The neurology of balance: Function and dysfunction of the vestibular system in dogs and cats

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ARTICLE INFO

Article history:
Accepted 29 October 2009

Keywords:
Equilibrium
Vestibular dysfunction
Neuroanatomy
Idiopathic vestibular disease
Otitis media/interna

ABSTRACT

Disorders affecting the vestibular system are a common neurological problem encountered in small animal practice. As a result, veterinarians are often faced with determining the underlying etiology of affected animals. In order to establish an accurate etiological diagnosis, proper interpretation of neurological deficits and precise neuroanatomical localization are essential. Neurological examination can confirm whether the vestibular dysfunction is of peripheral or central nervous system origin. Peripheral vestibular diseases include idiopathic vestibular syndrome, which has some similarities with vestibular neuritis in humans. Central vestibular diseases in general have a poor prognosis in comparison to those affecting the peripheral vestibular system.

Introduction

The vestibular system (VS) is the primary component of the nervous system responsible for maintaining equilibrium and balance. It is a sensory system that relays so called ‘special proprioception’ (DeLahunta and Glass, 2009). The VS is involved in the detection of the static position of the head as well as its acceleration, deceleration, and rotational movements. In addition, the VS coordinates movements of the head with movements of the eyes, trunk, and limbs via vestibulo-ocular and vestibulo-spinal projections within the central nervous system (CNS). Consequently, dysfunction of the VS results in a multitude of clinical signs demonstrating its widespread integration in normal neurological function. Critical to an understanding of the disease processes affecting the VS is knowledge of normal vestibular neuroanatomy and neurophysiology.

Anatomy, physiology and function of the vestibular system

Anatomically, the VS can be divided into peripheral and central components. The peripheral VS is composed of the vestibular division of cranial nerve (CN) VIII (vestibulocochlear nerve) and its receptors. These are contained within the inner ear which is composed of the cochlea, vestibule, and semicircular canals (Getty et al., 1956). These structures form the bony labyrinth of the petrous temporal bone (Fig. 1). The vestibule and semicircular canals subserve vestibular function while the cochlea is involved in auditory function (Getty et al., 1956).

Conforming to the internal structure of the bony labyrinth is the membranous labyrinth comprising the cochlear duct, utricule, saccule and the semicircular canals, all containing endolymph (Evans and Miller, 1993). The three semicircular canals are tubular structures that project from the vestibule and are approximately oriented at 90° to each other (Fig. 2). Each end of the individual canals is dilated into a structure called an ampulla which is connected to the vestibule. Sensory receptors, cristae ampullares, are located in the membranous labyrinth of the ampullae and are responsible for detection of angular movements of the head. On account of their strategic orientations, they are able to determine movement in every plane (DeLahunta, 1983).

Within the membranous vestibule, there are two additional sensory receptors: the macula of the utricule and macula of the saccule, which contain hair cells. Overlying the maculae are mucopolysaccharide otolithic membranes, in which are embedded calcium carbonate crystals known as otoliths. These maculae sense the static position of the head at any one time, and also are responsive to linear acceleration, deceleration, and gravitational forces (DeLahunta and Glass, 2009). The sensory epithelium of the cristae and maculae are similar in that both contain hair cells and supporting (sustentacular) cells. The hair cells function as transducers characterized by a high sensitivity to mechanical stimulation (i.e., they are mechanoreceptors) and a high degree of directional sensitivity.

Morphologically there are two types of hairs: stereocilia, which are modified microvilli, and kinocilia or modified cilia. Each cell has approximately 70 stereocilia arranged in rows, but only one kinocilium, which is longer than the stereocilia and is placed at one end of the specialized cell surface. The lengths of the stereocilia progressively increase toward the kinocilium. When the hairs deviate...
The hair cells of the maculae are embedded in the otolithic membrane; this ultimately leads to the generation of action potentials in the underlying nerve terminals. The hairs are bent by action of the surrounding endolymph due to linear movement or the action of gravity on the overlying otolithic membrane, which is composed of gelatinous substance containing the small otoliths. The hair cells alter their resting potential when the hairs are bent, which increases the firing rate of the sensory nerve fiber associated with that cell; when they deviate away from the kinocilium, they hyperpolarize. The kinocilium of each hair cell of the crista ampullaris of the lateral semicircular canal is oriented on the utricle side, while the kinocilium of each hair cell of the rostral and caudal semicircular canals is oriented away from the utricle.

It is important to realize that the left and right semicircular canals of each functional pair (such as the left and right horizontal canals) always respond oppositely to any head movement that affects them. This fact leads to the ‘push–pull’ concept function of vestibular function, which states that directional sensitivity to head movement is coded by opposing receptor signals. Because of commissural connections, neurons in the vestibular nuclei receive information from receptors on both sides of the head. These neurons act as comparator units that interpret head rotation on the basis of the relative discharge rates of left and right canal afferents. During a leftward head turn, the comparator units receive impulses at higher frequency from the left horizontal canal compared to the right horizontal canal; this is interpreted as a left head turn.

The hairs of the maculae are embedded in the otolithic membrane, which is composed of gelatinous substance containing the small otoliths. The hair cells alter their resting potential when the hairs are bent by action of the surrounding endolymph due to linear movement or the action of gravity on the overlying otolithic membrane; this ultimately leads to the generation of action potentials in the underlying nerve terminals. The hair cells of the cristae reside within a rounded cap shaped gelatinous mass, the cupula, which sways with endolymph flow (Jenkins, 1978). A change in speed and direction of head rotation causes deflection of the cupula in two or more membranous labyrinthine canals and results in movement of the hairs, which in turn generates action potentials in the underlying nerve endings.

The sensory receptors of the cristae ampullares and maculae are in synaptic relationship with neurons of the vestibular portion of CN VIII (DeLahunta and Glass, 2009). Axons of this nerve join up with axons of the cochlear branch of CN VIII after passing through the vestibular ganglion and then course through the internal acoustic meatus of the skull toward the rostral medulla oblongata (DeLahunta and Glass, 2009). The majority of the vestibular axons project to the four ipsilateral vestibular nuclei; however, some axons project directly without synapse to the cerebellum by way of the caudal cerebellar peduncle (DeLahunta and Glass, 2009).

The central VS is composed of the flocculonodular lobes and fastigial nuclei of the cerebellum, in addition to four vestibular nuclei situated on each side of the rostral medulla oblongata (Jenkins, 1978). The caudal vestibular nucleus is located on the medial side of the caudal cerebellar peduncle. The lateral vestibular nucleus lies immediately rostral to the caudal nucleus and is located medial to the caudal cerebellar peduncle and dorsomedial to the spinal tract and nucleus of the trigeminal nerve (DeLahunta and Glass, 2009). The medial nucleus is medial to the lateral nucleus and dorsalateral to the medial longitudinal fasciculus (MLF). The rostral vestibular nucleus is found at the level of the internal genu of the facial nerve (Jenkins, 1978). From these vestibular nuclei, axons project to the spinal cord, as the vestibulo–spinal tracts, and to the brain stem and cerebellum.

Axons of the lateral vestibular nuclei neurons project in the lateral vestibulo–spinal tract, located in the ventral funiculus of the spinal cord, to synapse on interneurons in the ventral grey matter of the spinal cord (DeLahunta and Glass, 2009). The medial vestibular nucleus sends fibers medially to the MLF, which descend bilaterally in the ventral funiculus of the cord to the mid-thoracic levels as the medial vestibulo–spinal tract (Jenkins, 1978). This smaller vestibulo–spinal tract serves as a reinforcement pathway for the neck and thoracic limbs.

The interneurons are facilitatory to the ipsilateral γ-motor and γ-motor neurons of the extensors of the limb and inhibitory to the flexors of the limbs (DeLahunta and Glass, 2009). In addition, the interneurons project to the contralateral grey matter of the spinal cord and are inhibitory to the limb extensors on that side (DeLahunta and Glass, 2009). Consequently, activation of one side of the VS results in increased ipsilateral extensor tone and decreased contralateral extensor tone (DeLahunta and Glass, 2009).

In addition to the spinal projections, axons of the rostral vestibular nuclei neurons project rostrally in the medial longitudinal fasciculus (MLF) of the brainstem to synapse on the motor nuclei of the oculomotor, trochlear, and abducens nerves (CN III, IV, and VI), respectively. Movement of the head and eyes are coordinated via these connections. In the normal animal, this is appreciated as physiological nystagmus, in which the eyes rhythmically oscillate in the direction of head movement (DeLahunta and Glass, 2009). As the head turns, the eyes slowly move in the direction opposite to the head movement followed by a faster movement in the direction of the head to a more central position.

**Rotational vestibulo–ocular reflex**

There are three types of rotationally induced eye movements: horizontal, vertical, and rotary. Each of the six pairs of eye muscles must be controlled in unison to produce the appropriate response. Thus, the vertical semicircular canals and the saccule are responsible for controlling vertical eye movements whereas the horizontal
All aspects of the neurological examination are important in the examination. Given the broad neuroanatomical extent of the VS, reactions, (4) spinal reflexes, (5) cranial nerve, and (6) sensory findings consistent with peripheral vestibular disease associated with lesions in the pons and medulla oblongata (DeLahunta and Glass, 2009). In general, the differentiation of peripheral vestibular disease results in pathological findings regardless of the position of the head. Vestibular strabismus should be differentiated from other deficits referable to the caudal brain stem (Chrisman, 1980).

Examination findings consistent with peripheral vestibular disease

The neurological examination can be divided into six components: (1) mental state assessment, (2) gait evaluation, (3) postural reactions, (4) spinal reflexes, (5) cranial nerve, and (6) sensory examination. Given the broad neuroanatomical extent of the VS, all aspects of the neurological examination are important in the evaluation of affected patients and subsequent determination of the lesion localization.

Generally, the clinical manifestation of vestibular dysfunction is a loss of balance. With rare exception, the signs are ipsilateral to the affected side of the VS (Chrisman, 1980; Schunk, 1988, 1990; Thomas, 2000). Animals may display a vestibular ataxia characterized by leaning, veering, stumbling, falling, and in severely affected individuals, rolling to the affected side (Chrisman, 1980; Schunk, 1988, 1990; Thomas, 2000). Animals also may circle toward the affected side, with the head often tilted. The head is tilted, rotated around the long axis of the body resulting in the ear on the affected side being closer to the ground, as opposed to a head turn in which the nose is deviated from the long axis of the body. The animal may stand with a broad base and exhibit exaggerated extensor tone of the contralateral limbs, accompanied by a decrease of tone in the ipsilateral limbs. The trunk may be curved with concavity toward the side of the lesion.

Nystagmus is defined as involuntary rhythmic oscillations of the eye. Normal physiological nystagmus, whereby the eyes move slowly in the direction opposite to movement of the head followed by a quick return in the direction of the movement of the head to a more central position, can be elicited by moving the patient's head from side to side. In many animals with vestibular disease, a pathological nystagmus may be present (Schunk, 1990). Pathological nystagmus can be spontaneous (resting) or positional (induced), in which a change in the position of the patient results in onset of the nystagmus. The oscillation can occur at the same frequency (pendular) or more usually demonstrates quick and slow phases (jerk nystagmus). The direction of the quick phase ascribes the direction of jerk nystagmus, and this can be horizontal, vertical, rotary or a combination of these.

In many vestibular patients, elevating the head causes the eye on the side of the lesion to deviate ventrally (Fig. 4; Chrisman, 1980; Schunk, 1988), referred to as vestibular strabismus. In positioning the head, inadvertent traction on the eyelids dorsally can result in the misinterpretation of a vestibular strabismus. Consequently, identification of vestibular strabismus should be made with caution. Vestibular strabismus should be differentiated from a fixed or static strabismus resulting from denervation of CN III, IV, or VI in which the eye remains fixed in a deviated position regardless of the position of the head.

Any one or combination of these signs of vestibular dysfunction may be present in animals affected with peripheral vestibular disease. In general, peripheral vestibular disease results in pathological
nystagmus, i.e., horizontal or rotary with the fast phase always directed in the direction opposite to the head tilt. The direction of the fast phase does not change with alterations in the position of the head. The nystagmus may be spontaneous or positional. Additionally, animals with peripheral lesions may exhibit Horner’s syndrome, which is the consequence of a lack of sympathetic innervation to the eye (Neer, 1984). Ipsilateral miosis, ptosis, an elevated third eyelid, and enophthalmus may be present with Horner’s syndrome (Fig. 5).

Sympathetic innervation of the eye originates in the intermediate horn of spinal cord segments T1 through T3 (Neer, 1984). After exiting the intervertebral foramen, preganglionic fibers course in the vagosympathetic trunk to the cranial cervical ganglion, which is located medial to the tympanic bulla (Neer, 1984). The post-ganglionic sympathetic axons course between the petrous temporal bone and the tympanic bulla before eventually reaching the eye (Neer, 1984). As a result, disease affecting the tympanic bulla may cause Horner’s syndrome. Facial nerve paresis or paralysis may also be associated with signs of peripheral vestibular disease subsequent to lesions in cranial nerve VII, which courses through the petrous temporal bone.

Bilateral peripheral vestibular disease occurs on rare occasions. Affected animals are reluctant to walk, exhibiting bilateral vestibular ataxia and wide head excursions, swinging their head from one side to the other (Chrisman, 1980; Schunk, 1990). There is an absence of a head tilt and pathological nystagmus (Chrisman, 1980; Schunk, 1990). Normal physiological nystagmus is absent bilaterally (Chrisman, 1980; Schunk, 1990). Affected animals can voluntarily move their eyes, which require the normal function of the extraocular muscles, innervated by CN III, IV, and VI and assessed by getting the animal to visually track moving objects.

Examination findings consistent with central vestibular disease

Although abnormal mentation can occur with lesions in all anatomical regions of the brain, abnormal mentation combined with signs of vestibular dysfunction is suggestive of central vestibular disease. The mentation of affected animals can range from quiet and dull, to stuporous or comatose. Unfortunately, an animal with peripheral vestibular disease may be profoundly disoriented as a consequence of severe disequilibrium, so mentation changes should be interpreted cautiously in severely affected animals.

Pathological nystagmus of any direction can occur with central vestibular disease; however, vertical nystagmus and nystagmus in which the direction of the fast phase changes with different positions of the head are typically associated with central vestibular disease (Schunk, 1988). Postural reactions, such as hopping and proprioceptive placing, are used to assess general proprioception (GP). Postural reaction deficits are the most important indicator of a centrally located lesion. Normal performance of postural reactions requires normal function of the ascending GP tracts as well as descending upper motor neuron (UMN) tracts. Additionally, normal neuromuscular function is necessary to maintain normal postural reactions. Therefore, these tests evaluate the entire nervous system. In central vestibular disease, ipsilateral postural reaction deficits may be observed as a result of dysfunction of the ipsilateral GP/UMN tracts, which is not present with peripheral vestibular disease (Chrisman, 1980; Schunk, 1988).

Finally, multiple cranial nerve deficits may be observed in association with central vestibular disease. Given the close anatomical relationship of the cranial nerves and their nuclei in the pons and medulla oblongata, deficits in CN V–XII are most likely (Chrisman, 1980; Schunk, 1988). Clinically, fixed strabismus associated with CN VI, dysphagia associated with CN IX–XI, and dysphagia, and lingual atrophy and paresis associated with CN XII may be observed in conjunction with vestibular dysfunction. The most common CN deficits observed in association with central vestibular disease include those of CN V and VII (Chrisman, 1980; Schunk, 1988). Absent facial sensation and atrophy of the muscles of mastication are associated with CN V deficits and facial paresis or paralysis is associated with CN VII deficits. However, CN VII deficits also may be present in association with peripheral vestibular dysfunction.

An uncommon presentation of central vestibular disease, in which the signs indicative of vestibular dysfunction are contralateral to the anatomical lesion, is referred to as paradoxical vestibular disease. Affected animals display a head tilt and vestibular ataxia in the direction opposite to the side of the lesion (Schunk, 1988). In such cases, the side of the lesion is clinically determined by the side on which there are postural deficits (DeLahunta, 1983). Lesions affecting the caudal cerebellar peduncle or flocculonodular lobes of the cerebellum most commonly are responsible for paradoxical vestibular disease (DeLahunta and Glass, 2009).

Diagnostics

Essential to an appropriate diagnostic work up is establishing a correct neuroanatomical diagnosis of peripheral or central vestibular disease. While many of the same diagnostic steps are involved in evaluating diseases affecting the peripheral and central VS, some differences exist. Diagnostics are aimed at defining an underlying etiology. Underlying every diagnostic work up for vestibular dysfunction is advanced imaging such as computed tomography (CT) or magnetic resonance imaging (MRI) which requires general anesthesia. Given the need for general anesthesia, diagnostics to evaluate the systemic health of an affected animal are necessary prior to imaging in order to reduce the potential for morbidity and mortality.

In all cases, a minimum data base should include a complete blood count, biochemistry profile, and urinalysis. Older animals should have radiographic evaluation of the thoracic cavity to exclude the possibility of systemic conditions with spread to the nervous system (i.e., infectious etiologies such as fungal disease or metastatic neoplasia). Similarly, in animals exhibiting clinical signs referable to the abdominal cavity, radiographic or ultrasonographic examination of the abdomen should be performed. Identifying an underlying systemic disease through noninvasive imaging technique may provide a presumptive diagnosis for vestibular dysfunction and thereby eliminate unnecessary risk to the animal and expense to owners. Owners should be cautioned that affected animals may experience exacerbation of neurological signs after such...
anesthesia. In most instances, this is temporary and improvement is observed within 1–2 days.

Peripheral vestibular disorders should initially prompt a thorough examination of the external ear canal given the intimate anatomical relationship between the external, middle, and inner ear. Examination of the external ear canal can be performed with a hand-held otoscope or with video otoscopy. While disease affecting the external canal commonly may be visualized, the presence of an intact tympanic membrane does not eliminate the possibility of disease affecting the middle ear.

Myringotomy is the deliberate puncture or incision of an intact, although not necessarily healthy, tympanic membrane for diagnostic purposes. Myringotomy allows for the procurement of specimens for microbiological testing in otitis media as well as tissue for histological evaluation of neoplasia within the tympanic bulla. Needle puncture and subsequent aspiration through the ventro-caudal part of the tympanic membrane allows for collection of fluid from the tympanic cavity for cytological examination and microbial culture and sensitivity testing. A 22-gauge spinal needle is guided to the tympanum through an otoscope; the needle is connected to a 5 or 10 mL syringe which is required to aspirate the middle ear contents. The effusion within the middle ear may be purulent or particulate and may block up the needle; in addition, the puncture hole made by the needle is often too small to allow for adequate drainage (Bruyette and Lorenz, 1993).

If greater access is required for drainage, a curvilinear or radial incision made with a myringotomy knife is advised; care must be taken not to incise the tympanum too deeply, as structures of the middle and inner ear may be damaged. Similarly, forceful flushing of the middle ear should be avoided. If appropriate antibiotics are administered, healing of the tympanum should take place within 21–35 days (Bruyette and Lorenz, 1993).

Brainstem auditory evoked potential (BAEP) testing can be used to assess the integrity and function of the peripheral and central auditory pathways, which indirectly allow for evaluation of the vestibular pathways due to their close association. BAEP are recordings of sound-evoked electrical activity in portions of the auditory pathway between the cochlea and the auditory cortex. The resulting BAEP consists of 6–7 positive time-locked peaks (I–VII) beginning at approximately 1 ms after the stimulation. Peak I represents activity in the cochlear nerve, and subsequent waves mark peak activities as sound is being processed through ascending portions of the auditory pathway. A lesion anywhere along the pathway can cause an increase in the inter-peak latencies and a decrease of the amplitudes (Fischer and Obermaier, 1994). Peripheral vestibular disease may be accompanied by reduced or absent BAEP (Myers et al., 1986). Additionally, disease in the middle ear can alter the BAEP in a pattern consistent with conductive deafness (Eger and Lindsay, 1997). Otitis can increase the latency of wave I while the inter-peak intervals remain normal (Eger and Lindsay, 1997). With increased severity of the otitis there may also be a decrease of the ratio of amplitude of wave I to wave V, and increase of the volume threshold at which sound produces a BAEP (Eger and Lindsay, 1997). In dogs with intracranial disease, BAEP may reveal an absence of some or all of the waves, an increase in wave latencies which most commonly affects wave V, and an abnormal ratio of the amplitudes of wave I to wave V (Steiss et al., 1994).

Cerebrospinal fluid (CSF) analysis is a useful adjunctive test in the determination of the cause of central vestibular disease but is rarely specific. Polymerase chain reaction (PCR) analysis of CSF can now be performed in specialized laboratories to evaluate for the presence of nucleic acids from infectious agents in parallel with serological tests (Schatzberg et al., 2003). The risk of iatrogenic CNS trauma or cerebellar herniation following cisterna magna puncture in cats or dogs with space-occupying lesions of the caudal fossa should not be underestimated.

There are several imaging modalities that can be used to examine the external, middle, and inner ear. Plain radiography uses five conventional radiographic views to investigate the osseous bullae which include dorsoventral, lateral, open-mouth, in addition to right and left 20° lateral oblique views (Hoskinson, 1993). Each is designed to highlight a specific region of the middle ear cavity. Radiographic evaluation of animals with vestibular disease is hampered by the complexity of the anatomy of the head, superimposition of structures, and the lack of specificity associated with radiographic findings. Consequently, unless advanced imaging such as CT or MRI is unavailable, radiographic investigation is typically not pursued. CT has several advantages over conventional radiography, including elimination of superimposition, improved soft tissue differentiation, greater accuracy and reliability (Rohleder et al., 2006). Despite the potential drawback of poor bone detail, MRI may be more beneficial in the evaluation of the external, middle, and inner ear given the greater sensitivity to soft tissue pathology compared to CT (Allgoewer et al., 2000; Garosi et al., 2003b).

Diagnostic imaging directed at structures of the caudal fossa including the pons, cerebellum, and medulla oblongata is necessary when investigating the central VS and MRI is the imaging modality of choice.

**Diseases associated with peripheral vestibular dysfunction**

There are numerous disorders associated with peripheral vestibular disease (Table 1). The two most common disorders associated with peripheral vestibular disease are otitis media/interna, and idiopathic dysfunction.

**Otitis media/interna**

While there are many disease processes which cause peripheral vestibular disease, the most common etiology is otitis media/interna (Chrisman, 1980). Otitis media/interna often occurs secondary to otitis externa but this extension is not necessary (Rosser, 2004). Etiologies associated with otitis externa can be classified into predisposing, primary, secondary, and perpetuating causes (Rosser, 2004). Predisposing causes include pinnae and external ear conformation. Primary causes include etiologies such as ectoparasites, atopy, food allergies, foreign bodies and neoplasia. These primary etiologies often lead to secondary infections. Finally, with chronic infection, pathological changes develop which perpetuate infection. Organisms commonly isolated from affected bullae include *Staphylococcus spp.*, *Streptococcus spp.*, *Pasteurella spp.*, *Proteus spp.*, *Escherichia coli*, *Enterococcus spp.*, *Pseudomonas spp.*, obligate anaerobes and yeasts (Rosser, 2004).

Diagnosis is based on visualization via otoscopic examination, bacteriology, and imaging findings. Myringotomy may be performed if fluid is present in the tympanic cavity in order to obtain specimens for cytological assessment and anaerobic/aerobic culture and sensitivity testing. Cultures obtained from the external ear canal may also be evaluated. Care should be exercised when interpreting culture and sensitivity patterns obtained from the external ear canal and tympanic cavity. The same bacterial organism with differing sensitivity patterns or different organisms with differing sensitivity patterns can be isolated from the same sampling site in the external ear (Graham-Mize and Rosser, 2004). Likewise, different bacteria with different sensitivity patterns can be isolated from the external ear canal and tympanic cavity, respectively (Cole et al., 1998).

Radiographic findings associated with otitis media/interna include soft tissue opacity in the tympanic cavity, thickening of the tympanic bulla and bony proliferation of the petrous temporal
bone (Garosi et al., 2003b). CT findings associated with otitis media/interna include thickening of the tympanic bulla and the presence of soft tissue density compatible with fluid or tissue within the tympanic bulla (Detweiler et al., 2006; Love et al., 1995). Occasionally, lysis of the tympanic bulla may be observed (Garosi et al., 2003b).

MRI findings associated with otitis media/interna include observation of material in the tympanic bulla with intermediate signal intensity on T1-weighted (T1 W) images and hyperintense signal intensity on T2-weighted (T2 W) images (Allgoewer et al., 2000; Dvir et al., 2000; Garosi et al., 2000). Occasionally, peripheral enhancement along the interior of the tympanic bulla is observed on T1 W images after intravenous contrast administration (Sturges et al., 2006). Additionally, absence of signal intensity from the labyrinthine fluid on T2 W images may be suggestive of involvement of the inner ear (Garosi et al., 2001). Absence of signal intensity of the fluid within the inner ear on T2 W images may represent replacement of the fluid with fibrous tissue or alterations in the fluid composition (Fig. 6; Garosi et al., 2001). Meningeal enhancement on T1-weighted post-contrast images has also been described secondary to otitis interna (Garosi et al., 2001).

Treatment of otitis media/interna consists of medical and surgical therapy. Medical therapy involves long-term (6–8 weeks) antibiosis ideally based on culture and sensitivity results of material retrieved from the tympanic cavity (Morris, 2004). Empiric therapy may be initiated based on cytological evaluation of external ear detritus. Caution should be exercised regarding the use of aminoglycoside antibiotics given their ototoxic and vestibulotoxic potential. With appropriate treatment, improvement is typically observed within 1–2 weeks. Animals with extensive pathological changes, recurrent clinical signs, or cases refractory to medical therapy may require surgical intervention. In such instances, surgical intervention may consist of total ear canal ablation combined with bulla osteotomy (Beckman et al., 1990; Mason et al., 1988).

Neoplasia involving the ear and tympanic bulla

Tumors involving the ear canal and tympanic bulla may cause peripheral vestibular disease. In addition to vestibular dysfunction, affected animals often present for signs consistent with chronic otitis that initially responds to treatment but recurs after cessation of treatment or otitis that is resistant to antibiotics. Additional signs include pain on opening the mouth, Horner’s syndrome, and facial paralysis. Tumors involving the ear canal are more commonly observed than tumors arising in the tympanic bulla (Little et al., 1989). Most tumors affecting the tympanic bulla represent extension from the ear canal. Although malignant ear tumors are more commonly observed, benign tumors have been reported (London et al., 1996).

Ear tumors occur in older cats (mean age, 7 years for benign tumors and 11 years for malignant tumors) and dogs (mean age, 9 years for benign tumors and 10 years for malignant tumors). No gender predilection exists in either species. The Cocker spaniel appears to be over-represented for both benign and malignant tu-

### Table 1

<table>
<thead>
<tr>
<th>Disease mechanism</th>
<th>Specific disease</th>
<th>Diagnosis</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anomalous</td>
<td>Congenital vestibular disease</td>
<td>Based on age, breed and ruling out other causes of PVD</td>
<td>Guarded but compensation is possible. May be associated with deafness</td>
</tr>
<tr>
<td>Neoplasia</td>
<td>Squamous cell carcinoma</td>
<td>Otoscopy, imaging and histopathology</td>
<td>Poor but radical resection and radiation treatment may be effective in the short term</td>
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<td></td>
<td>Fibrosarcoma</td>
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<td></td>
<td>Osteosarcoma</td>
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<td>Ceruminous gland or sebaceous gland adenocarcinoma</td>
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<tr>
<td>Inflammatory/infectious</td>
<td>Bacterial otitis media/interna labyrinthitis</td>
<td>Otoscopy, ear swab, myringotomy and imaging</td>
<td>Good but is dependent on the infectious agent responsible</td>
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<td></td>
<td>Cryptococcus</td>
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<td></td>
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<tr>
<td></td>
<td>Nasopharyngeal polyps</td>
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<td></td>
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<tr>
<td>Idiopathic</td>
<td>Idiopathic vestibular syndrome</td>
<td>Based on an acute onset without progression and exclusion of other causes of the PVD</td>
<td>Good</td>
</tr>
<tr>
<td>Toxic</td>
<td>Aminoglycosides</td>
<td>Acute onset of clinical signs in relationship with toxin exposure</td>
<td>Usually fair for compensatory recovery but deafness may accompany the clinical signs and this may be permanent</td>
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<tr>
<td></td>
<td>Furosemide</td>
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<td>Chlorhexidine</td>
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<td></td>
<td>10% fipronil solution (aural administration)</td>
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<tr>
<td>Traumatic</td>
<td>Iatrogenic – External ± middle ear flushing/bulla osteotomy Bulla fracture/hemorrhage</td>
<td>Acute onset of clinical signs in relationship with traumatic episode</td>
<td>Usually fair for compensatory recovery but deafness may accompany the clinical signs</td>
</tr>
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Fig. 6. A transverse T2-weighted MRI demonstrates unilateral otitis media/interna. There is a loss of signal intensity in the petrous temporal bone in the region of the vestibular apparatus, when compared to the other side (arrowheads). There is also an increased signal intensity seen lining the bulla on this side (arrow).
mor development. The most common malignant tumor encountered in the dog is ceruminous gland adenocarcinoma, followed by squamous cell carcinoma and carcinoma of unknown origin (London et al., 1996; Moisan and Watson, 1996). Ceruminous gland adenocarcinoma and squamous cell carcinoma may be equally common in the cat (London et al., 1996).

Diagnosis involves otoscopic examination, imaging findings, and histopathology. Approximately 25% of malignant tumors show evidence of bulla involvement, and skull radiographs are recommended as part of the initial diagnostic workup. MRI findings may include boney lysis of the tympanic bulla and petrous temporal bone. Additionally soft tissue masses may be observed in the external ear canal or tympanic cavity. Neoplastic tissue may be observed extending into the surrounding soft tissue or cranial vault.

Malignant ear canal tumors are less aggressive in dogs than they are in cats. In dogs with malignant ear canal tumors treated primarily by surgical excision, a median survival time of 58 months has been reported (London et al., 1996). In cats with sebaceous gland adenocarcinoma treated by surgical excision, median survival times of approximately 42, 49, and 50 months have been reported (Bacon et al., 2003; London et al., 1996; Marino et al., 1994). In cats with squamous cell carcinoma, the median survival time was 11.5 months (London et al., 1996). Importantly, the median survival time in cats displaying neurological signs was 1.5 months compared to 15.5 months in cats not displaying neurological signs (London et al., 1996). Neurological signs likely reflect a more invasive behavior (i.e., central extension) of the underlying neoplasm which likely impacts survival.

**Idiopathic vestibular syndromes**

Idiopathic peripheral vestibular syndromes occur in both the dog and cat. In dogs, the syndrome is sometimes referred to as old dog or geriatric vestibular disease reflecting the age of affected dogs. The average age of affected dogs is 12–13 years (Blau and Martin, 1974; Schunk and Averill, 1983). In cats, there is no breed or sex predilection, but cats more commonly present in July and August compared to other times of the year in certain parts of the USA (Burke et al., 1985). The onset of clinical signs is often peracute to acute. Affected animals display a head tilt, vestibular ataxia, and abnormal nystagmus (horizontal or rotary) with the fast phase directed opposite to the head tilt. Presumptive diagnosis is based on exclusion of other diseases resulting in similar clinical signs.

Importantly, idiopathic vestibular syndromes are not associated with other neurological deficits and the presence of neurological deficits not associated with peripheral vestibular disease should prompt an alternative diagnosis (Schunk and Averill, 1983). Through examination of the external ear combined with imaging of the tympanic bullae should be performed in order to exclude other disease processes. Treatment consists of supportive and symptomatic care. Affected animals display improvement in several days. Initially, resolution of abnormal nystagmus is observed followed by improvements in gait. Clinical signs resolve over 3–4 weeks. Occasionally, severely affected animals maintain a residual head tilt.

There are several forms of peripheral vestibular disease in humans with uncertain etiologies. Ménière disease is the most classically described of these and is characterized by recurrent attacks of vertigo associated with fluctuating tinnitus and deafness. It has been speculated that the paroxysmal attacks of vertigo are related to ruptures of the membranous labyrinth and a dumping of potassium-containing endolymph into the perilymph, changes that have a paralyzing effect on vestibular nerve fibers (Sajjadi and Paparella, 2008); however this etiology is only one of many proposed. The attacks are severe and characteristically abrupt, lasting for several minutes to hours but typically resolve within 24 h. This is much shorter that the duration of the events classically described in dogs and cats. Although there is currently no cure for Ménière disease, more than 85% of patients are helped by either changes in lifestyle and medical treatment, or minimally invasive surgical procedures such as intratympanic steroid therapy, intratympanic gentamicin therapy, and endolymphatic sac surgery (Sajjadi and Paparella, 2008); there are no current randomized clinical trials proving that any intervention is effective. Vestibular neuritis has a very high rate of vertigo control and is available for patients with good hearing who have failed all other treatments. Labyrinthectomy is undertaken as a last resort and is best reserved for patients with unilateral disease and deafness.

Benign positional vertigo is more frequent than Ménière disease and is characterized by paroxysmal vertigo and nystagmus that occur only with the assumption of certain positions of the head; lying down or rolling over in the bed, bending over and straightening up, and tilting the head backwards are the most common instigating movements. Individual episodes last for less than a minute, but they may recur periodically for days or months (Boniver, 2008). It is now generally believed that otolithic crystals become detached, break up to form debris which results in a free floating clot in the endolymph of the canal (calalolithiasis) and gravitates to the most dependent part of the canal during changes of the position of the head (Boniver, 2008). As such attacks may come and go for years; the condition is not exactly analogous to what is described in veterinary patients.

Vestibular neuritis is a distinctive disturbance of vestibular function in humans characterized clinically by a paroxysmal and usually prolonged single attack of vertigo without deafness (Bartual-Pastor, 2005). Usually the onset of vertigo is fairly abrupt with associated nausea and vomiting and persistence of the signs for several days, which differentiates it from Ménière disease and makes it most analogous to idiopathic vestibular syndromes in dogs and cats. The severe vertigo and associated symptoms subside in a matter of several days, but lesser degrees of these symptoms may persist for several weeks to months. The cause is uncertain but many think it is due to a viral infection of the eighth cranial nerve (Bartual-Pastor, 2005). This may be a consideration for veterinary patients.

**Hypothyroidism**

Hypothyroidism has been associated with peripheral and central vestibular disease and has been associated with a variety of neurological disorders including polyneuropathy, laryngeal paralysis, and cranial nerve dysfunction (Bichsel et al., 1988; Dewey et al., 1995; Dixon et al., 1999; Greco et al., 1998; Indrieri et al., 1987; Jaggy et al., 1994; Kaelin et al., 1986; Panciera, 1994). The exact pathogenesis related to polyneuropathy is unknown. Decreased axonal transport and Schwann cell dysfunction have been implicated (Beghi et al., 1989). Myxedematous deposits along peripheral nerves have also been suggested (Dyck and Lambert, 1970). The most common cranial nerve dysfunctions associated with hypothyroidism affect CN VII and VIII. Clinical signs may be the result of mucin deposits leading to compression of CN VII and VIII in their course through the internal acoustic meatus. Decreased axonal transport may also play a role. The observation of vestibular disease and facial paralysis in dogs in which other conditions such as otitis media/interna have been excluded should prompt an investigation for hypothyroidism.

**Otoxicity**

Despite the relatively common occurrence of otitis in dogs and cats and the frequent use of topical and parenteral medications in
its treatment, ototoxicity has received little attention in the veterinary literature. Much of the information regarding ototoxicity is founded on experimental data and anecdotal reports. In general, ototoxicity can be unilateral or bilateral. Hearing loss, vestibular dysfunction, or a combination of both can occur. Although signs of toxicity often develop acutely, delayed toxicity can occur (Merchant, 1994).

Among drugs with known or suspected ototoxic potential, aminoglycoside (AG) antibiotics are the most widely recognized (Mansfield, 1990). AG antibiotics concentrate in the perilymph and endolymph resulting in damage to the hair cells at the base of the cochlea which are responsive to noise in the high frequency range as well as the neuroepithelium of the maculae and crista (Merchant, 1994). While several mechanisms have been proposed, AG ototoxicity is likely associated with the drugs’ ability to chelate iron and form free radicals which result in apoptosis of hair cells (Selimoglu, 2007). Toxicity varies depending on the specific AG antibiotic and dose, duration of administration (Selimoglu, 2007). Neomycin and amikacin have a greater tendency to cause auditory dysfunction while gentamicin has a greater likelihood to cause vestibular dysfunction, especially in cats (Morris, 2004).

Both parenteral and topical administration can result in ototoxicity. However, twice daily gentamicin administered topically for 21 days in dogs with surgically removed tympanic membranes did not result in auditory dysfunction based on BAEP testing or clinical signs of vestibular dysfunction (Strain et al., 1995). Ultimately, compounding factors such as the presence of inflammation, endotoxin, or co-administration of other ototoxic medications may potentiate AG ototoxicity (Selimoglu, 2007); for example, furosemide may potentiate AG ototoxicity (Merchant, 1994).

Antiseptics such as chlorhexidine may also be ototoxic (Merchant, 1994). At 2% concentration, topical administration of chlorhexidine causes ototoxicity to the cochlea and VS (Igarashi and Oka, 1988a,b). Even with concentrations at 0.05%, pathological changes can be observed (Igarashi and Oka, 1988a,b). Despite this, topical application at a clinical relevant concentration of 0.2% concentration administered twice daily for 21 days did not cause auditory damage as measured by BAEP or clinical signs of vestibular dysfunction (Merchant et al., 1993). Other drugs such as loop diuretics such as furosemide or chemotherapeutic drugs such as cisplatin and nitrogen mustards drugs are potentially ototoxic, however, veterinary reports documenting ototoxicity are lacking (Mansfield, 1990).

The practice of ear flushing for the treatment of otitis is associated with ototoxicity (Gortel, 2004). Hearing loss, vestibular dysfunction, Horner’s syndrome, and facial nerve paresis/paralysis can occur after ear flushing. Ootoxicity may be the result of mechanical damage from instruments or aggressive irrigation (Gortel, 2004). Alternatively, translocation of bacteria or bacterial products into the middle ear cavity may occur during flushing. Bacterial toxins may penetrate through an intact round or vestibular window to enter the inner ear and lead to ototoxicity (Schachern et al., 1987). Additionally, the presence of inflammation may enhance the penetration into the inner ear through an intact membrane (Cureoglu et al., 2005).

Ultimately the administration of many compounds and the use of certain practices can result in ototoxicity. The relatively rare occurrence of complications may reflect the inability of owners to appreciate subtle changes in hearing. Similarly, it is difficult for veterinarians to document ototoxicity based on clinical examination or based on BAEP testing. However, this should not detract from the importance of judicial use of medications with ototoxic potentials as complications can be debilitating and are often permanent.

Diseases associated with central vestibular disease

There are numerous disorders associated with central vestibular disease. Table 2 lists many of the disorders along with the onset, progression, diagnosis, treatment, and prognosis.

Infectious CNS disease

Inflammatory diseases involving the CNS are frequently associated with signs of vestibular disease. A variety of infectious and parasitic diseases have been associated with vestibular dysfunction, including canine distemper virus, feline infectious peritonitis virus, rickettsial disease such as erlichiosis, Rocky Mountain Spotted fever, cryptococcosis, histoplasmosis, coccidiomycosis, phaeohyphomycosis, Cuterebra larval migration, and rabies (Berthelin et al., 1994; Burtch, 1998; Fiske et al., 1986; Hass et al., 1989; Hendrix et al., 1989; Hibler et al., 1986; Jones and Miller, 1996; Kline et al., 1994; Kornegay, 1978; Kurtz and Finco, 1970; Mikszewski and Vite, 2005; Schaer et al., 1983; Tipold et al., 1992; White et al., 2007).

Bacterial meningoencephalitis is an uncommon condition (Radaelli and Platt, 2002; Tipold et al., 1992). Bacteria gain entry into the nervous system hematogenously, via direct penetration from exogenous trauma, or through extension from contiguous sites (Radaelli and Platt, 2002). Bacterial otitis media/interna represents a common source of infection. Consequently, bacterial meningoencephalitis may result in clinical signs of central vestibular disease (Cook et al., 2003; Irwin and Parry, 1999; Spangler and Dewey, 2000; Sturges et al., 2006). Affected animals may present with acute or chronic signs (Spangler and Dewey, 2000; Sturges et al., 2006). In addition to signs of vestibular dysfunction, affected animals may have CV and VII deficits, ipsilateral postural deficits, changes in mentation, and seizures (Spangler and Dewey, 2000; Sturges et al., 2006).

MRI reveals a tympanic bulla containing material of mixed intensity (Sturges et al., 2006), and potential disruption of the petrous temporal bone (Fig. 7). Thickened meninges, edema, and a globose mass affecting the cerebellopontine medullary angle may be observed in some animals (Klopp et al., 2000a; Sturges et al., 2006). CT assisted identification of poorly defined contrast enhancing masses adjacent to a tympanic bulla containing material or fluid, is suggestive of intracranial extension of bacterial infection (Spangler and Dewey, 2000). CSF analysis reveals a neutrophilic pleocytosis in most instances (Sturges et al., 2006) and intracytoplasmic bacteria may be observed.

Anaerobic and aerobic bacteriological cultures should be performed for identification of the organism involved as well as its antibiotic sensitivity. Treatment mainly consists of surgical drainage of the cranial vault may be indicated in some affected animals (Sturges et al., 2006). The outcome remains guarded depending on the neurological deficits and relapses can occur. Some affected animals require lifelong antibiotic therapy.

Granulomatous meningoencephalomyelitis (GME) and meningoencephalomyelitis of unknown etiology (MUA)

Granulomatous meningoencephalomyelitis is an inflammatory disorder of the brain without a known etiology (Adamo et al., 2007a,b). Definitive diagnosis requires histological evaluation of the brain through biopsy or post mortem (Adamo et al., 2007a,b). Presumptive diagnosis can be made by assessment of the neurological examination, clinicopathological data, and imaging findings (Cherubini et al., 2006). Clinical signs may involve vestibular dys-
function, abnormal mentation, seizures, paresis, cranial nerve deficits, and cervical pain (Adamo et al., 2007a,b).

Treatment involves immunosuppression, usually consisting of corticosteroid therapy. In recent years, additional chemotherapeutics have been used in conjunction with corticosteroids resulting in an improved long-term survival in affected dogs but the prognosis remains guarded (Adamo and O’Brien, 2004; Coates et al., 2007; Zarfoss et al., 2006). Currently, many referral institutions initiate therapy utilizing cytarabine and prednisone in dogs with a clinical diagnosis of GME or MUA (Zarfoss et al., 2006).

In the authors’ practice, daily administration of prednisone at an immunosuppressive dosage is combined with cytarabine administered at 50 mg/m² subcutaneously twice daily for 2 days. This treatment cycle is repeated every 3 weeks for three cycles. Subsequently, the interval between treatment cycles is increased by 1 week and the dog receives three treatment cycles at the new treatment interval. After three treatments, the interval between treatment cycles is extended by another week. This is repeated after three treatment cycles at each new interval. Treatment cycle intervals are gradually extended to every 6 weeks. Concurrently, the dose of prednisone is gradually tapered to a low dosage administered every other day. Alternatively, some practitioners use cyclosporine. Dosages ranging from 3 to 15 mg/kg orally every 12 h alone or in conjunction with prednisone are used. In some cases, cyclosporine can be used at doses ranging from 5 to 12 mg/kg orally every 24 h combined with ketoconazole at 8 mg/kg orally every 24 h (Adamo et al., 2007a,b). Doses should be adjusted to achieve blood levels between 200 and 400 ng/mL (Adamo et al., 2007a,b).

Dogs with focal neurological signs are associated with an improved prognosis when compared to dogs with multifocal signs (Munana and Luttgen, 1998). Radiation therapy has also been proven as an effective therapy for focal variations of GME.

**Neoplasia**

Primary intracranial neoplasia located in the caudal fossa is often associated with central vestibular signs (Snyder et al., 2006). Common primary intracranial neoplasms include meningioma, glial tumors, and choroid plexus tumors (Westworth et al., 2008; Zarfoss et al., 2006).

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Table 2

<table>
<thead>
<tr>
<th>Disease mechanism</th>
<th>Specific disease</th>
<th>Diagnosis</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degenerative</td>
<td>Cerebellar cortical abiotrophy</td>
<td>Slowly progressive clinical signs in young often purebred animals. Enzyme levels in tissues and fluids and histopathology</td>
<td>Poor</td>
</tr>
<tr>
<td>Anomalous</td>
<td>Lysosomal storage diseases Hydrocephalus</td>
<td>Slowly progressive clinical signs. Advanced imaging required</td>
<td>Guarded. Surgical therapy may be required</td>
</tr>
<tr>
<td>Anomalous</td>
<td>Intra-arachnoid cysts Dermoid and epidermoid cysts Thiamine deficiency</td>
<td>Acute, progressive signs associated with compatible diet or gastrointestinal system history. Response to thiamine</td>
<td>Fair to good</td>
</tr>
<tr>
<td>Nutritional</td>
<td>Meningioma</td>
<td>Acute to slowly progressive clinical signs. Imaging and histopathology</td>
<td>Poor. Surgical resection and radiation therapy are possible</td>
</tr>
<tr>
<td>Neoplasia</td>
<td>Oligodendroglioma Medulloblastoma Lymphoma Metastasis</td>
<td>Acute to subacute progressive clinical signs. Cerebrospinal fluid analysis and advanced imaging. Infectious disease titers and PCR analysis</td>
<td>Fair to poor. Depends on precise etiology, extent of disease and initial response to treatment</td>
</tr>
<tr>
<td>Inflammatory/infectious</td>
<td>MUA</td>
<td>Subacute progressive clinical signs with compatible toxin exposure history</td>
<td>Good</td>
</tr>
<tr>
<td>Toxic</td>
<td>Bacteria, viral, fungal, protozoal, rickettsial, parasitic Metronidazole</td>
<td>Acute onset of clinical signs in association with history of trauma. Advanced imaging</td>
<td>Poor to fair. Compensation is possible but depends on overall severity of head trauma</td>
</tr>
<tr>
<td>Traumatic</td>
<td>Lead</td>
<td>Acute onset, non-progressive clinical signs which improve with supportive care alone. Advanced imaging</td>
<td>Fair to good</td>
</tr>
<tr>
<td>Vascular</td>
<td>Cerebrovascular accidents Feline ischemic encephalopathy</td>
<td>Subacute progressive clinical signs with compatible toxin exposure history</td>
<td>Good</td>
</tr>
</tbody>
</table>

MUA, meningoencephalomyelitis of unknown (a)etiology; PCR, polymerase chain reaction.
Snyder et al., 2006). Secondary (metastatic) intracranial neoplasia has also been associated with central vestibular disease (Snyder et al., 2008). Additionally, tumors involving the ear canal and tympanic bulla may cause central vestibular disease secondary to lysis of the petrous temporal bone and compression of the cerebellopontine angle (Lucroy et al., 2004).

Thiamine deficiency

Thiamine deficiency is rare in dogs and cats. Most cases are the result of inappropriate preparation of food, inadequate concentration in the diet, or feeding diets high in thiamininas (Loew, 1977; Read and Harrington, 1981; Studdert and Labuc, 1991). Other proposed causes of thiamine deficiency include interference with intestinal absorption, abnormal utilization secondary to liver disease, and increased requirements (Garosi et al., 2003a). Clinical signs include abnormal mentation, seizures, dilated unresponsive pupils, opisthotonus, tetraparesis, and vestibular dysfunction (Garosi et al., 2003a; Loew, 1977; Read and Harrington, 1981; Read et al., 1977; Steenbeck and Fischer, 2007).

In dogs and cats, pathological changes include hemorrhage necrosis of specific brain stem nuclei including caudal colliculus, lateral geniculate, medial vestibular, and oculomotor nuclei (Read and Harrington, 1982, 1986). The ‘gold standard’ for diagnosis remains unclear, but MRI may disclose lesions in affected brain stem nuclei (Garosi et al., 2003a). Often a presumptive diagnosis is reached based on dietary history, neurological examination, advanced imaging studies, and response to therapy (Garosi et al., 2003a; Loew, 1977; Read and Harrington, 1981; Read et al., 1977; Steenbeck and Fischer, 2007).

Metronidazole intoxication

Metronidazole is a commonly used antibiotic for dogs and cats in the treatment of a variety of conditions which include protozoal infections, anaerobic bacterial infections, inflammatory bowel disease, and hepatic encephalopathy (Groman, 2000). Metronidazole has a high bioavailability, is metabolized by the liver, and is excreted in urine (Groman, 2000). Neurological adverse affects of metronidazole include vestibular dysfunction and, rarely, seizure activity (Caylor and Cassimatis, 2001; Dow et al., 1989; Saxon and Magne, 1993). Toxicity is reported with dosages >60 mg/kg/day but has occurred in animals receiving lower dosages (Caylor and Cassimatis, 2001; Dow et al., 1989; Saxon and Magne, 1993). Presumptive diagnosis is based upon neurological signs and a history of drug administration. Therapy involves discontinuation of the drug and supportive care including intravenous fluid diuresis. Diazepam administration may shorten the time to recovery (Evans et al., 2003).

Hypothyroidism

Although hypothyroidism has been most commonly associated with peripheral vestibular disease, an association with CNS disease has been made resulting in signs including coma, seizures, and central vestibular disease (Bichsel et al., 1988; Coates, 1997; Henik and Dixon, 2000; Higgins et al., 2006; Patterson et al., 1985; Vitale and Olby, 2007; Zeiss and Waddle, 1995). In some affected dogs, the pathogenesis underlying central vestibular disease may be related to ischemic infarction. Gross and histopathological findings consistent with ischemic infarction of the brain in dogs with hypothyroidism have been identified (Patterson et al., 1985; Zeiss and Waddle, 1995).

In dogs, an association between hypothyroidism and atherosclerosis has been observed in both experimental and spontaneous cases (Liu et al., 1986; Manning, 1979). Atherosclerosis leading to infarction has been documented (Patterson et al., 1985; Zeiss and Waddle, 1995) and such vascular lesions may predispose to thrombosis formation (Indrieri et al., 1987). In affected dogs, MRI of the brain may disclose lesions suggestive of infarction, classically hypo-intense on T1 W, and hyperintense on T2 W images (Higgins et al., 2006; Vitale and Olby, 2007). CT images may disclose a focal, well defined hypodense lesion (Higgins et al., 2006). Alternatively, hypothyroid associated CNS dysfunction may be related to hyperlipidemia causing increased viscosity resulting in decreased perfusion of the brain (Vitale and Olby, 2007).

Diagnosis is based on clinicalpathological documentation of hypothyroidism and exclusion of other disease processes which result in similar neurological deficits. Treatment consists of thyroid hormone supplementation. Generally, dogs with peripheral vestibular disease respond well to treatment. Dogs with central vestibular disease may not respond as well depending on the presence of brain infarction, the degree of dysfunction and the involvement of other pathological processes such as myxedema.

Conclusions

Vestibular dysfunction is a common disorder in the dog and cat with many etiologies. The key to an appropriate diagnostic investigation is a neurological examination which serves to localize the causative disease to either the peripheral or central vestibular anatomy. Vestibular disease of peripheral origin has a better prognosis than that of CNS origin but is disease dependent, and even central vestibular dysfunction can resolve. Many cases of peripheral vestibular disease in dogs and cats are classed as idiopathic, with some similarities to the human condition of vestibular neuritis. If the two conditions are analogous, it is unlikely that inflammatory disease is the cause of all veterinary cases, but in the future, more targeted diagnostics may help us confirm that at least a subset of idiopathic vestibular diseases may benefit from anti-inflammatory treatment regimens.

Conflict of interest statement

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

Acknowledgements

The authors wish to thank Kip Carter CMI, of the Dept. of Educational Resources, College of Veterinary Medicine, The University of Georgia, for the anatomical illustrations.

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Neurology 1, 247–254.


