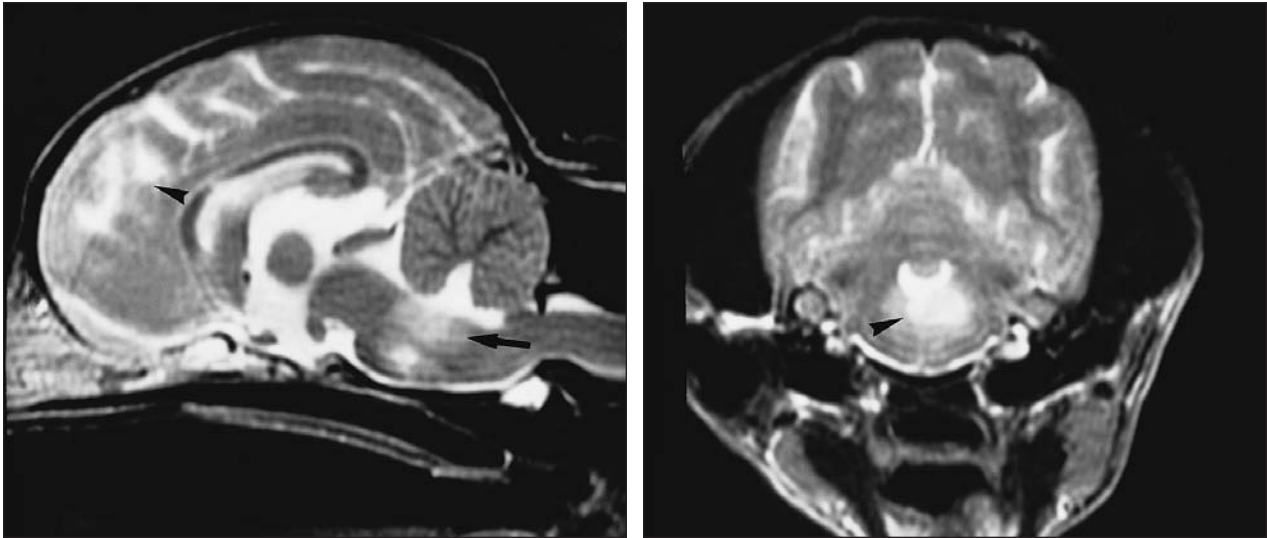


Figure 5—Sagittal (left) and transverse (right) T2-weighted magnetic resonance images of a 7-year-old dog with an acute left-sided central vestibular disorder. On the sagittal image, ill-defined hyperintense intra-axial lesions at the level of the myelencephalon (arrow) and frontal lobe (arrowhead) can be seen. On the transverse image, an ill-defined hyperintense intra-axial lesion affecting the left vestibular nuclei (arrowhead) can be seen. Results of CSF evaluation were compatible with a diagnosis of nonsuppurative meningoencephalitis.



Figure 6—Dorsal T1-weighted magnetic resonance image at the level of the fourth ventricle obtained after IV administration of gadolinium contrast in a 7-year-old dog with a progressive left-sided paradoxical vestibular disorder. A well-defined hyperintense extra-axial mass (arrowhead) is affecting the left cerebellopontine angle and resulting in a severe mass effect compressing the fourth ventricle. The histologic diagnosis was choroid plexus papilloma.

lesion had a single lesion localized to the caudal fossa on MR images. Nine of the 13 dogs with clinical signs of multifocal lesions had multiple lesions on MR images, and 4 had only a single lesion. Of these 4 dogs, 3 had a solitary forebrain lesion on MR images that did not appear to involve the vestibular structures, and 1

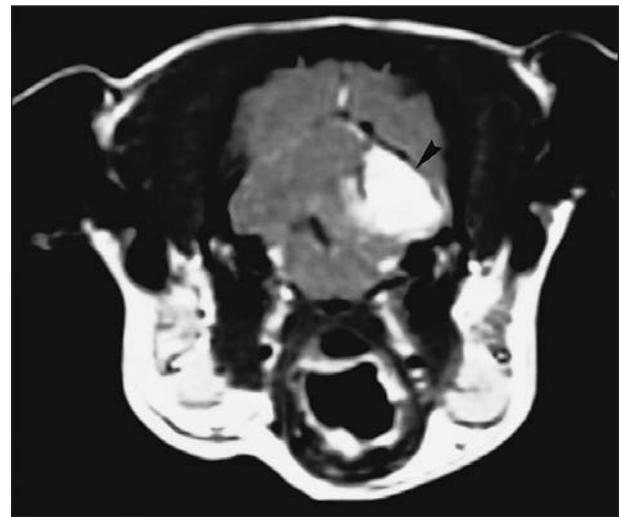


Figure 7—Transverse T1-weighted magnetic resonance image at the level of the fourth ventricle obtained after IV administration of gadolinium contrast in a 9-year-old dog with a progressive right-sided paradoxical vestibular disorder. A well-defined hyperintense extra-axial mass (arrowhead) affecting the left cerebellar hemisphere is evident. The histologic diagnosis was meningioma.

had hydrocephalus with dilatation of the lateral, third, and fourth ventricles as the only detectable lesion that could be related to the vestibular disorder.

All 13 dogs with extra-axial lesions had a single lesion on MR images, and in all 13 of these dogs, clinical signs were suggestive of a focal lesion. Nine of the 18 dogs with multiple intra-axial lesions on MR images had clinical signs suggestive of multifocal lesions.

Dogs with paradoxical VD—All 21 dogs with a paradoxical VD had MR imaging abnormalities, including a single extra-axial lesion (12 dogs; Fig 6 and 7), a single intra-axial lesion (5), and multiple intra-axial lesions (4). Dogs with single lesions had lesions of the brainstem (2 dogs), cerebellopontine

angle (9), or cerebellum (6). Dogs with multiple lesions had lesions of the brainstem (2 dogs), cerebellopontine angle (1), or cerebellum (1).

On the basis of the side and distribution of the lesion, results of MR imaging agreed with the expected clinical localization in 19 (90%) of the dogs with a paradoxical VD. These 19 dogs had lesions on MR images affecting the ipsilateral vestibular structures. Two dogs with contralateral clinical signs had a single intra-axial lesion affecting the cerebellopontine angle with signs of a mass effect and mild edema. Two dogs with a single intra-axial lesion affecting the contralateral cerebellar hemisphere had signs of a marked mass effect involving the hemisphere ipsilateral to the side suspected to be affected on the basis of clinical signs. All 17 dogs with clinical signs of a focal lesion had a single lesion on MR images, and all 4 with clinical signs of multifocal lesions had multiple lesions on MR images.

Discussion

Peripheral VD are pathologic processes that affect the inner ear, vestibular ganglion, or vestibular portion of cranial nerve VIII.³⁸ In the past, evaluation of inner ear abnormalities relied on radiography or computed tomography of the middle ear,^{9,11} as otitis interna does not produce radiographic abnormalities in most affected animals, and abnormalities of the inner ear are poorly, if ever, evident on computed tomographs. For this reason, a diagnosis of otitis interna was often made on the basis of clinical signs and radiographic evidence of otitis media.¹²

In people, MR imaging has provided a new method of evaluating abnormalities of the inner ear.^{18,23} Previous studies, however, have emphasized the need for unique imaging parameters for analysis of this complex anatomic region.²³ The inner ear structures are extremely small and require a thin slice thickness to allow visualization in any detail. Because most standard MR imaging protocols image the brain using 3.5- to 5-mm-thick sections, the inner ear structures may not appear in their entirety. Thus, MR images of the inner ear are best obtained by use of a volume acquisition procedure with slice thickness < 2 mm, and volume acquisition has become the gold standard for imaging the intra-labyrinthine structures in humans. Volume acquisition represents an alternative to production of thin slices. Instead of acquiring data from individual 2-mm-thick slices, the whole of the imaging volume is excited, and the resulting data are reconstructed with the specified number of slices and slice thickness. Volume acquisition with T2-weighted fast spin-echo images is particularly useful to demonstrate the normal intra-labyrinthine fluid because of its high signal intensity contrasting with the surrounding bony labyrinth (signal void).²³ Such MR imaging protocols allow visualization of anatomic detail and various pathologic lesions of the membranous labyrinth. For instance, with chronic otitis interna, fibrous obliteration of the fluid-containing spaces of the inner ear can be detected as an absence of signal in T2-weighted images of the affected side.^{18,22,29} A major step forward in the investigation of inner ear abnormalities was

achieved with the introduction of gadolinium-enhanced MR imaging. Examination of T1-weighted images obtained after administration of contrast allows detection of intra-labyrinthine abnormalities such as labyrinthitis.^{22,23,39} During the acute phase of labyrinthitis, gadolinium may enhance the membranous labyrinth as a result of leakage of gadolinium into intra-labyrinthine fluid following breakdown of the hematoperilymphatic barrier or uptake of gadolinium by inflammatory tissue.²³

Results of MR imaging in a dog with otitis media that was also suspected to have otitis interna have been described.³⁷ In the present study, 6 dogs had MR imaging evidence of otitis interna. In all 6 dogs, the normal signal from the intra-labyrinthine fluid contrasting with the surrounding bony labyrinth was not seen on T2-weighted images, suggesting that the fluid-containing spaces of the inner ear had been replaced with fibrous tissue.

On the other hand, the normal signal from intra-labyrinthine fluid in the unaffected inner ear could be seen in only 8 of the dogs with a peripheral VD. This emphasizes the lack of sensitivity of MR imaging protocols used to investigate inner ear abnormalities. Because most protocols involve collection of 3- to 5-mm-thick sections, definition of the cochlea and semi-circular canals may be affected by partial volume-averaging artifacts. Furthermore, in most of the dogs in the present study, MR images used to evaluate possible causes of peripheral VD were obtained with spin-echo sequences optimized for the brain (T2-weighted images with TR = 2,000 to 2,500 milliseconds and TE = 80 to 120 milliseconds and T1-weighted images with TR = 400 to 500 milliseconds and TE = 12 to 25 milliseconds). Pulse sequences that would be considered optimal for inner ear structures on the basis of studies in humans were used in only 2 dogs in the present study (T2-weighted fast spin-echo volume images with TR = 4,000 milliseconds and TE = 250 milliseconds and T1-weighted images with TR = 487 milliseconds and TE = 25 milliseconds). In these 2 dogs, the volume sequence had a slice thickness of 0.75 mm overcontiguous, resulting in 1.5-mm-thick slices with no slice gap but with each slice overlapping the 1 before it by 0.75 mm. Such sequences allowed detection of intra-labyrinthine fluid in these 2 dogs.

Except for the 6 dogs with MR imaging evidence of inner ear lesions, a diagnosis of peripheral VD in the present study relied on clinical signs and lesions on MR images compatible with middle ear disease. Hyperintense material that fills the tympanic bulla on T2-weighted images and gadolinium enhancement along the inner margin of the tympanic bulla on T1-weighted images appeared to be 2 of the most common findings of middle ear involvement. In all dogs confirmed to have middle ear neoplasia, destruction of the tympanic bulla and petrous portion of the temporal bone with invasion of adjacent structures was observed.

Two dogs with signs consistent with a peripheral VD were shown with MR imaging to have an ipsilateral extra-axial cerebellopontine angle mass. Clinical signs in these dogs were considered to be a result of the involvement of the intracranial portion of the vestibular nerve.

Idiopathic peripheral VD was suspected in 7 dogs in the present study, because results of MR imaging, CSF analysis, and thyroid stimulating hormone tests were normal. However, some of these dogs had concurrent facial paralysis or Horner's syndrome, which are not usually observed in dogs with idiopathic peripheral VD.⁴ This suggests that these dogs may have had an underlying middle or inner ear abnormality and emphasizes the lack of sensitivity of MR imaging techniques used to date. The clinical importance of a hyperintense focus on T2-weighted images in the region of the ipsilateral vestibular nerve in 3 of these dogs is unknown. Unfortunately, samples from these dogs were not submitted for histologic evaluation.

Central VD result from lesions involving the vestibular nuclei. In the present study, all dogs with central VD had abnormalities on MR images. However, in 3 dogs with clinical signs of a central VD and a fore-brain disorder, only a single intra-axial lesion involving the temporofrontal lobe was found on MR images. No abnormality of the caudal fossa could be seen on MR images that would explain the central VD. Results of CSF analysis were normal, and a necropsy was not performed on these 3 dogs. Similar findings in dogs with central VD secondary to edema associated with lesions affecting the piriform lobe or the ventral aspect of the temporal lobe have been described.⁴⁰ Apart from 2 dogs with contralateral signs, side of the lesion evident on MR images for dogs with central VD corresponded with the side of the lesion indicated by clinical signs. With focal brainstem involvement, clinical signs of central VD may be the sole neurologic deficit observed clinically, or other neurologic signs suggestive of a multifocal lesion may be seen. On the basis of location and distribution of the lesion, results of MR imaging corresponded with expected clinical localization in 23 of the 37 (62%) dogs with central VD in the present study. Magnetic resonance imaging appeared to be particularly useful for detecting multifocal brain involvement in dogs in which clinical signs were suggestive of a focal lesion.

In dogs in the present study with multifocal lesions involving the brainstem on MR images, the lesions were mainly restricted to the region of the vestibular nuclei within the myelencephalon, and T2-weighted images were the most sensitive for detecting caudal fossa lesions. In 8 dogs with clinical signs suggestive of multifocal lesions, lesions were detected only on T2-weighted images. Lesions localized specifically to the area of the vestibular nuclei were evident in 6 of these dogs.

Paradoxical VD are typically a result of mass lesions, including neoplasia and focal forms of meningoencephalomyelitis.^{3,41} In the present study, all dogs with clinical signs of paradoxical VD had abnormalities on MR images.

Cerebellopontine angle lesions were seen in less than half (10/21) of the dogs in the present study with paradoxical VD, and dogs with cerebellopontine angle lesions on MR images had various types of VD, with clinical signs suggestive of a peripheral VD in 2 dogs, a central VD in 2 dogs, and a paradoxical VD in 10 dogs. The intracranial portion of the vestibular nerve, the

vestibular nuclei, and the caudal cerebellar peduncles and flocculonodular lobe are in close proximity to the cerebellopontine angle, and lesions developing in this region could potentially affect any or all of these structures.

Four dogs in the present study with paradoxical VD had lesions of the brainstem evident on MR images, and 7 had lesions of the cerebellum. A mass effect was observed in most of these dogs, which would account for disruption of the inhibitory cerebellar control over the ipsilateral vestibular nuclei, resulting in the paradoxical clinical signs. On the basis of side and distribution of the lesion, results of MR imaging agreed with expected clinical localization in 19 (90%) dogs with paradoxical VD.

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^bOmniscan, Nycomed Amersham, Little Chalfont, Buckinghamshire, England.

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