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Developmental Disorders (17-Dec-2004)

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This chapter reviews the major structural malformations and developmental defects encountered in dogs and cats and their related effects on the central nervous system. Note that congenital deafness and congenital vestibular disorders are discussed with deafness and vestibular disease in the chapter on peripheral nerve disorders (See Myopathies and Neuropathies).

An outline of this chapter is as follows:

Arachnoid Cysts

Arachnoid cysts, also known as intra-arachnoid cysts, meningeal cysts, leptomeningeal cysts, and arachnoid diverticula, have been reported with increasing frequency over the past few years in dogs and cats [1-13]. It has been suggested that spinal arachnoid cysts in dogs most closely resemble type III spinal meningeal cysts in people [297]. As far as breed predilection is concerned, Rottweilers are often cited cited (in one report, 8/14 dogs were Rottweilers [297]) and the condition has been observed in related Schipperkes [7] and Shih Tzu littermates [10], suggesting an inherited etiology. The cysts are characterized as cerebrospinal fluid (CSF)-filled, dorsal midline, intradural, extramedullary cavitational lesions associated with coarse arachnoid trabeculation, that result in spinal cord compression. Occasionally, cysts located in ventral and dorsolateral locations in the cervical spinal region have been observed [14]. The cystic cavities are reportedly separated from the compressed spinal cord by an intact pia mater. In one series of affected dogs, numerous blood vessels with enlarged perivascular spaces were noted caudal to the cyst [4]. A cranial opening to the cysts, presumably continuous with the subarachnoid space and allowing flow of CSF, has been noted [7]. Usually there is no evidence of inflammation within the meninges or tissues lining the cysts, however, a mixed cellular inflammatory reaction and reactive connective tissue proliferation was reported in the cyst wall surgically removed in one case [7]. In this dog, the cyst wall was composed of pia-arachnoid meningothelial cells [7]. Many animals are less than 1 year of age, but cysts have been reported in animals up to 12 years of age. Onset of signs between 11 and 24 months was reported in one series of cases [7]. Arachnoid cysts have been observed mainly in rostral cervical and caudal thoracic/thoracolumbar sites; however, multiple cysts in the caudal cervical area of three Rottweiler dogs have been observed [14]. Cysts may also be multilobed or bilobed [297].

The pathogenesis is unknown [15] although congenital spinal dysraphism due to failure of fusion of the neural crest has been suggested [4], and indeed, in people, primary arachnoid cysts are regarded as a developmental abnormality of the arachnoid [16]. Ultrastructurally, the cyst is formed by splitting of the arachnoid membrane and the wall of the cyst is independent of the inner layer of the dura mater [16]. The wall of the cyst consists of an outer collagenous membrane and an inner layer of

cells that appear similar to normal arachnoid cells. Immunocytochemically, in people, arachnoid cysts react positively with antibody to epithelial membrane antigen, but are negative for glial fibrillary acidic protein, S-100 protein (a glial-associated protein), prealbumin, and carcinoembryonic antigen [17]. In people and in animals, arachnoid cysts reportedly may occur secondary to trauma, infection, inflammation, or subarachnoid hemorrhage [14,16]. While no evidence of trauma, other diseases, or malformations was found in Frykman's series of cases [7], disk herniation was thought to contribute to cyst formation in at least one dog in the study by Rylander's group [297].

Clinical syndromes will reflect the location of the lesion. To date, cervical syndromes and thoracolumbar syndromes have been observed. Pain is usually not a feature. Curiously, behavioral changes of depression and aggression in one Rottweiler with a C2 - C3 arachnoid cyst, disappeared following surgery, suggesting possible relief of pain [7]. Scoliosis has been reported in one dog [18]. Analysis of CSF is usually normal, although changes may include mild protein and/or mononuclear cell increase [297]. Survey radiographs tend to be non-diagnostic, although vertebral canal enlargement, possibly secondary to pressure atrophy of bone caused by the cyst [14], may be found in some cases [12]. Additionally, presence of spinal curvature, such as scoliosis, can be detected [18].
Diagnosis can be made using myelography, since the cysts usually fill with contrast agent, and there is often partial blockage to flow of the contrast medium, with associated moderate to severe (usually dorsal) spinal cord compression [19]. The cysts often appear as drop-shaped or oval contrast-filled cavities [7]. Computed tomography provides additional information on localization and lateralization of the cyst, and allows measurement of the degree of spinal cord compression [8]. Cysts may extend over several spinal cord segments. Magnetic resonance imaging may identify spinal cord parenchymal changes, such as presence of syringomyelia [8]. Sonography can be used to define the cyst wall, to characterize the internal architecture of the cyst wall, and to orientate the surgeon to the location and extent of the cyst [8]. Surgical decompression of the spinal cord appears to be the treatment of choice, using dorsal laminectomy or hemilaminectomy, in association with durotomy, drainage and/or partial excision of the cyst (surgical fenestration), and dural marsupialization often leads to permanent clinical improvement in a majority of dogs [2,4,12,13,297]; however, recurrences can occur [7,10] and neurologic deficits may persist [297]. Long-term follow-up studies (e.g., up to 4 years post-surgery) suggest that durectomy around the border of the cyst and dissecting it free from pia mater may give a more permanent recovery than durotomy and drainage [7]. Medical treatment alone, using a decreasing anti-inflammatory dosage of prednisolone, was reported to be successful in one dog [4]. Arachnoid cysts (see also intracranial intra-arachnoid cysts) have also been reported in brainstem locations, including cerebellar pontine area in a cat [20] and in the pineal region and quadreminal system of dogs [21,293].

Atlantoaxial Subluxation
Atlantoaxial subluxation is instability of the atlantoaxial articulation that produces excessive flexion of the joint causing the cranial aspect of the axis to rotate dorsally into the vertebral canal with subsequent spinal cord compression often resulting in severe, acute neurological deficits. The disorder occurs most frequently in dogs and it may result from fracture, separation, absence, or malformation of the dens (odontoid process), from hypoplastic deformity of the dens along with shortening of the atlas, from fracture of the body of the axis or fracture of the atlas, from rupture or stretching of the atlantoaxial ligaments with an intact normal dens, or from absence of the transverse ligament of the atlas [22-30].
The pathogenesis of the developmental malformations remains uncertain. Anatomical studies indicate that the dens develops from 2 separate ossification centers [31]. In this report, the authors suggested that dens dysplasia was unlikely to be a result of failure of development of one of the ossification centers but that vascular-related ischemia might lead to postnatal resorption of at least the middle part of the dens and result in dens dysplasia with subsequent atlantoaxial subluxation [31]. While hereditary factors may be involved in some lines of miniature and toy breeds of dogs in which this congenital anomaly is most common (e.g., Yorkshire Terrier, Chihuahua, Pomeranian, Japanese Chin, Toy Poodle, Pekingese, etc.), fracture and insufficient ligamentous support of the dens may occur in any breed. The condition has been reported as a congenital disorder in several large breeds, including Rottweiler and Doberman Pinscher [32,33]. Congenital atlantoaxial subluxation occurs most commonly in dogs less than one year of age; however, older animals exposed to various stresses also may be affected. Atlantoaxial subluxation has been sporadically reported in cats [34-36]. Atlantoaxial subluxation may also occur in dogs and cats in association with occipitoatlantoaxial malformation (OAAM) [37-39], a congenital deformity of the upper cervical spine that is characterized by absence of occipital condyles with fusion of the atlas to the occiput and hypoplasia of the atlas, axis and dens [40]. The atlanto-occipital and atlantoaxial joints are regarded as a single complex on both anatomical and biomechanical grounds [40,41]. Fusion of the atlanto-occipital joint may exacerbate instability of the atlantoaxial joint and complicate surgical attempts to correct it [42]. Atlantoaxial subluxation associated with dorsal dens angulation [43] and abnormal occipitoatlantal articulation [44] have been seen in adult Cavalier King Charles Spaniels with Chiari malformations.
Clinical signs vary according to the degree of luxation. They may range from cervical rigidity and pain to spastic paraparesis, and sometimes tetraplegia (see cervical syndromes). The signs may develop slowly over several months or they may occur

acutely. In some instances, hemorrhage and edema from severe trauma to the upper cervical cord may extend to the caudal brainstem resulting in cranial nerve deficits [45] (see pontomedullary syndrome).
When atlantoaxial subluxation is suspected, survey radiographs should be made without anesthesia before manipulating the animal excessively. Lateral view radiographs will reveal widening of the space between the arch of the atlas and spinous process of the axis, angulation of the axis relative to the atlas, a fractured dens, or the rounded end of the axis indicating the absence of the dens. Oblique lateral or ventrodorsal views may be useful in determining the presence or absence of the dens. Open mouth frontal and flexed lateral views are not necessary in most cases and are likely to cause severe compression of the spinal cord [46]. Use of specialized neuroimaging techniques, including computed tomography (CT) and computed tomographic myelography, are also recommended [14,47].
The prognosis is guarded. In a recent study on risk factors affecting the outcome of surgery for atlantoaxial subluxation in 46 dogs, an age of onset less than 24 months, duration of clinical signs less than 10 months, and preoperative neurological status were found to be significant positive prognostic factors [48]. In an earlier surgical study involving 23 dogs with atlantoaxial subluxation, only 4 of 7 non-ambulatory dogs recovered [49]. A potential complication from myelography and/or surgical manipulation in animals with atlantoaxial subluxation is cardiopulmonary arrest [50,51]. Medical treatment involves similar protocols as outlined under acute spinal trauma. Neck and head splinting in extension for animals with mild luxations and cervical pain or minimal neurological deficits followed by cage rest for at least 6 weeks has been successful [14,45,52]. Internal stabilization of the luxation generally is regarded as the therapy of choice [53], especially in animals with moderate to severe neurological deficits or in animals treated conservatively having recurring episodes of pain. Results of several studies [49,54] suggest that vertebral stabilization using a ventral approach [55] may be safer than dorsal stabilization of the atlas and axis. The application of ventral pins and polymethylmethacrylate has been used successfully in the surgical treatment of congenital and traumatic atlantoaxial instability [56,294]. In one case report involving an 8 month old Rottweiler with hypoplasia of the dens, use of cannulated screws was considered superior to K-wires and conventional screws for arthrodesing the atlantoaxial joint [57]. Stabilization with bone plates via a ventral approach has been successful in dogs [51]. The subluxated atlantoaxial joint of a tetraplegic Yorkshire terrier was reduced and secured in position by means of a novel cross pinning technique applied via a dorsal approach [58]. Use of the nuchal ligament as a means of securing the spinous process of the axis to the dorsal arch of the atlas has also been reported to be successful in small- and large-breed dogs [59]. In dogs and cats with OAAM, a combination of substantial internal and external fixation, odontectomy, and arthrodesis of the atlantoaxial articulation is recommended [39,42]. Poor results have been reported [60] using the Kishigami atlantoaxial tension band [61].

Congenital Cerebellar Disorders
Congenital cerebellar abnormalities tend to be either:

a. Primary developmental defects or malformations or
b. Hypoplasia and atrophy secondary to an *in utero* or perinatal viral infection [62].

As with most other congenital anomalies, malformations of the cerebellum in domestic animals usually result from unknown causes. Various forms of cerebellar agenesis (absence of the whole or parts), aplasia (faulty development with no tissue differentiation) and cerebellar hypoplasia (faulty development with some tissue differentiation), have been reported in dogs, including Beagle, Silky Terrier, Airedale Terrier, Chow Chow, Irish Setter, Boston Terrier, Bull Terrier, and Wire-Haired Fox Terrier [63-68]. The Wire-haired Fox Terriers and Irish Setter puppies also had lissencephaly [65]. An unusual, probably inherited cerebellar cortical dysplasia has been reported in St. Bernard puppies characterized by abnormal laminar cytoarchitecture of the cerebellar cortex: loss of distinction between granule cell, Purkinje cell or molecular layers along with pallor and cavitation of the subcortical white matter of cerebellum and cerebum [306]. Cerebellar abiotrophy (see cerebellar cortical abiotrophies) is a post-natal degenerative disorder associated with an intrinsic developmental abnormality of various neurons, especially Purkinje cells, causing their premature death [62]. Affected animals are normal at birth or at the time they first begin to ambulate (around 3 to 4 weeks of age) [65]. Occasionally, a neonatal cerebellar abiotrophy is seen in which animals show cerebellar signs at birth [65,69]. The cerebellum may also be involved with heterogeneous developmental disorders seen in animals with Dandy-Walker Syndrome and Chiari malformations.

In utero infection with feline panleukopenia virus (parvovirus) results in destruction of actively dividing cells in the external germinal layer, which is actively proliferating at birth and for the first 2 weeks postnatally [70-73]. Postnatal infections with this virus rarely involve the central nervous system; however, since the cerebellum continues to develop postnatally, viral infection at birth might be expected to result in significant cerebellar hypoplasia [62]. Gross cerebellar lesions vary from marginal overall reduction in size to extensive loss of cerebellar tissue and associated reduction in size of the transverse fibers in the pons and the pontine nuclei [62]. Microscopically, lesions range from mild granuloprival hypoplasia (depletion

of granule cells and heterotopia of Purkinje cells within narrowed molecular layers) to rudimentary folia without any neurons [62,70,71]. Rarely, other developmental anomalies can occur in affected kittens, such as hydrocephalus (from aqueductal stenosis) and hydranencephaly. Infrequently, perivascular necrosis and mineralization in cerebral internal capsules or periventricular tissues may be observed [62]. Cerebellar agenesis or hypoplasia in conjunction with hydrocephalus and hydranencephaly has also been reported in kittens secondary to *in utero* parvovirus infection, possibly due to vaccination that occurred late in the first, or early in the second, trimester of pregnancy [74]. To date, a comparable viral-related cerebellar disorder is less clearly defined in dogs, although microscopic lesions similar to those seen in cats following *in utero* viral infection was observed in a young adult Beagle [62,65]. Further, results of recent molecular studies suggest that cerebellar hypoplasia may be associated with *in utero* parvoviral infection in dogs [295].

The signs of cerebellar disease are generally symmetrical and include limb spasticity, dysmetria, head tremor, truncal swaying, loss of balance, and wide-based stance. Some animals have difficulty standing and are unable to take more than a few steps without falling [65]. Ataxia in Samoyeds with neonatal cerebellar abiotrophy is most severe in pelvic limbs with marked spasticity and hypermetria. Irish Setter puppies with HQA are unable to walk. Abnormal nystagmus is unusual in these conditions [65], although it was observed in Irish Setter puppies with HQA [69]. Generalized seizures were observed in one Wire-Haired Fox Terrier with cerebellar malformation and lissencephaly after reaching one year of age [65]. Signs in St. Bernard puppies included inability to stand, spontaneous searching nystagmus, ventrolateral strabismus, and occasional thoracic limb paddling movements [306].

Diagnosis of congenital cerebellar disorders usually is based on age, breed/species, history (e.g., of viral infection), histopathology, immunofluorescence, or DNA studies using polymerase chain reaction. It has recently been shown that parvoviral DNA can be amplified from archival and fresh tissues from both cats and dogs with cerebellar hypoplasia [295]. As the condition usually is non-progressive, prognosis for longevity may be favorable. There is no treatment.

Chiari Malformations

Chiari malformations are complex developmental disorders involving the caudal brainstem, cerebellum and cranial cervical spinal cord. In people, Chiari malformations have been divided into two types based on severity of the hindbrain deformity [75]. In patients with Chiari I, there is elongation and caudal displacement of the cerebellar tonsils (vermis and paravermis lobes) and sometimes, part of the medulla oblongata, through the foramen magnum into the cranial cervical vertebral canal. The cord, pushed caudally by medulla and the fourth ventricle, is kinked. Hydrosyringomyelia (this term is used to denote presence of either syringomyelia or hydromyelia since it is often impossible to differentiate syringomyelia and hydromyelia using imaging techniques [76], although some authors prefer the term "syrinohydromyelia") may be associated with the Chiari I malformation and may develop secondary to overcrowding of the foramen magnum and obstruction of CSF flow, although its pathogenesis remains unclear. In Chiari II patients, there is herniation of the cerebellar vermis and sometimes, the inferior lateral cerebellar hemispheres, over the dorsal aspect of the cervical spinal cord. The fourth ventricle, pons, and medulla are also elongated and partially located in the spinal canal, usually in association with meningomyelocele [75].

Chiari I malformations, similar to those in people, have been described in dogs [43,44,76-78]. The condition is over represented in Cavalier King Charles Spaniels (CKCS) and a familial/genetic basis is suspected, with the disease having an earlier onset and increased severity with increased inbreeding [299,312]. It has been reported also in a Maltese Poodle [76]. The condition in CKCS appears to be associated with occipital bone hypoplasia which results in caudal fossa overcrowding, obstruction of CSF pathways and secondary hydrosyringomyelia [299]. Trauma superimposed on a pre-existing Chiari type 1 congenital abnormality may play a role in some clinical cases [44]. In published reports, the age range of affected animals extends from 6 months to 10 years. The clinical course may be acute [76] or run an extended course over several months or years [43,44,78].

Clinical signs may include cervical pain, torticollis, spinal hyperesthesia, exercise intolerance, paresis in one or both thoracic limbs or tetraparesis, ataxia/hypermetria in thoracic or in all four limbs, bunny-hopping hindlimb gait, poor hopping responses, and proprioceptive deficits. Spinal reflexes may be exaggerated. In a recent study of affected CKCS, a variety of cranial signs were also seen, including facial nerve deficits (9/22 dogs), seizures (7/22 dogs), and vestibular syndrome (7/22 dogs) [300]. Paroxysmal involuntary flank scratching, sometimes extended over several years, has been noted in CKCS, of either gender, usually between 6 months and 2 years of age [77,78,299]. There is no dermatologic cause and the scratching seems to be intensified by excitement, barking, exertion, wearing of collars, or when the shoulder, neck or ear of the "scratched" side are touched [77,78]. Affected animals often showed evidence of pain or hyperesthesia around the neck, ear or thoracic limb. This unusual scratching feature may be due to disinhibition of hindlimb reflex activity [44] or to some form of paresthesia secondary to the hydrosyringomyelia [78] (that was present in all 7 dogs of this study and all of whom manifested this peculiar scratching reaction), possibly related to interruption of the decussating spinothalamic tracts and dorsal/ventral horn damage due to a progressively expanding hydrosyringomyelia [44,78]. Interestingly, hydrosyringomyelia was lacking in one report in a CKCS, in whom the persistent flank scratching was not present [43]. Variable lower motor neuron deficits, such as muscle atrophy, weakness, and decreased spinal reflexes, have been noted in several dogs, especially

affecting the thoracic limb ipsilateral to the "scratched" side [78]. Presumably, these signs of a cervicothoracic syndrome could be explained if the hydrosyringomyelic lesions extended to low cervical and cranial thoracic cord levels. Denervation of spinal epaxial muscles may lead to muscle atrophy and scoliosis [18,79] and, when cervical muscles are involved, torticollis. Electromyographic studies may reveal evidence of denervation in paraspinal and thoracic limb muscles [78]. Analysis of CSF in animals with Chiari I malformation may be normal or show a mild, mononuclear pleocytosis. Radiographs of skull and cervical spine are usually normal, however, cervical scoliosis has been observed [78], and in another case, radiography revealed a developmental angulation of the dens with spinal cord compression and scalloping of the dorsal arch of C1 [43]. Magnetic resonance imaging (MRI) may show varying degrees of ventricular enlargement/hydrocephalus, hydrosyringomyelia of cervical spinal cord that occasionally is seen to extend all the way to the caudal lumbar spinal cord segments, and sometimes, caudal displacement of the caudal lobe of the cerebellum to the level of or through the foramen magnum [43,44,76,78,300]. In one series of cases involving the CKCS, the foramen magnum was small using MRI and the shape of the caudal fossa was abnormal due to a rostral indentation of the occipital bone, leading to overcrowding within the foramen magnum and apparent compression of the brainstem at the cervicomedullary junction [78]. Additionally, the tentorium cerebelli appeared more horizontal than normal, the caudal medulla oblongata had a kinked and elongated appearance, and the dorsoventral diameter of the craniocervical vertebral canal was small [78]. In other dogs, there may be abnormal alignment of the occipito-atlantal articulation and dorsal displacement of the caudal medulla and C1 spinal cord segment. MRI studies in CKCS have also revealed that the malformation may also be clinically silent in some dogs [300].

Treatment has been empirical with variable success. In one dog, furosemide (2 mg/kg, bid, over a 2-week period) resulted in moderate neurological improvement, reduced frequency of paroxysmal scratching episodes, and clinical stability 3 years after diagnosis [44]. In the study of 7 CKCS [78], low levels of oral prednisone (0.5 mg/kg PO every other day) and dexamethasone (0.25 to 0.5 mg, PO sid or every other day) provided an initial mild improvement in neurological signs that subsequently remained stable or slowly deteriorated. Use of neuralgesics carbamazepine and amitriptyline was unsuccessful. Carprofen (2mg/kg PO bid) had some temporary effect but was considered to be less effective than the glucocorticoids. Meloxicam (0.1 mg/kg PO sid) improved clinical signs in one dog. More recent studies of CKCS suggest that mild cases may not require treatment or may be managed using non-steroidal anti-inflammatory agents [299], while surgical management (eg, subtotal occipital craniectomy with durotomy to relieve obstruction at the level of the foramen magnum) for dogs with progressive signs. A surgical subdural shunt draining to the abdomen has also been successfully employed (Dr. G. Skerritt, personal communications, 2002). Anti-inflammatory doses of prednisolone are recommended for dogs where surgery is not possible or results in limited improvement [299].

Dandy-Walker Syndrome

The eponym, Dandy-Walker syndrome, refers to complex heterogeneous developmental anomalies in people characterized by the morphological triad of aplasia or hypoplasia of the cerebellar vermis (especially the caudal portion), cyst-like dilatation of the fourth ventricle, and hydrocephalus [75]. The Dandy-Walker syndrome is believed to be a disorder of fusion of dorsal midline structures of the primitive neural tube [80]. Failure of development of the midline portion of the cerebellum forms the basis of this syndrome with subsequent enlargement of the posterior fossa, abnormally high placement of the tentorium, and elevation of the transverse sinuses. The syndrome may also be associated with syringomyelia and agenesis of the corpus callosum. A similar syndrome has been reported in several breeds of dogs including Beagle, Silky Terrier, Chow Chow, Tervuren, Boston Terrier, Briard, Labrador Retriever, Bull Terrier, Weimaraner, and Dachshund [64,81,82] and in a Domestic shorthair kitten [83]. Cases are characterized by cerebellar vermian aplasia or hypoplasia, often associated with a fluid-filled, cyst-like structure in continuity with a dilated fourth ventricle that fills the posterior fossa. A communicating hydrocephalus is frequently present. The pyramis, uvula, and nodulus cerebellar lobules were commonly involved in several reports involving dogs [64,82]. Additionally, portions of the cerebellar hemispheres and flocculus can be affected. Microscopic changes may include focal or scattered Purkinje cell chromatolysis and atrophy, indistinct deep cerebellar nuclei, scattered axonal spheroids, and reduction of granule cells in the cerebellar cortex. Retrograde transynaptic neuronal degeneration, such as chromatolysis or vacuolation of neurons, may be noted in brainstem nuclei that project to the cerebellum, including olivary, lateral reticular, lateral cuneate and vestibular nuclei. The lateral apertures through which the fourth ventricle communicates with the subarachnoid space appear to be microscopically normal in dogs [82]. Similarly, no evidence of foraminal atresia was found in the affected kitten [83]. The wall of the posterior fossa cyst may be lined by pia-arachnoid, neuropil, and an inner layer of flattened ependymal cells [64] or by ependymal cells alone [82]. Hydromyelia is not usually a feature but has been reported in two adult dogs [76]. A comparison of pathological features seen in animals with Dandy-Walker syndrome and Chiari I malformation is shown in Table 1.

Table 1. Comparison of features of Chiari I malformation and Dandy-Walker Syndrome in dogs *.		
	Chiari I Malformation	**Dandy-Walker Syndrome**
Hydrocephalus	Variable	Common
Fourth Ventricle	Normal	Cystic and may descend into cervical cord
Cerebellum	Ectopic	Hypoplastia / aplasia
Cerebellar position	caudal displacement of the caudal lobe of the cerebellum to the level of or through the foramen magnum	Normal
Posterior fossa cysts	None	Present
Hydromelia	Common	Uncommon
Meningomyelocele	None	None

*Modified from Kirberger RM et al., [76].

Clinical signs of ataxia, dysmetria, absent menace response, and intention tremors reflect a cerebellar syndrome. In addition, some animals with flocculonodular lobe lesions may show a vestibular syndrome, such as head tilt, nystagmus, ventromedial strabismus, circling, and falling. Seizures, behavioral abnormalities and visual impairment may be seen in animals with hydrocephalus [82,83]. A bunny-hopping gait was observed in one 12 week old Beagle [64]. Clinical signs tend to be non-progressive and may be seen in young animals as early as 2 weeks of age or may be delayed until 3 or 4 months of age. The condition has also been reported in adult dogs: a 4 year old Cavalier King Charles Spaniel and a 2.5 year old Maltese Poodle with signs of intermittent pain and paresis/hypermetria, respectively [76]. The 4 month old kitten was presented with acute-onset collapse and lethargy. Signs of stupor, intermittent rotatory nystagmus, partially constricted pupils, lack of menace response, but with normal pupillary light reflexes, were noted. Tactile and visual placing reactions were diminished. Late-onset aggression occurred in this kitten [83].

Analysis of cerebrospinal fluid is normal. Radiographic studies may reveal a very thin and dome-shaped calvarium with a smooth ground glass" appearance, suggestive of hydrocephalus. Scalloping of the inner table of occipital bone was observed in one dog [81]. A dilated ventricular system and cystic dilatation of the fourth ventricle can be identified using MRI [76,83] or cisternography [81]. Hydromyelia was diagnosed in two adult dogs using myelography and MRI [76].

Prognosis depends on severity of clinical signs. If the signs are mild, prognosis for longevity and quality of life may be good, especially since signs tend to be non-progressive. Ventriculoperitoneal shunting was performed in the kitten that did well for 13 weeks before its condition deteriorated [83].

Dermoid Sinus

A dermoid sinus, also termed pilonidal sinus, pilonidal cyst or dermoid cyst, is a neural tube defect resulting from incomplete separation of skin and neural tube during embryonic development. Dermoid sinus was once considered to be unique to the Rhodesian Ridgeback breed or Ridgeback crosses [84-90], however, the condition has now been reported in several breeds of dogs [91-96] and rarely in cats [97,98]. It is believed that the sinus is hereditary in nature in Ridgebacks, probably as a simple autosomal recessive gene.

The dermoid sinus typically occurs in the dorsal midline in the cervical, cranial thoracic, and sacrococcygeal regions. One or more may occur in the same animal. The sinuses form a small external opening about 1 mm in diameter and the hair around the orifice is concentrated in a little tuft. The sinus is lined by modified skin, incorporating hair follicles and sebaceous glands, so that the lumen contains hair, exfoliated cells, and sebum. There may be histological evidence of a pyogranulomatous foreign body-type reaction to hair fragments and other debris. The sinus runs from the skin toward the supraspinous ligament to which it may or may not be attached by fibrous tissue. Occasionally, the sinus may extend through the vertebral canal to communicate with the dura mater and subarachnoid space, especially in the sacrococcygeal region, and less commonly in the thoracic and cervical regions. This seems to be the case for Rhodesian Ridgeback dogs, but may be seen in other breeds too [91]. There is the suggestion, based on limited case numbers, that dermoid sinus in non-Rhodesian

Ridgeback breeds may occur more commonly in cranial thoracic (e.g., T1 - T4) [92,93,96] or mid thoracic regions (e.g., T6 - T7) [93], and that there may be a proportionally higher prevalence for dermoid sinus-dural mater communication in these breeds [91]. The dermoid sinus occurred at T3 vertebral level in the affected cat [98]. In the cervical area, the sinus is commonly attached to the area of the spinous process of the second cervical vertebra. In one report, a C2 transosseous communication with the vertebral canal was reported in a Rhodesian Ridgeback/Dalmatian cross [87]. Some dogs with dermoid sinus have other congenital anomalies as spinal cord myelodysplasia [96] and vertebral anomalies including rachischisis, vertebral fusion, and hemivertebra [91,93].
The sinus tract is often palpable as a firm cord of tissue that continues ventrally to the level of the dorsal spinous processes of the underlying vertebrae [91]. An exudate may be seen emanating from the skin orifice. Neurological signs can occur in dogs at any age when the sinus communicates with the subarachnoid space and becomes infected, leading to meningitis, myelitis, or spinal cord compression. To the author's knowledge, only a single case of spinal cord involvement has been reported in cats (in a 16 month old Balinese cat, at the level of the third thoracic vertebra) [98]. According to the location of the sinus, and degree of involvement of the spinal cord and/or meninges, neurological signs may reflect either a cervical syndrome, cervicothoracic syndromethoracolumbar syndrome, or lumbosacral syndrome. Not every animal in which the sinus communicates with the subarachnoid space will show clinical or neurological deficits [89]. Various organisms, including *Staphylococcus intermedius*, may be cultured from the sinus. Analysis of CSF may reveal increased protein content and elevated white cell count if there is an underlying meningitis/myelitis present [91]. Radiography can be used to identify presence of any vertebral anomalies, while contrast studies such as fistulography/sinography (e.g., using a non-ionic contrast medium, such as Omnipaque) may help determine the extent of the sinus, the central region of which may be enlarged to form a cyst-like cavity. Myelography can be used to detect the presence of meningeal abnormalities and possible spinal cord compression [93,96]. The sinus and adjacent vertebrae may also be characterized using special imaging techniques, including computed tomography and ultrasonography [87,93]. In one dog, computed tomography identified schisis (cleft) of the T7 dorsal arch, displacement of the spinal cord and dural sac, and the dermoid sinus dorsal to the vertebra [93]. Surgical excision, typically in conjunction with dorsal laminectomy, is the treatment of choice, along with appropriate antibiotic therapy based on culture of the sinus and sensitivity testing. Prognosis is guarded, as recurrence of infection may occur with incomplete surgical removal [87].

Nasal dermoid sinus cysts, rare developmental defects, and characterized by intermittent discharge from a small opening in the midline on the bridge of the nose at the junction between the nasal planum and the skin, have been reported in dogs (3 of 6 dogs were Golden Retrievers). These cysts have the potential for extending into the cranial vault causing cerebral abscesses or recurrent meningitis. Complete surgical excision has a good prognosis.

Fetal Akinesis Deformation Sequence
A lethal developmental disorder called fetal akinesis deformation sequence has been described in a breeding colony of dogs that is inherited as an autosomal recessive trait [301]. Fetal akinesis was demonstrated by abdominal ultrasonography of late-gestation bitches. Puppies died at birth due to respiratory failure and exhibited scoliosis and arthrogryposis. Grossly, changes included microencephaly, small cerebellum and brainstem, reduced caudal cerebal sulcation, thin spinal cord, and generalized neurogenic muscle atrophy. Neuronal degeneration and gliosis were found in spinal cord, brainstem nuclei, and cerebellum in which there was reduced foliation, marked loss of Purkinje cells in some folia, loss of cells in the external granular layer, and absence of cells in the deep cerebellar nuclei. The cerebral cortex had normal layers but with reduced cell numbers. The condition is thought to be associated with slowing or arrest of CNS development due to accelerated neuronal degeneration in mid to late gestation, with the ensuing neurogenic fetal immobility causing contracture of skeletal muscles leading to global arthrogryposis and respiratory failure at birth. The disorder is considered to resemble pontocerebellar hypoplasia type I in humans, an autosomal recessive neurodegeneration disorder associated with anterior horn cell disease and neurogenic muscle atrophy [302].

Hydranencephaly
Hydranencephaly and porencephaly are rare, related malformations associated with failure of development (hypoplasia) and destruction (secondary atrophy) of primarily the neopallial part of the telencephalon (the neocortex and the ventricular zone) [62,99,100]. Dogs and cats may be affected. The pathogenesis of this anomaly is not always certain. In people, a fetal cerebrovascular accident may result in massive necrosis and resorption of tissue [99]. In animals, the most common cause is *in utero* viral infection [62,100]. While many different viruses (including Akabane, Bluetongue and Rift Valley fever) are implicated in large animals, hydranencephaly in cats has been linked with vaccine-induced intrauterine feline panleukopenia / parvovirus infections [74,101]. Porencephaly refers to the occurrence of single or multiple cystic cavities in the cerebrum, usually communicating with the lateral ventricles or subarachnoid space. According to Summers and colleagues [62], porencephaly might occur if infection occurs later in the period of fetal nervous system vulnerability or if it is less

destructive. Hydranencephaly is characterized by virtual absence of the cerebral hemispheres usually with preservation of olfactory and hippocampal components, fornix, and basal nuclei [62]. The cerebral hemispheres are replaced by cerebrospinal fluid-filled sacs lined by leptomeninges, a glial membrane, and ependymal remnants. Microphthalmia has been reported [102] and there may be loss of nerve fibers and reduced myelin staining in optic nerves. Other structures including the brainstem and cerebellum may or may not be affected. In kittens with *in utero* parvovirus infection, hydranencephaly occurred in conjunction with cerebellar agenesis and hypoplasia [74]. Involvement of structures other than the cerebral cortex may depend on the developmental stage of the nervous system at the time of fetal infection.
Clinical signs are usually seen within several weeks after birth and depend upon nervous structures involved. Animals with predominant cerebral cortex involvement may have behavioral changes, including dummy-like characteristics, indifference to their environment, and episodes of rage, are usually blind, and may be unable to suckle. Urinary and fecal incontinence may be present. In animals with cerebellar involvement ataxia, dysmetria, and difficulty standing may be noted. Other animals can appear active but have difficulty in prehending food and drinking water. Unilateral hydranencephaly has been observed in an 8-month old Miniature Poodle whose only clinical sign was a visual defect [100]. Accordingly, prognosis varies from guarded to poor. Diagnosis is suggested by clinical signs and neuroimaging techniques, such as MRI, and confirmed by histopathology, immunofluorescence, or DNA studies using polymerase chain reaction [74].

Hydrocephalus
Hydrocephalus is one of the most common manifestations of developmental disorders in dogs and cats [103-105] and is the result of a disturbance in the normal cerebrospinal fluid (CSF) fluid dynamics [75]. It is characterized by increased CSF volume and dilatation of the cerebral ventricles. It may be congenital or acquired postnatally. It may occur passively in which the increased volume of CSF fills voids left by loss of brain parenchyma [106]. This has been called compensatory hydrocephalus or hydrocephalus ex vacuo and is often seen with congenital defects or malformations, such as hydranencephaly and cerebellar hypoplasia, and may follow severe destructive parenchymal lesions, such as cranial trauma or ischemic encephalopathy in adult cats [107]. The most common form of hydrocephalus in animals is obstructive (non-communicating) hydrocephalus [108] typically caused by obstruction to CSF flow in the intraventricular pathway, in which ventricular dilatation occurs proximal to the obstruction site, with preservation of normal ventricular size distal to the block. Obstruction may also occur at the point of CSF resorption by the arachnoid villi in the subarachnoid spaces (e.g., meningitis, malformation of arachnoid villi, or tumors compressing the venous sinuses [107]). CSF pressure tends to be increased (hypertensive) in cases of obstructive hydrocephalus [107]. While obstruction may occur anywhere along the ventricular pathway in congenital hydrocephalus, it occurs most commonly in the mesencephalic aqueduct of Sylvius. Obstructive hydrocephalus in dogs and cats may be associated with various developmental defects, e.g., myelodysplasia, Dandy-Walker syndrome, spina bifida, syringomyelia and hydromyelia, optic nerve hypoplasia, occipital dysplasia, craniofacial abnormalities in Burmese cats [109], polymicrogyria in Poodles [110], triploidy (a fatal condition characterized by the presence of three haploid sets of chromosomes, instead of two, in all cells) in a stillborn puppy [111], aphakia (absence of the lens) and multiple ocular defects in Saint Bernard puppies [112], and griseofulvin teratogenesis [113], as well as intra-uterine infectious diseases such as parvovirus [74] and panleukopenia virus [114]. Postnatal, acquired obstructive hydrocephalus, again often involving the mesencephalic aqueduct, has been associated with feline infectious peritonitis [115-117], parainfluenza virus [118,119], necrotizing periventricular encephalitis [120-122], cryptococcal granulomatous ependymitis [123], methylmercury poisoning [124], parasitic migration[125,126] and occasionally it may be caused by mass lesions that block CSF flow at the interventricular foramen, third ventricle, mesencephalic aqueduct, or lateral apertures [107,125,127-131]. Meningitis may also result in blockage of CSF flow at the lateral apertures [107,132]. Hydrocephalus has been seen in several miscellaneous disorders, including galactosialidosis in a 5 year old Schipperke dog [133], cerebellar degeneration in Bull Mastiff puppies [134,135], neuroaxonal dystrophy in a 9-week-old Jack Russell Terrier [136], primary ciliary dyskinesia in dogs [137-139], hypertrichosis (growth of hair in excess of normal) in Golden Retrievers [140], hereditary cerebellar abiotrophy in Australian Kelpie dogs [141], arachnoid cysts within the quadrigeminal cistern [308], and in a dog presented with continuous tail chasing [142]. Hydrocephalus is thought to play a role in the development of hydrosyringomyelia (see syringomyelia and hydromyelia) in dogs and hypodypsic hypernatremia in dogs and cats [143,144].
The use of additional classification terms as non-obstructive or communicating hydrocephalus can be confusing and has been challenged in people, in whom increased pressure leading to hydrocephalus is virtually always a result of blockage, whether it is along the pathway of CSF flow or at the site of resorption [75]. Overproduction of CSF in cases of choroid plexus papillomas is considered a rare cause of hydrocephalus in people, and to my knowledge, has yet to be reported in animals. At this time, the form of hydrocephalus in people termed "normal pressure hydrocephalus" which is the result of an imbalance between production and resorption of CSF, usually around the brain convexities, and is seen in late middle-aged and elderly groups, has not been reported in animals. The term "external" hydrocephalus refers to excessive collection of CSF within the subarachnoid space rather than in the ventricular system and is seen in cases of generalized brain atrophy. This form has been reported in a 12 week old Fox Terrier presented with hydrocephalus [304].

On gross inspection the brain may be enlarged with loss of gyral pattern and decreased depth of sulci. In severe cases the cerebral hemispheres contain extremely large, fluid-filled lateral ventricles, with the cerebral cortex often being reduced to 3 - 4 mm in thickness. The loss of white matter from distension and atrophy is generally more severe than the gray matter loss [106]. The lateral ventricle may extend into the olfactory peduncle and bulb. Pressure from ventricular enlargement may result in atrophy of the corpus callosum, disruption of the septum pellucidum and atrophy of associated structures, including subcortical white matter, optic radiation, internal capsule and auditory radiation. The basal nuclei are usually intact. Blockage of the lateral apertures will result in extensive dilatation of the entire ventricular system. Dilatation of the fourth ventricle may result in marked cerebellar compression along with flattening of the pons and medulla oblongata [106]. Distension of the central canal (hydromyelia) and syrinx formation may also occur in the cervical spinal cord due to the increased intraventricular pressure [145,146]. A developmental stenotic mesencephalic aqueduct is typically associated with fused rostral colliculi [106]. Microscopically, the ependymal lining is frequently disrupted and there may be evidence of forking, gliosis and septum formation. A pronounced subependymal edema is usually present. In one report of acquired hydrocephalus in puppies, there was severe periventricular, choroidal, and meningeal inflammation with fibrinous exudate and neutrophilic and mononuclear cell infiltrates, and multiple false diverticula emanating from the lateral ventricles [120]. Severe meningitis, choroid plexitis, and ependymitis can occur with feline infectious peritonitis virus [117]. Bleeding is a potential complication of hydrocephalus. Chronic subdural hematomas have been reported in a hydrocephalic 2 month old Newfoundland puppy [307].
Small, toy, and brachycephalic breeds (Maltese, Yorkshire Terrier, English Bulldog, Chihuahua, Lhasa apso, Pomeranian, Toy Poodle, etc.) are at high risk for hydrocephalus. In one study, 53% of 564 hydrocephalic dogs manifested clinical signs by 1 year of age [108]. A distinction between congenital and acquired forms of hydrocephalus may be very difficult from a clinical viewpoint especially since infectious agents may cause hydrocephalus postnatally in young puppies [120]. Furthermore, the confusion in terminology is reflected in the results of one epizootiologic study from 14 veterinary schools in the United States in which 30% of 564 dogs classified as having "hydrocephalus due to congenital origin" were over 2 years of age [108]. Genetic disease has been reported. In Siamese cats, hereditary hydrocephalus is transmitted as an autosomal recessive trait [147]. The congenital hydrocephalus seen in New Zealand Golden Retriever puppies with hyertrichosis appears to have an autosomal mode of inheritance [140].

Clinical examination of newborn and immature hydrocephalic animals typically reveals an enlarged, dome shaped cranium, and open sutures and/or fontanelles that may be bulging in an animal that continuously cries out, has visual and auditory impairment, and altered mental status (ranging from hyperexcitability to severe depression). Other signs may include sporadic seizures, a gait that is uncoordinated, spastic, and clumsy, head tilt, circling, dilated and fixed pupils, and head pressing [148]. Ventrolateral strabismus may occur as a result of encroachment on the orbit from expanding frontal bones, in which case eye movements are normal. Less common signs are positional and spontaneous nystagmus, vomiting, and cervical pain. Some adult Golden Retrievers with hydrocephalus and hypertrichosis manifest behavioral abnormalities (e.g., aggression, hyperactivity, slow learning and other temperament changes) that make them unacceptable pets [140].
Hydrocephalus may be confirmed by radiographic demonstration of enlarged lateral ventricles. Plain radiography will often reveal a ground glass appearance throughout the cranial vault. Cranial sutures and/or open fontanelles may be evident after the normal age for closure and skull ossification. Ultrasonography through open fontanelles [149], CT, or MRI are very useful diagnostic aids [129,150]. Measuring ventricular volume using quantitative MRI also appears to be a useful tool and may help in understanding the relationship between ventricular volume and neurological disease [151]. In one study, a high incidence of asymptomatic (ventricular enlargement or ventriculomegaly) was noted in clinically normal dogs [152], a finding sometimes termed "occult hydrocephalus". Measurement of basilar artery resistance index (a correlate of intracranial pressure) using transcranial dopler ultrasonography, a non-invasive and relatively inexpensive technique, reportedly correlates with neurologic status in dogs with congenital hydrocephalus [296]. Electroencephalographic traces usually have a characteristic pattern of high amplitude (25 - 200 mV), slow wave (1 - 5 Hz) activity, often with a superimposed fast frequency of 10 to 12 Hz. Fundic examination may reveal papilledema. Collection of CSF for analysis is usually not performed since it may precipitate brain herniation due to the presence of increased intracranial pressure.
Prognosis is sometimes related to an underlying disease (such as cerebral neoplasm), but tends to be guarded to poor. Treatment of animals with severe congenital hydrocephalus is futile due to the large amount of tissue destruction and atrophy. Indeed, the efficacy of corticosteroids and surgical shunt procedures in animals with "acquired" hydrocephalus remains uncertain due to the lack of well controlled clinical trials and to incomplete knowledge of the underlying pathogenesis of hydrocephalus. Treatment of the cause of acquired, adult-onset hydrocephalus would seem to be a logical pursuit. Successful surgical shunting procedures have been reported in "acquired" hydrocephalus in both immature and mature dogs [104,153-156]. A ventriculoperitoneal shunt has been used to treat cats with hydrocephalus [157]. Common complications include catheter blockage and sepsis. Dexamethasone, administered at an oral dose of 1 mg divided 4 times daily, for 2 to 3 kg dogs has been used empirically [104]. This dose is gradually reduced over a 2 to 3 week course of

therapy . Some animals may be maintained on alternate day dosage schedules. Dexamethasone at 2 - 4 mg/kg has been suggested for patients with exacerbated/progressive signs [107]. In cats with mild signs, intermittent or short- and long-term corticosteroid usage may be helpful, e.g. prednisone at 1 - 2 mg/kg, sid or bid, PO, along with (or given separately) furosemide at 2 mg/kg bid or tid, PO [105]. Corticosteroids are believed to primarily affect brain bulk and CSF production, not CSF absorption [158]. In humans, acetazolamide, isosorbide, and furosemide can reduce CSF production considerably and may provide short-term benefits [75].

Lissencephaly

Lissencephaly is a rare developmental defect characterized by a small, smooth-appearing cerebrum with rudimentary or no gyri (agyria) or sulci present and derangement of cells of the cerebral cortex. This anomaly has been reported in Lhasa apso dogs, in several breeds of dogs with cerebellar hypoplasia and dysplasia, including Wire-Haired Fox Terriers, Irish Setters, and Samoyeds [65,159,160,309] and in Korat cats with associated microencephaly [106]. Lissencephaly results from disturbance of neuronal migration and proliferation during development. The condition involves only the neocortex, with the hippocampal and olfactory lobes being normal [106,159]. The neocortex is thicker than normal (pachygyria) and contains scattered heterotopic white matter bundles, especially in the thin superficial molecular layer and in the 4th cortical layer. Randomly arranged neurons may be seen in the deeper cortical layers, suggesting arrested migration. In affected Lhasa apso dogs in which the cerebellum was grossly normal, changes were also observed in the flocculonodular lobe of the cerebellum that were characterized by marked heterotopic changes in several folia in which Purkinje cells were irregularly dispersed within the granular layer, the molecular layer was hypercellular and nests of heterotopic glial cells were in the roof nuclei [159].

Clinical signs usually are detected in the first year of life and are characterized by erratic behavior patterns, including episodic aggression, growling at imaginary objects, confusion, depression, hyperactivity, visual deficits, and seizures. Behavior alterations, including self-mutilation, also occur in cats. Gait and posture are usually normal but slight hypermetria may be present when running. Postural reactions tend to be sluggish but normal, although mild proprioceptive deficits have been observed [159]. Spinal reflexes are normal. Bilateral menace deficit may be the only deficit in cranial nerve testing. The observation that neurological abnormalities were mild or delayed in onset after birth suggests the dog is less dependent on the cerebral cortex for sensorimotor function than is man [159]. Abnormal wave tracings are detected electroencephalographically. Neuroimaging studies in animals have demonstrated a smooth cerebral brain surface, as in humans, along with a broad cortex in relation to a narrow white matter layer [75,309].

Prognosis is guarded. Treatment is symptomatic. Seizures may be controlled with anticonvulsant therapy.

Neuronal heterotopia in Lagotto Romagnolo dogs is a recently reported disorder that remains to be classified, although it may be within the spectrum of lissencephalic malformations [298]. Clinical signs began around 7 weeks of age and included tetraparesis with hypermetria, intention tremor, and poor conscious proprioception. Mentation and spinal reflexes are normal. Affected dogs have facial dysmorphism characterized by inferior prognathia and an atypical brachycephalic skull. With time, cerebellar signs progressively improve to apparent clinical normality by 1 year of age. Gross examination of the brain is normal (including normal gyration). Microscopic lesions are characterized by diffuse abnormal neuronal migration and maturation in the cerebral cortex, cerebellum and pons. The abnormal neurons appear monomorphic with vesicular nuclei and basophilic cytoplasm. Similar cells are also present in hemispheric and cerebellar white matter. A genetic disorder is suspected.

Meningoencephalocele

This is a lethal malformation characterized by herniation of part of the brain and meninges through a defect in the skull (cranioschisis or cranium bifidum) [106,109]. The condition may occur spontaneously in animals [161]. It has been seen in kittens following exposure of pregnant cats to a variety of teratogenic agents, including methylmercury, hydroxyurea and griseofulvin [113,162-164], and it occurs in male and female Burmese kittens in which it is inherited as an autosomal recessive trait (the phenotype is impenetrant in at least some homozygote cats) [165,166]. Other related dysraphic anomalies associated with failure of closure of the neural tube include meningocele, exencephaly, anencephaly, and meningomyelocele. In affected animals, the two cerebral hemispheres develop but do not separate from the skin ectoderm that inhibits normal intramembranous ossification from which the calvaria develop. This results in the large skull defect that allows the brain to protrude [106]. Lateral ventricles may be dilated. The cerebrum is often herniated through openings in frontal and parietal bones and may contain a central cavity. Medulla oblongata, midbrain, cerebellum, hypothalamus, and sometimes the thalamus remain in the skull, but are often compressed and distorted. Craniofacial abnormalities in Burmese kittens are characterized by skin-covered masses (encephaloceles) bulging from the top of the head, shortened maxilla, bifid tongue, and absence of eyes, eyelids, and external nares [109,166]. Controlled breeding in Burmese colonies may eliminate the trait; however, a high rate of carriers reportedly exists in the Burmese breed.

Myelodysplasia

Myelodysplasia refers to spinal cord malformation and in humans this developmental disorder may involve several structures including spinal cord, vertebral column, muscles, and skin [167-170]. Myelodysplasia in dogs primarily affects the spinal cord and as such, has been termed "neurospinal dysraphism" [171] or "spinal dysraphism" [172]. This myelodysplastic condition most commonly occurs in Weimaraner dogs [172-175] in which it is transmitted by a codominant lethal gene with reduced penetrance and variable expression [176]. The homozygous condition is lethal. This disorder has also been reported sporadically in other breeds of dogs, including but not limited to Dalmatian, Rottweiler, West Highland White Terrier, German Shepherd, Golden Retriever, and an Alaskan Malamute [177-183] (see also links to other developmental disorders, below). Prenatal studies have shown that dysplastic changes, resulting from abnormal migration of mantle cells, are evident in embryos (24 - 28 days of gestation) obtained by mating severely dysplastic Weimaraner dogs [171,184]. Pathologically, the malformation includes hydromyelia, duplicated, stenotic, or absent central canal, syringomyelia (usually in dorsal columns and often delayed in its formation until dogs are several months old [106,172, 175], chromatolysis and loss of nerve cell bodies in gray matter, disrupted dorsal median septum and ventral median fissure, and gray matter ectopias. In any affected animal, these morphological changes may be present in varying degrees in different cord segments, but occur most commonly in thoracic and upper lumbar spinal cord segments. However, in one prenatal Weimaraner study, major histological differences between normal and dysraphic fetuses were confined to the lumbosacral region of the cord [171,184]. Dysraphic lesions in fetuses included failure of the dura mater to differentiate/separate from the vertebral canal periosteum, absence of the ventral median fissure and fusion of ventral white matter, and gray matter architectural disruption. In some dysraphic fetuses, misplaced gray matter caused marked reduction in size of the central canal. Central canal diverticula were common and the ratio of gray matter diameter to spinal cord diameter was significantly greater in affected fetuses [171,184]. Clinical signs usually appear by 4 to 6 weeks of age; however, abnormal spinal reflexes reportedly are observed in newborn dysplastic puppies. Affected animals have a symmetrical bunny hopping pelvic limb gait, wide based stance, and overextended pelvic limbs with depressed proprioception. Less constant signs include scoliosis, abnormal hair streams in the dorsal neck region, and koilosternia (gutter-like depression of the chest) [172]. Clinical signs neither progress nor retrogress. There is often a poor correlation between the severity of the clinical signs and the histopathological lesions [174]. Indeed, Summers and colleagues [106] have seen affected Weimaraner puppies without microscopic spinal cord lesions. Routine hematology, radiography and CSF analysis are usually within normal limits. Animals can lead a normal life. There is no treatment.

Note that vertebral anomalies may be associated with myelodysplasia as a result of the close embryonic origin of the spinal cord and vertebral column (i.e. notochord, neural tube, and sclerotomal mesoderm), e.g., malformations of the vertebral bodies and ribs have been reported in a Pekingese dog with spinal dysraphism, along with agenesis of the cauda equina [185]. Similarly, myelodysraphism may be seen with other developmental conditions, such as spinal canal stenosis [45,181], spina bifida, meningoencephalocele, syringomyelia, hydrocephalus, and arachnoid cysts.

Occipital Dysplasia

Occipital dysplasia refers to an abnormally large foramen magnum, resulting from a defect in development of the occipital bone (incomplete ossification of the ventromedial part of the supraoccipital bone [186], has been described in small/medium and toy breed dogs that are often brachycephalic, including Yorkshire Terrier, Pomeranian, Maltese Terrier, Chihuahuas, Pekingese, as well as in Miniature and Toy Poodle, Miniature Keeshond, and Beagle [186-191]. The abnormality, which is readily revealed by frontal radiographs of the skull, consists of a key shaped dorsal midline extension of the foramen magnum into the occipital bone. In one morphometric radiographic study of skulls from 80 Pekingese dogs (75 adult and 5 juvenile), the shape of the foramen varied from ovoid to rectangular and the dorsal notch was observed in all but 2 skulls [192]. Variability in the area of the foramen was mainly correlated with total height of the foramen, including the dorsal notch. The foramen magnum index (the ratio between the maximum width and the total height of the foramen) was not significantly correlated with age, but was significantly larger in female dogs. It was concluded that the large variability in the shape and size of the foramen magnum and the absence of any neurological problems in dogs of this study indicated that the dorsal notch of the foramen magnum in brachycephalic dogs is a normal morphological variation, rather than a pathological condition [192]. This has been confirmed by other studies [186,193]. In another morphometric study involving German Shepherd puppies, occipital dysplasia was not found [194].

The absence of neurological deficits in animals of the above-mentioned studies is consistent with earlier reports of occipital dysplasia being a subclinical (or nonclinical) condition [100,186], and that presence of neurological signs such as ataxia, cervico-occipital pain, personality changes, convulsions, pawing at the side of the face, ear or neck, protrusion of the tongue,

and dysphagia in dogs with this malformation reflects some other underlying condition, such as hydrocephalus [195]. A more recent report suggests that intramedullary CNS abnormalities, such as hydrosyringomyelia, may be present concurrently with occipital dysplasia and should be considered as a possible cause of clinical signs such as cervical hyperesthesia and paresis/tetraparesis [196]. Occipital dysplasia and hydrosyringomyelia are sometimes seen in people with Chiari malformations. Interestingly, some of the signs originally described by Bardens [195], especially the cervical pain and frequent scratching, have been reported in dogs with Chiari I malformation, usually with accompanying hydrosyringomyelia (see Chiari malformations). It is has also been suggested that there may be an increased potential for herniation of the cerebellum or brainstem through the enlarged foramen magnum [197], although such prolapse is normally prevented by a fibrous membrane (dura mater and connective tissue) covering the dorsal notch [186,192]. In the report by Bagley and colleagues, this membrane appeared to compress the underlying spinal cord and brainstem in one dog [196].

Optic Nerve Hypoplasia

Optic nerve hypoplasia is an uncommon congenital abnormality of the posterior segment that may be unilateral or bilateral and may be accompanied by microphthalmia or other congenital ocular defects, such as retinal dysplasia, retinal detachment, and sometimes, hydrocephalus. The underlying pathogenesis has not been established. Pathologically, the optic nerve is atrophic with reduced numbers of optic nerve fibers. Vacuolation and paucity of neurons may be observed in ganglion cells of the retina. The optic nerve foramen/canal may be markedly narrowed in some affected animals. Optic nerve hypoplasia is thought to be inherited in Miniature Poodles and has been seen occasionally in several canine breeds, including Beagle, Dachshund, German Shepherd, Miniature Schnauzer, Rough Coated Collie, St. Bernard, Miniature and Toy Poodle, Russian Wolfhound, Tervuren, English Cocker Spaniel, and Great Pyrenees [198-206]. Unilateral optic nerve hypoplasia and hydrocephalus were reported in a 3 year old Pekingese [207]. A possible relationship between small optic nerve heads and optic nerve hypoplasia was described in colony Beagles [208]. Optic nerve dysplasia was reported in American Cocker Spaniels with inherited (probably autosomal recessive) multifocal retinal dysplasia [209]. Congenital blindness associated with multiple ocular anomalies, including optic nerve hypoplasia, has been reported in a family of Bouvier des Flandres (successive litters from the same parents as well as from father x daughter matings were affected) [210]. The diameter of the optic nerve was reportedly reduced in a colony of Dachshunds homozygous for the merle (dappled M) gene [211]. Optic nerve hypoplasia and microphthalmia have also been reported in cats as a sporadic condition [212], in kittens secondary to griseofulvin treatment of the queen during gestation [113], and in association with the inherited craniofacial malformation of Burmese cats [166].

Clinical signs of severe unilateral optic nerve hypoplasia include ipsilateral mydriasis, blindness, menace deficit, and absent direct pupillary reflex, but with a normal consensual reflex in the affected eye following stimulation of the normal eye. Severe bilateral involvement will result in blindness, bilateral mydriasis, absent menace response, and reduced/absent pupillary reflexes.

Diagnosis is suggested by a history of visual impairment from birth. Ophthalmoscopic examination reveals variable reduction in the size of the optic disk with normally appearing retinal vessels. Visual evoked potentials will be absent while ultrasonography may be a useful diagnostic technique [213,214] (also see Electrodiagnostics). Note that electroretinography will be normal since neuroretinal structures (e.g., rods and cones) responsible for generating the electroretinogram are not affected. The pattern evoked response, generated more from ganglion cells than photoreceptors, may also be abnormal (Dr. J.E. Steiss, Tuskegee University, personal communication, 2002). Prognosis is poor. There is no treatment.

Optic nerve aplasia is a very rare congenital anomaly characterized by absence of optic nerve, optic disk and retinal vessels. Interestingly, the size of the optic nerves, density of axons, and total number of axons were not affected in the autosomal recessive mutation carried in a family of achiasmatic (lacking an optic chiasm) black Belgian sheep dogs [106,215]. In these dogs each optic nerve was continued by an ipsilateral optic tract. Affected dogs had a congenital rapid pendular nystagmus with unimpaired vision.

Osteochondromatosis

Osteochondromatosis is a relatively uncommon clinical disease entity in dogs and, especially, in cats (based on few reported cases in cats) in which multiple cartilage-capped, partially ossified protuberances or exostoses arise (usually near metaphyseal growth plates) from the cortex of bones of endochondral origin [45,216-222]. Synonyms for osteochondromatosis include multiple cartilaginous exostoses, hereditary multiple exostoses, multiple osteochondromatosis, diaphyseal aclasis, dyschondroplasia, and hereditary deforming chondrodysplasia [223]. Osteochondromatosis implies involvement of several bones (polyostotic), although single bone involvement (monostotic) may be seen, in which case the term chondroma has been used, indicating that the growths are benign tumors. However, osteochondromas are not true chondromas but developmental disturbances since their growth is controlled by growth hormone and cease enlargement at time of growth plate closure and are, therefore, unlike true tumors that demonstrate uncontrolled growth (Dr. R. Pool, Mississippi State University, personal communication, 2001). The cartilage-cap portion of osteochondromas undergo

endochondral ossification with subsequent replacement of much of their central mass by bone, so that eventually the cortical surfaces of the parent bone and the developing bony stalk are continuous and have confluent marrow spaces [223]. Although canine osteochondromas are a developmental, chondrodysplastic anomaly [223], for purposes of differential diagnosis they are also included as one of several primary skeletal tumors (see spinal cord tumors).

The etiology of canine osteochondromas is uncertain. They may arise directly from growth plate cartilage as a result of a defect in the perichondrial ring, from physical stresses causing proliferative responses at the margin of the physis, or from some form of periosteal disturbance that induces perichondrial growth. Any bone of endochondral origin may be affected; however, in decreasing frequency, vertebrae (especially spinous processes, but also body and arch), ribs, long bones, feet and pelvis are most often involved in dogs [223]. Bones of intramembranous origin (i.e., calvarium and facial bones) are not affected in dogs. Growth of osteochondromas in dogs typically ceases at the time of skeletal maturation, although occasionally, some may progress after skeletal maturity [224]. While a familial or genetic etiology is suspected [223,225], there is no apparent breed or sex predisposition, although several reports involve Alaskan Malamutes, and in one study, seven of the eight affected dogs had mixed Terrier breeding [221].

Osteochondromatosis is frequently a subclinical condition diagnosed as an incidental radiographic finding. However, neurological signs occasionally occur in animals associated with spinal cord compression secondary to vertebral osteochondromas in any region of the spinal column, but most commonly cervical and/or thoracic areas [219,224, 226,227]. Signs observed will depend on the location of the masses (e.g., cervical syndrome, cervicothoracic syndrome, and thoracolumbar syndrome).

There may be variable signs of pain on palpation of the thoracic or cervical spine. Onset of neurological signs typically occurs prior to 1 year of age, although osteochondromatosis may be first diagnosed in older dogs (see also, malignant transformation, below). Osteochondromatosis may involve other tissues such as synovial joints, and tracheal rings. Concurrent skeletal and tracheal osteochondromatosis has been observed in a young Alaskan Malamute [226].

Diagnosis may be made using survey radiography but evidence of cord compression will require myelography and/or imaging [311]. Radiographically, osteochondromas usually appear as large, smoothly contoured cystic bony masses, with irregular or well-delineated borders, sometimes with mottled patterns of radiolucency and radiodensity [223,224]. Fusion of vertebrae at articular facets in the presence of normal intervertebral disks, may be observed [224]. Microscopic examination of a biopsy specimen, which includes the cartilage cap and bony stalk covered by a membrane continuous with the periosteum, will confirm the diagnosis [223]. During active growth, the cartilage resembles a physis with typical endochondral ossification present. The cartilage cap may be incomplete or absent in mature lesions. Osteochondromas may also be characterized using special imaging techniques, such as CT [227].

Surgical excision (including removal of the perichondrial membrane on the surface of the cartilage cap), spinal cord decompression, and perhaps vertebral stabilization, are necessary in animals with clinical evidence of spinal cord attenuation. While post-operative vertebral fracture has been reported [228], there are several reports of successful surgical outcomes [226,227,229]. Surgical removal may be easier when osteochondromas are less well developed, at which time they are softer and poorly vascular, since within a few months, the cancellous bone becomes harder and much more vascular [226]. Recurrences may occur. Prognosis is guarded, especially in young animals with osteochondromas involving multiple vertebral sites where subclinical masses may assume importance as they grow until the skeleton matures. Early surgical removal may eliminate development of clinical complications. Furthermore, there is evidence that osteochondromas may undergo malignant transformation to chondrosarcoma and osteosarcoma in older dogs, frequently between 7 and 10 years of age [224](7), with potential for metastasis [221,230,231]. Thus, early removal will also remove this latent threat of malignancy. Breeding of affected dogs should be discouraged because of the occurrence of osteochondromas in 2 dogs from a litter of 5 sired by a dog that also had the condition [225]. Recently, malignant transformation of solitary spinal osteochondroma to an osteosarcoma was reported in 2 mature dogs [232].

Osteochondromatosis in cats differs significantly from the condition in dogs. The osteochondromas typically first appear in the skeletons of mature cats (e.g., from 2 to 4 years of age), growth of the bony mass is progressive, and the lesions show microscopic transformation from hyperplasia to characteristics of virus-induced parosteal sarcomas [223]. Virus particles have been identified ultrastructurally from feline osteochondromas and are morphologically identical to feline leukemia virus [233]. Other viruses suggested are feline fibrosarcoma virus or another member of the feline retrovirus family [223]. Any bone can be affected in cats, including the flat bones of the skull. Most common sites, in decreasing frequency, are rib cage, scapulae, vertebrae, skull and pelvis [223]. Osteochondromatosis in cats has no breed or sex predisposition or hereditary pattern. Prognosis is grave for any affected cat. Some tumors undergo transformation into osteosarcoma and chondrosarcoma and no cat has lived longer than a year after onset of clinical signs [223].

There are sporadic reports of a focal cartilaginous lesion, termed solitary cartilaginous exostosis, resulting in spinal cord compression [25,234]. Young and mature, large-breed dogs (4 month old Rottweiler, 5 month old Bernese Mountain dog, 3.5 month old St. Bernard, and a 3.5 year old Bernese Mountain dog) were affected and the mass in each dog occurred between the dorsal arch of the atlas and the spinous process of the axis. Radiographically, the masses were partially calcified, seemed

to arise from the dorsal arch of the atlas or from the dorsoatlantoaxial ligaments and extended into the vertebral canal [25]. In some cases, the dorsal arch of the atlas was irregular or thickened with erosion and shortening of the pedicles and spinous process. Histologically, the masses were composed of a fibrocartilaginous matrix, but without bone formation. Surgical removal of the mass in one dog resulted in a complete recovery [234]. At this time, these focal cartilaginous lesions remain difficult to classify. They seem to be radiographically similar to calcinosis circumscripta/tumoral calcinosis (CC-TC) [235], a possible metabolic disorder [236] having an apparent predilection for the atlantoaxial articulation. However, CC-TC is histopathologically different from osteochondroma and cartilaginous exostosis (Dr. R. Pool, Mississippi State University, personal communication, 2001). A lesion of CC-TC consists of a radiodense aggregation formed of multiple loculi of amorphous calcareous deposits located in periarticular soft tissue. The calcium deposits are bordered by macrophages and giant cells and are encapsulated by fibrous tissue septa of variable thickness that may rarely contain foci of metaplastic cartilage and bone tissue [237].

Sacrocaudal Dysgenesis

Congenital malformations of the sacrocaudal (sacrococcygeal) spinal cord and vertebrae have been well described in tailless Manx cats, in which the disease is transmitted as an autosomal dominant trait [238-241]. This disease is also known as 'caudal dysgenesis' and exemplifies a malformation brought about by breeders selecting for tailless cats. The disorder is associated with varying degrees of agenesis/aplasia (absence of formation) or dysgenesis/dysplasia (defective development) of caudal lumbar, sacral and caudal (coccygeal) vertebrae, and spina bifida. The variable expression of Manx taillessness is a salient and consistent feature of the Manx syndrome [242]. Pathologically, subcutaneous cyst formation, meningocele, meningomyelocele, shortening of the spinal cord and absence of cauda equina, and myelodysplasia of the caudal lumbar, sacral, and caudal spinal cord segments including central canal defects, syringomyelia, myeloschisis (cleft within spinal cord) and abnormal gray matter differentiation have been described in affected animals [106,240, 243,244].

Clinical signs in seriously affected cats may be progressive after birth, perhaps associated with progressive syringomyelia [14], or they may remain static in cats with a partial disability. Neurological signs include plantigrade posture, hopping gait, pelvic limb paresis/paraplegia, fecal and urinary incontinence, and perianal sensory loss. Urodynamic studies have shown significant abnormalities of vesiculourethral function: detrusor areflexia, autonomous pressure response to bladder filling, a dysfunctional proximal urethra, and poor quality pelvic floor electromyographic activity [245]. Catecholaminergic histochemical studies of the bladder and urethra have demonstrated complete absence of adrenergic fibers, including the trigone area [245]. Myelography or MRI may outline the meningocele or meningomyelocele, if present.

Prognosis is guarded. There is no treatment. Mildly affected animals may attain longevity if fecal and urinary incontinence are managed. Sacrococcygeal dysgenesis may be seen sporadically in other breeds of cats and in dogs [246], the English Bulldog in particular [247].

Spina Bifida

Spina bifida is a developmental anomaly characterized by the presence of a midline cleft in the vertebral arch of a single or several vertebrae. The cleft may involve most of the vertebral arch or only the dorsal spinous process. This anomaly results from failure of fusion of the halves of the dorsal spinous processes and may be accompanied by protrusion of the spinal cord or its membranes. Spina bifida manifesta, cystica, and operta are synonymous subclassifications indicating presence of meningocele cyst (protrusion of the spinal cord membranes through a defect in the spinal column), myelocele (protrusion of the spinal cord) or meningomyelocele (protrusion of the spinal cord and its membranes through a defect in the spinal column) [247]. Rarely, rachischisis (embryonic failure of fusion of the vertebral arches and neural tube) and myeloschisis (cleft spinal cord resulting from failure of the neural folds to close normally in the formation of the neural tube) are reported together [248]. Spina bifida occulta is characterized by a bony defect without visible protrusion of enclosed vertebral canal structures and is usually associated with smaller defects in the lamina. Most meningoceles and meningomyeloceles occur in the lumbosacral area and mainly involve nerve roots and spinal nerves of the cauda equina rather than spinal cord itself [106]. In such conditions, the meninges and their associated subarachnoid space extend through the vertebral defect to attach to the overlying skin from which CSF may leak. Subdermal or epaxial accumulation of CSF may also be found. As a consequence of the meningeal attachment in the meningomyelocele, abnormal tension may be exerted on the spinal cord. This has been termed tethered cord syndrome [106,249]. The degree of spinal cord dysfunction in tethered cord syndrome appears to be related to both the force and duration of traction [250]. Other anomalies, such as hydrocephalus, multiple thoracic and/or sacral hemivertebrae, may also be present in affected animals [45,247,251,252].

Myelodysplasia, especially in sacrocaudal and lower lumbar segments, consisting of gliosis, hydromyelia (dilation of the central canal), syringomyelia (cavitations within the spinal cord), myeloschisis, or abnormal position of the central gray matter and anomalies of dorsal and ventral horns, may occur with spina bifida. In some instances of myelodysplasia, necrosis of dorsal horns and dorsal white columns has been observed, creating a spongiform appearance to the parenchyma. Astrocytosis may be seen in affected white matter [253].

The embryonic pathogenesis of this anomaly is controversial: it may represent overgrowth of cells of the dorsal neural tube that, in turn, interferes with fusion of the neural tube and vertebral arches; or the vertebral arches may fail to fuse as a result of a neuroschistic bleb [247]. Developmental arrest and hydrodynamic theories have also been suggested [45]. Spina bifida (involving cervical vertebrae C1 to C4) was found among multiple congenital malformations in kittens of cats treated during gestation with griseofulvin [113]. Spina bifida/meningomyelocele has also been observed in kittens following methylmercury and ethylenethiourea toxicity studies in pregnant queens [163,254].
While spina bifida has been reported in a wide variety of dogs and cats [253,255-258], there is a high incidence of this condition in young English Bulldogs [247,253] and in Manx cats with sacrocaudal dysgenesis. Spina bifida may occur anywhere along the spinal column but is most common in the lumbar region. In some instances, the defect can be extensive, involving most of the thoracic, lumbar, and caudal vertebrae [257]. Spina bifida is often a subclinical condition and an incidental radiographic finding [259]. Clinical signs in animals with spina bifida usually indicate an associated myelodysplasia or protrusion of the meninges, spinal cord or cauda equina and are usually noticed when affected animals begin to ambulate. Signs may include pelvic limb ataxia and paresis, fecal and urinary incontinence, perineal analgesia, and flaccid anal sphincter [247,252,260]. The analgesia may extend to the most proximal part of the posterior surface of the thighs, to the level of the scrotum and prepuce anteriorly, in male dogs, and to the tail caudally. The site of the bony defect may be marked by dimpling of the overlying skin, streaming of hair coat, and palpable cavitation in the dorsal spinous process. Meningocele alone can be present without neurological deficits [255,261]. Decreased serum and CSF chloride concentrations were documented in a 5 year old Manx cat with spina bifida associated with chloride loss through a fistulated meningomyelocele [261]. In an 8 month old Manx-type cat with neurological deficits and CSF draining from a skin mass dorsocaudal to the sacrum, exploratory surgery and histopathology confirmed a tethered spinal cord and an intradural lumbosacral lipoma associated with a meningocele [262].
Plain radiographs will demonstrate abnormalities ranging from non-fusion of dorsal laminae to a cleft spinous process; however, myelography or advanced imaging techniques (e.g., ultrasonography, CT, or MRI) may demonstrate protrusion of spinal cord, nerve roots, and/or meninges through the sacral defect to the skin or subcutaneous spaces [251,262,263].

Prognosis is guarded to poor, particularly when myelodysplasia is present. In some animals with a fistulated meningocele/ meningomyelocele, surgical ligation of the meningocutaneous tract can correct problems associated with loss of CSF [261,262] and surgical untethering may reverse some of the neurological dysfunction caused by the tethered cord syndrome and prevent further deterioration of the motor, sensory and urinary functions [251,262,264].

Syringomyelia and Hydromyelia
Congenital syringomyelia (cavitation of the spinal cord parenchyma) and hydromyelia (dilatation of the central canal within the spinal cord) are relatively uncommon malformations of the spinal cord that result from incomplete closure or development of the neural tube [259]. They may occur in isolation or together (hydrosyringomyelia) and may be localized to a short segment of the spinal cord or along great distances. These conditions are most often seen as primary developmental defects in association with congenital conditions such as myelodysplasia [182,185], spina bifida, sacrocaudal dysgenesis, meningomyelocele, and other CNS malformations such as hydrocephalus, Chiari malformations [44,78], occipital dysplasia [196], and Dandy-Walker syndrome [76]. Since it is often impossible to differentiate syringomyelia and hydromyelia using imaging techniques [76], I have used the combined term hydrosyringomyelia frequently in this review in line with human nomenclature, although some authors prefer the term "syringohydromyelia". The pathogenesis of primary hydrosyringomyelia is uncertain. It may be a hydrodynamic compensatory lesion that occurs in some animals with hydrocephalus and increased intraventricular pressure, especially where there is an obstruction of CSF circulation through the lateral apertures of the fourth ventricle [106,107,265]. Experimental syringomyelia has been induced in dogs with cisternal kaolin injection [266]. The dogs had arachnoiditis, hydrocephalus, and syringomyelia that communicated with the fourth ventricle. In a dog with spontaneous disease, partial obstruction to CSF was found associated with cervical cord pachymeningeal fibrosis [79]. Dynamic changes in cervical spinal cord intramedullary pressure with the neck in the flexed position have been postulated to play an important role in syrinx growth in experimental studies using dogs [267]. Hydrosyringomyelia may also occur secondary to edema of neoplasms, spinal cord trauma, vascular compromise, or inflammation [79,106,268]. Cervical hydrosyringomyelia with communication to the 4th ventricle has been observed in a dog with a nerve sheath tumor involving a C6 nerve root [269]. A rare vascular malformation primarily involving thick-walled veins was causally implicated in an 8.5 year old Lhasa apso dog with hydrosyringomyelia (the condition in this dog was considered similar to Foix-Alajouanine syndrome in people, an angiodysgenetic necrotizing myelopathy) [146]. Obstructive hydrocephalus and malformations of the cerebellar vermis and hypoplasia of the roof of the fourth ventricle were also present. Hydrosyringomyelia has also been described as an idiopathic condition in absence of a primary or developmental cause [79,106,270].
Syringomyelia is considered to result from a rupture of the ependymal lining of a dilated central canal with dissection of

adjacent spinal cord parenchyma or is the result of edema collecting in the dorsal funiculi secondary to the hydromyelia [106]. The syrinx is often found in the center of the dorsal funiculi and may expand into the median areas of the dorsal gray columns [106]. In many cases, a communication between the syrinx and the dilated central canal is not apparent. Accordingly, syringomyelia may be communicating or non-communicating. The cavity may be glial-lined (e.g., by astrocytes) but is not lined by ependymal cells. Syringohydromyelia is often prominent in the cervical cord and may communicate with the fourth ventricle [76,196,271], but also may occur in thoracic and lumbar spinal cord segments [78,106]. It is possible that the syrinx may progressively expand, especially through planes of structural weakness, such as the gray matter of the dorsal horns [79,106], leading to progressive clinical signs [14,78,79]. Neuronal necrosis and chromatolysis, edema and variable fibrillary astrocytosis in gray matter, and presence of spheroids and swollen axonal sheaths have been reported in dogs with hydrosyringomyelia [79,106].
Affected animals of various breeds (not including Weimaraners with myelodysplasia) range in age from 12 weeks to 12 years. Clinical signs are variable depending on the location and severity of the hydrosyringomyelia as well as presence or absence of other congenital CNS malformations. Cervical syringomyelia, with or without hydromyelia, has been reported in several immature and mature dogs in conjunction with signs of paraparesis, tetraparesis, scoliosis, torticollis, or cervical pain [78,79,145,182,196,269,271,272]. Signs of a central canal spinal cord lesion extending to cervicothoracic cord segments may include dermatomal paresthesia over the shoulder or neck, leading to persistent intense scratching at the shoulder or flank region, muscle atrophy of cervical epaxial muscles and/or thoracic limb muscles, weakness, especially in thoracic limbs, and decreased spinal reflexes [77,78]. A direct causal relationship between scoliosis and hydrosyringomyelia has been suggested via progressive destruction of gray matter by the cavitation resulting in denervation and atrophy of epaxial muscles unilaterally [78,79,107,145]. Mild dysphagia has been reported in one affected dog [271]. Progressive paresis, paraparesis and pelvic limb proprioceptive deficits were reported in an 11 year old Fox Terrier dog with what was believed to be an acquired syringomyelia localized in upper lumbar cord levels [270]. Onset of signs may be peracute [269] or insidiously progressive over several weeks, months or years [79,271]. Weimaraners with myelodysplasia typically do not show progressive clinical signs. Cervicothoracic syringomyelia and myelodysplasia (including thoracolumbar cord hypoplasia), but without hydrocephalus, was observed in a 5 month old West Highland White Terrier puppy with urinary and fecal incontinence, bunny-hopping pelvic limb gait, and mild scoliosis of the thoracolumbar spine [182]. Syringomyelia has also been identified in animals with arachnoid cysts [8].

CSF analysis is usually normal in animals with hydrosyringomyelia; however, it should be noted that a CSF tap led to respiratory arrest and death in one affected dog [79]. Electromyography may reveal abnormal spontaneous potentials in cervical epaxial or thoracic limb muscles (with cervical hydrosyringomyelia). In some cases, myelography has revealed diffuse spinal cord enlargement [76,145,270,272] and presence of contrast agent within the central canal (canalogram) [76,79,272]. In other cases, myelography has been negative. Imaging techniques such as CT and MRI may help outline the extent and location of the lesions [8,76,196 269-271]. The latter is considered better for defining intraparenchymal spinal cord abnormalities [196,269,273].
The exact nature of the hydrosyringomyelia and its variable progressive or non-progressive course, as well as possible presence of other congenital CNS malformations, make prognosis difficult to assess. At this stage of our knowledge, prognosis is probably guarded, at best. However, successful medical, e.g., long-term prednisolone and furosemide [8,272] or surgical treatment, including syringotomy [270] and drainage [196] have been reported. Hydrocephalus and cervical/thoracic syringomyelia in 3 month old Japanese cat appeared to resolve following establishment of a ventriculoperitoneal shunt [305].

Vertebral Anomalies
A wide variety of congenital developmental abnormalities of the spinal column can occur in animals, but the majority, at least in dogs, are minor and cause no clinical signs [274]. Vertebral anomalies often result from disruption of normal development and regression of the embryonic notochord, segmentation of mesoderm into somites, or vascularization and ossification of the vertebrae [45,259]. The term "complex congenital vertebral anomalies" denotes the presence of several vertebral malformations occurring in an animal.

Hemivertebra - Is a malformation that may be the result of hemimetameric displacement of somites, resulting in right and left hemivertebrae, or it may result from altered vascularization and ossification of vertebrae. While the majority of cases do not produce any obvious clinical signs, hemivertebra is more often associated with neurological deficits than any other congenital vertebral anomaly . Affected animals are usually less than one year of age [275-277]. Neurological signs may result from:

a. Progressive, severe angulation of the spine, e.g., kyphosis (associated with dorsal hemivertebra), lordosis (ventral hemivertebra), or scoliosis (most often associated with lateral hemivertebra);
b. Narrowing of the spinal canal (spinal stenosis);

c. Instability of the involved segments ultimately producing spinal cord compression;
d. Vertebral luxation or fracture at the site of hemivertebra following a sudden jump, fall or trauma.

The spinal curvatures depend on the number of involved vertebrae and degree of individual vertebral deformity [197]. The breeds of dogs that have been reported to be most commonly affected are the "screw-tailed" breeds: English Bulldog, French Bulldog, Pug, Pekingese, and Boston Terrier (the kinked tail is itself due to hemivertebrae in the coccygeal region). Thoracic hemivertebra was present in a 3 month old English Bull dog with tethered cord syndrome, spina bifida and myeloschisis, and hydrocephalus [251]. The condition has also been seen sporadically in other breeds, e.g., West Highland White Terriers, Fox Terriers, and Yorkshire Terriers. Vertebrae most commonly affected are in the region T7 to T9. Hemivertebra has also been reported in dogs (Rottweiler and Pekingese) with spinal cord dysraphism [181,185] (see myelodysplasia) and in a 4 year old Beagle with an associated arachnoid cyst [2]. Hemivertebra of the 2nd and 3rd lumbar vertebrae was present in an 8 week old Rottweiler puppy with associated scoliosis and syringomyelia of the 2nd lumbar spinal cord segment [278].
Clinical signs may include varying degrees of pelvic limb paresis and paralysis, muscle atrophy, pain on palpation of the spinal column, and often fecal and urinary incontinence. Radiographs show an obvious abnormality of the spinal column affecting a single, or in some cases, several vertebrae. There is usually a marked dorsal deviation of the thoracic or lumbar vertebral column with one or more wedge-shaped vertebral bodies. Disk spaces are usually well preserved. The vertebral end plates are smooth and of normal thickness. Missing vertebrae may be detected [277]. Myelography will often outline compression of the subarachnoid space over one or more of the anomalous vertebrae. Thoracic hemivertebra has been reported as an autosomal recessive disorder in some lines of German Shorthair Pointers [279] and has been associated with rapidly developing flaccid paraplegia in puppies about 6 weeks of age. In these dogs, hemivertebra was found at T4, along with kyphosis (from T3 to T5), incomplete development of end-plates at the caudal aspect of T3 and cranial aspect of T4, and misshapen dorsal spinal processes in this region. Necropsy revealed narrowing of the vertebral canal and compression of the spinal cord adjacent to T3, T4, and T5 vertebrae in each of the affected puppies. The parents were clinically normal and had no phenotype characteristic of the carrier state. An association between vertebral anomalies, including hemivertebra, and neonatal mortality has been noted in Bulldogs [276]. Note that dogs with hemivertebra often have other vertebral malformations, such as transitional vertebrae (see below) [258].
Diagnosis of clinically significant hemivertebrae is based on age, breed, clinical history, clinical signs, radiography, myelography, or specialized imaging techniques. In one radiographic study in Pugs, interpretation of findings was difficult, especially in the thoracic spine due to the massive thorax and the sternum superimposing on the spine [258]. Dogs may be treated with surgical decompression, vertebral realignment and stabilization.

Block Vertebrae - May involve vertebral bodies, arches, or the entire vertebra in any spinal region, and result from disturbed somite segmentation [259]. Partial blocking may occur along with incomplete intervertebral disk development. While abnormal spinal angulation can occur, block vertebrae tend to be stable and be clinically insignificant. Block vertebrae might be confused with traumatic intervertebral disk protrusion or with fused vertebrae following diskospondylitis, vertebral neoplasia, or vertebral fracture-luxation [197], although reactive bone associated with these processes is not present in block vertebrae [45]. The presence of both block vertebrae and hemivertebrae were reported in a 12 week old Rottweiler with clinical and radiographic features of severe cervical scoliosis and mild kyphosis [280]. Apart from pain when head and neck were manipulated, no other neurological deficits were observed. Radiographs revealed a misshapen and foreshortened C6 vertebra, while C3, C4 and C5 vertebrae were largely fused to each other from the caudal aspect of the axis. There was marked left-right asymmetry, normal disc spaces and articular processes were not recognized, and dorsal spinous processes were considerably shortened. The vertebral canal did not appear to be severely compromised. Block vertebrae may occasionally be associated with a stenotic vertebral canal [45] and have been observed in a 7 month old dog with an intracranial arachnoid cyst [281]. Vertebral canal stenosis was noted at the C3 vertebral level in a 5 month old Afghan Hound presented with pronounced cervical kyphosis and moderate cervical scoliosis [282]. The vertebral defects were associated with a reduction in length and diameter of the body of C3, aplasia of the facets between C2 and C3 vertebrae, dorsal arching of C3, duplication of the dorsal spine of C3, and rotation of C1 and C2 about their long axis. No neurological deficits were identified.

Butterfly Vertebra - Results from persistence of the notochord or sagittal cleavage of notochord producing a sagittal cleft of the vertebral body that extends through the body dorsoventrally. The cranial and caudal vertebral end-plates are funnel shaped and this produces a butterfly effect when viewing a dorsovental radiograph [259]. Butterfly vertebrae are most often detected in brachycephalic, screw-tailed breeds. This anomaly is rarely clinically significant.

Spina bifida - is a developmental vertebral anomaly characterized by the presence of a midline cleft in the vertebral arch of a single or several vertebrae. The cleft may involve most of the vertebral arch or only the dorsal spinous process. It is often an

incidental finding but sometimes severe neurological signs ensue with involvement of the spinal cord or cauda equina. There is a high incidence of spina bifida in young English Bulldogs and in Manx cats with sacrocaudal dysgenesis.

Transitional Vertebrae - Are abnormal vertebrae occurring at cervicothoracic, thoracolumbar, lumbosacral or sacrocaudal junctions that possess characteristics of other vertebral spinal regions, e.g. a rib present on the transverse process of C7 or a transverse process present on the first sacral vertebra [197]. Only the transitional lumbosacral vertebral anomalies appear to be clinically significant, presumably by affecting the size, shape, and plane of the vertebral body, vertebral canal, and intervertebral disk [14,197,283]. Transitional lumbosacral vertebral anomalies are considered to be inherited in German Shepherd dogs and a possible cause of cauda equina syndrome associated with degenerative lumbosacral stenosis [284,285]. The anomaly is characterized by separation of the first sacral segment, identified on the lateral view by the presence of a radiolucent disc space between what are normally the first and second sacral segments. On the ventrodorsal view, the anomaly is characterized by separation of the spinous processes between what are normally the first and second sacral segments. It is hypothesized that in the presence of the transitional segment, the sacroiliac joint at the level of the anomaly is weakened leading to instability, spinal canal stenosis and intervertebral disk degeneration [284]. Lumbosacral transitional vertebra has also been reported in a 3 month old Chihuahua puppy with thoracic limb malformations but without neurological signs [286]. Transitional vertebrae were also one of several subclinical CT abnormalities found in the lumbosacral spine of older large- breed dogs [287].

Scoliosis - As mentioned above, may develop in animals with hemivertebra. It also occurs in cats with hypervitaminosis A. The important association between developmental anomalies of the spinal cord, including Weimaraners with spinal dysraphism/myelodysplasia, and vertebral anomalies such as scoliosis has been previously noted [172,288]. In particular, there are increasing reports of scoliosis occurring in animals with congenital or acquired cystic lesions involving the spinal cord, especially with cervical hydrosyringomyelia (see syringomyelia and hydromyelia), in which the spinal curvature often presents clinically as torticollis [78,79,145,271]. A direct causal relationship between scoliosis and hydrosyringomyelia has been suggested via progressive destruction of gray matter by the hydrosyringomyelic cavitation resulting in denervation and atrophy of epaxial muscles unilaterally, followed by asymmetrical lateral muscle tension and subsequent vertebral deviation [78,79,145]. Unilateral epaxial cervical muscle spasms may also play a role in the scoliosis [145]. Because of this relationship, it has been suggested that the observation of scoliosis and cervical pain in an animal may be the first clinical sign of hydrosyringomyelia [145]. Mid-lumbar scoliosis and mild kyphosis has also been reported in a dog with an arachnoid cyst at T11 - T13 vertebral levels [18]. The focal point of the scoliosis was at L1 - L2. Denervation atrophy was present in the paraspinal epaxial muscles at this level, presumably secondary to the cyst. The cranial endplate of L1 and the articular facets of L1 - L2 were malformed. Thoracolumbar scoliosis has been reported in association with severe myelodysplastic hypoplasia of the thoracolumbar spinal cord in a 5 month old West Highland White Terrier, with accompanying cervicothoracic cord hydrosyringomyelia [182]. The scoliosis in this case may have been the result of asymmetric denervation atrophy of the paravertebral muscles associated with the localized myelodysplasia in the caudal thoracic cord segments.

Stenosis of the Vertebral Canal - May occur with congenital vertebral anomalies, especially in animals with hemivertebrae and block vertebrae (see above), and may be focal, segmental or generalized throughout the vertebral column [45]. A segmental stenosis in the cranial thoracic spine (T3 - T6) of Doberman Pinschers (mainly mature but occasionally, immature dogs) has been reported, sometimes in association with mild lordosis and kyphosis, but usually without clinical spinal cord compression [45]. Most of these cases were incidental findings in dogs being investigated for cervical spondylomyelopathy (Dr. C.S. Bailey, University of California, Davis, personal communication, 2001), a condition in which stenosis of the cervical vertebral canal seems to be a developmental anomaly. Focal vertebral canal stenosis due to malformation of the vertebral lamina of T12 and cranial portion of T13, with associated spinal cord compression and progressive hindlimb paresis, has been reported in a 3 month old Basset Hound [289]. Myelographic studies may help confirm focal vertebral stenosis in animals with signs commensurate with spinal cord compression [45,289,290]; however note that not all animals with vertebral anomalies have spinal cord compression at the site of spinal deformity [290]. Routine decompressive surgery is indicated in cases with clinical signs of spinal cord compression [45,290]. Lumbosacral stenosis of the vertebral canal is sometimes seen in young animals as a developmental anomaly [291]. Cervical stenosis may be seen in developmental malformations of the axis and/or atlas resulting in instability of the atlantoaxial joint and potential attenuation of the upper cervical spinal cord (see atlantoaxial subluxation). Some animals with odontoid process malformations also have a malformed atlas or occipital dysplasia.

Miscellaneous Developmental Disorders - Caudal vertebral malformations occur in Scottish Fold cats (immature and mature) with short, thick, inflexible tails, including shortened vertebrae with enlarged bony vertebral endplates, reduced vertebral

spaces and new bone formation tending towards ankylosis of adjacent vertebrae [292]. This osteochondrodysplastic condition appears to be inherited as an autosomal recessive trait. Signs of pain and gait abnormalities are typically orthopedic rather than neurological. A monolateral hippocampal cortical hamartia characterized by pyramidal cells arranged in a gyrus-like pattern and intermingled with gemistocytic and fibrillary astrocytes was an incidental finding in a 4 year old Pekingese dog with encephalitis [310].

References

1. Gage ED, Hoerlein BF, Bartels JE. Spinal cord compression resulting from a leptomeningeal cyst in the dog. J Am Vet Med Assoc 1968; 152:1664-1670.
2. Parker AJ, Adams WM, Zachary JF. Spinal arachnoid cysts in the dog. J Am Anim Hosp Assoc 1983; 19:1001-1008.
3. Wolf M, Lang J. What is your diagnosis? Chronic myelopathy in a dog caused by leptomeningeal cyst. Schweiz Arch Tierheilkd 1991; 133:317-318.
4. Dyce J, Herrtage ME, Houlton JEF, et al. Canine spinal "arachnoid cysts". J Small Anim Pract 1991; 32:433-437.
5. Bentley JF, Simpson ST, Hathcock JT. Spinal arachnoid cyst in a dog. J Am Anim Hosp Assoc 1991; 27:549-551.
6. Hashizume CT. Cervical spinal arachnoid cyst in a dog. Can Vet J 2000; 41:225-227.
7. Frykman OF. Spinal arachnoid cyst in four dogs: diagnosis, surgical treatment and follow-up results. J Small Anim Pract 1999; 40:544-549.
8. Galloway AM, Curtis NC, Sommerlad SF, et al. Correlative imaging findings in seven dogs and one cat with spinal arachnoid cysts. Vet Radiol Ultrasound 1999; 40:445-452.
9. Webb AA. Intradural spinal arachnoid cyst in a dog. Can Vet J 1999; 40:588-589.
10. Ness MG. Spinal arachnoid cysts in two shih tzu littermates. Vet Rec 1998; 142:515-516.
11. Cambridge AJ, Bagley RS, Britt LG, et al. Radiographic diagnosis: arachnoid cyst in a dog. Vet Radiol Ultrasound 1997; 38:434-436.
12. Shamir MH, Shahar R, Aizenberg I. Subarachnoid cyst in a cat. J Am Anim Hosp Assoc 1997; 33:123-125.
13. McKee WM, Renwick PW. Marsupialisation of an arachnoid cyst in a dog. J Small Anim Pract 1994; 35:108-111.
14. LeCouter RA, Grandy JL. Diseases of the spinal cord. In: Ettinger SJ, Feldman EC, eds. Textbook of Veterinary Internal Medicine. 5th ed. Philadelphia: WB Saunders Co, 2000; 608-657.
15. Summers B, Cummings J, de Lahunta A. Veterinary Neuropathology. St Louis: Mosby, 1995; 351-401.
16. Harding B, Copp A. Malformations. In: Graham DI, Lantos P, eds. Greenfield's neuropathology. 6th ed. London: Arnold, 1997; 397-533.
17. Lantos PL, Vandenberg SR, Kleihues P. Tumours of the nervous system. In: Graham DI, Lantos P, eds. Greenfield's neuropathology. 6th ed. London: Arnold, 1997; 583-879.
18. Bagley RS, Silver GM, Seguin B, et al. Scoliosis and associated cystic spinal cord lesion in a dog. J Am Vet Med Assoc 1997; 211:573-575.
19. Vignoli M, Rossi F, Sarli G. Spinal subarachnoid cyst in a cat. Vet Radiol Ultrasound 1999; 40:116-119.
20. Milner RJ, Engela J, Kirberger RM. Arachnoid cyst in cerebellar pontine area of a cat - diagnosis by magnetic resonance imaging. Vet Radiol Ultrasound 1996; 37:34-36.
21. Koie H, Kitagawa M, Kuwabara M, et al. Pineal arachnoid cyst demonstrated with magnetic resonance imaging. Canine Practice 2000; 25:14-15.
22. Ladds P, Guffy M, Blauch B, et al. Congenital odontoid process separation in two dogs. J Small Anim Pract 1970; 12:463-471.
23. Parker AJ, Park RD. Atlanto-axial subluxation in small breeds of dogs: diagnosis and pathogenesis. Vet Med Small Anim Clin 1973; 68:1133-1137.
24. Cook JR, Jr., Oliver JE, Jr. Atlantoaxial luxation in the dog. Compend Contin Educ Pract Vet 1981; 3:242-252.
25. Bichsel P, Lang J, Vandevelde M, et al. Solitary cartilaginous exostoses associated with spinal cord compression in three large-breed dogs. J Am Anim Hosp Assoc 1985; 21:619-622.
26. Johnson SG, Hulse DA. Odontoid dysplasia with atlantoaxial instability in a dog. J Am Anim Hosp Assoc 1989; 25:400-408.
27. Watson AG, de Lahunta A. Atlantoaxial subluxation and absence of transverse ligament of the atlas in a dog. J Am Vet Med Assoc 1989; 195:235-237.
28. Gibson KL, Ihle SL, Hogan PM. Severe spinal cord compression caused by a dorsally angulated dens. Prog Vet Neurol 1995; 6:55-57.
29. McCarthy RJ, Lewis DD, Hosgood G. Atlantoaxial subluxation in dogs. Compend Contin Educ Pract Vet 1995; 17:215-226.
30. Tomlinson J. Surgical conditions of the cervical spine. Semin Vet Med Surg (Small Anim) 1996; 11:225-234.
31. Watson AG, Stewart JS. Postnatal ossification centers of the atlas and axis in Miniature Schnauzers. Am J Vet Res 1990; 51:264-268.
32. Hoerlein BF. Canine Neurology: Diagnosis and Treatment. 2nd ed. Philadelphia: WB Saunders Co, 1971; 269.
33. Wheeler SJ. Atlantoaxial subluxation with absence of the dens in a Rottweiler. J Small Anim Pract 1992; 33:90-93.

34. Richter K, Lorenzana R, Ettinger SJ. Traumatic displacement of the dens in a cat: case report. J Am Anim Hosp Assoc 1983; 19:751-753.
35. Shelton SB, Bellah J, Chrisman C, et al. Hypoplasia of the odontoid process and secondary atlantoaxial luxation in a Siamese cat. Prog Vet Neurol 1991; 2:209-211.
36. Thomson MJ, Read RA. Surgical stabilisation of the atlantoaxial joint in a cat. Vet Comp Orthop Traumatol 1996; 9:36-39.
37. Watson AG. Congenital occipitoatlantoaxial malformation (OAM) in a dog. Anat Histol Embryol 1979; 8:187.
38. Watson AG, Hall MA, de Lahunta A. Congenital occipitoatlantoaxial malformation in a cat. Compend Contin Educ Pract Vet 1985; 7.
39. Jaggy A, Hutto VL, Roberts RE, et al. Occipitoatlantoaxial malformation with atlantoaxial subluxation in a cat. J Small Anim Pract 1991; 32:366-372.
40. Read R. Instability of the occipito-atlanto-axial joint complex. Aus Vet Pract 1987; 17:179-182.
41. Watson AG, Lahunta Ad, Evans HE. Prenatal development of the composite occipito-atlanto-axial synovial joint cavity in the dog. Anat Rec 1986; 216:423-433.
42. Read R, Brett S, Cahill J. Surgical treatment of occipito-atlanto-axial malformation in the dog. Aus Vet Pract 1987; 17:184-189.
43. Bynevelt M, Rusbridge C, Britton J. Dorsal dens angulation and a Chiari type malformation in a Cavalier King Charles Spaniel. Vet Radiol Ultrasound 2000; 41:521-524.
44. Churcher RK, Child G. Chiari 1/syringomyelia complex in a King Charles Spaniel. Aust Vet J 2000; 78:92-95.
45. Bailey CS, Morgan JP. Congenital spinal malformations. Vet Clin North Am Small Anim Pract 1992; 22:985-1015.
46. Oliver JE, Jr. , Lewis PE. Lesions of the atlas and axis in dogs. J Am Anim Hosp Assoc 1973; 9:304-313.
47. van Ham LM, Bree HJv, Tshamala M, et al. Use of computed tomography and computed tomographic myelography for assessment of spinal tumoral calcinosis in a dog. Vet Radiol Ultrasound 1995; 36:115-118.
48. Beaver DP, Ellison GW, Lewis DD, et al. Risk factors affecting the outcome of surgery for atlantoaxial subluxation in dogs: 46 cases (1978-1998). J Am Vet Med Assoc 2000; 216:1104-1109.
49. Thomas WB, Sorjonen DC, Simpson ST. Surgical management of atlantoaxial subluxation in 23 dogs. Vet Surg 1991; 20:409-412.
50. Huibregtse BA, Smith CW, Fagin BD. Atlantoaxial luxation in a Doberman Pinscher. Canine Practice 1992; 17:7-10.
51. Stead AC, Anderson AA, Coughlan A. Bone plating to stabilise atlantoaxial subluxation in four dogs. J Small Anim Pract 1993; 34:462-465.
52. Gilmore DR. Nonsurgical management of four cases of atlantoaxial subluxation in the dog. J Am Anim Hosp Assoc 1984; 20:93-96.
53. Gage ED, Hoerlein BF. Surgical repair of cervical subluxation and spondylolisthesis in the dog. J Am Anim Hosp Assoc 1973; 9:385-390.
54. Denny HR, Gibbs C, Waterman A. Atlanto-axial subluxation in the dog: a review of thirty cases and an evaluation of treatment by lag screw fixation. J Small Anim Pract 1988; 29:37-47.
55. Sorjonen DC, Shires PK. Atlantoaxial instability: a ventral surgical technique for decompression, fixation, and fusion. Vet Surg 1981; 10:22-29.
56. Schulz KS, Waldron DR, Fahie M. Application of ventral pins and polymethylmethacrylate for the management of atlantoaxial instability: results in nine dogs. Vet Surg 1997; 26:317-325.
57. Rochat MC, Shores A. Fixation of an atlantoaxial subluxation by use of cannulated screws. Vet Comp Orthop Traumatol 1999; 12:43-46.
58. Jeffery ND. Dorsal cross pinning of the atlantoaxial joint: new surgical technique for atlantoaxial subluxation. J Small Anim Pract 1996; 37:26-29.
59. LeCouteur RA, McKeown D, Johnson J, et al. Stabilization of atlantoaxial subluxation in the dog, using the nuchal ligament. J Am Vet Med Assoc 1980; 177:1011-1017.
60. van Ee RT, Pechman R, van Ee RM. Failure of the atlantoaxial tension band in two dogs. J Am Anim Hosp Assoc 1989; 25:707-712.
61. Kishigami M. Application of an atlantoaxial retractor for atlantoaxial subluxation in the cat and dog. J Am Anim Hosp Assoc 1984; 20:413-419.
62. Summers B, Cummings J, de Lahunta A. Veterinary Neuropathology. St Louis: Mosby, 1995; 36-207.
63. McGrath J. Neurologic examination of the dog. Philadelphia: Lea & Febiger, 1960; 281.
64. Pass DA, Howell JM, Thompson RR. Cerebellar malformation in two dogs and a sheep. Vet Pathol 1981; 18:405-407.
65. de Lahunta A. Veterinary Neuroanatomy and Clinical Neurology. 2nd ed. Philadelphia: WB Saunders Co, 1983; 255-278.
66. Kay WJ, Budzelovich GN. Cerebellar hypoplasia and agenesis in the dog. J Neuropathol Exp Neurol 1970; 20:156.
67. Kronevi T, Ostensson K, Lesser J. A case of partial cerebellar hypoplasia in a cat. Nord Vet Med 1978; 30:221-222.
68. Innes JRM, Saunders LZ. Comparative Neuropathology. New York: Academic Press, 1962; 304-308.
69. Palmer AC, Payne JE, Wallace ME. Hereditary quadriplegia and amblyopia in the Irish Setter. J Small Anim Pract 1973; 14:343-352.
70. Kilham L, Margolis G, Colby ED. Congenital infections of cats and ferrets by feline panleukopenia virus manifested by

cerebellar hypoplasia. Lab Invest 1967; 17:465-480.
71. Johnson RH, Margolis G, Kilham L. Identity of feline ataxia virus on the feline panleukopenia virus. Nature 1967; 214:175.
72. Kilham L, Margolis G, Colby ED. Cerebellar ataxia and its congenital transmission in cats by feline panleukopenia virus. J Am Vet Med Assoc 1971; 158:Suppl 2:888+.
73. Johnson RT. Viral infections and malformations of the nervous system. Birth Defects Orig Artic Ser 1971; 7:56-63.
74. Sharp NJ, Davis BJ, Guy JS, et al. Hydranencephaly and cerebellar hypoplasia in two kittens attributed to intrauterine parvovirus infection. J Comp Pathol 1999; 121:39-53.
75. Golden JA, Bonnemann CG. Developmental structural disorders. In: Goetz CG, Pappert EJ, eds. Textbook of Clinical Neurology. Philadelphia: WB Saunders Co, 1999; 510-537.
76. Kirberger RM, Jacobson LS, Davies JV, et al. Hydromyelia in the dog. Vet Radiol Ultrasound 1997; 38:30-38.
77. Rusbridge C. Persistent scratching in Cavalier King Charles spaniels. Vet Rec 1997; 141:179.
78. Rusbridge C, MacSweeny JE, Davies JV, et al. Syringohydromyelia in Cavalier King Charles spaniels. J Am Anim Hosp Assoc 2000; 36:34-41.
79. Child G, Higgins RJ, Cuddon PA. Acquired scoliosis associated with hydromyelia and syringomyelia in two dogs. J Am Vet Med Assoc 1986; 189:909-912.
80. Adams RD, Victor M. Principles of neurology. 5th ed. New York: McGraw-Hill Inc, 1993; 1020-1021.
81. Schmid V, Lang J, Wolf M. Dandy-Walker-like syndrome in four dogs: cisternography as a diagnostic aid. J Am Anim Hosp Assoc 1992; 28:355-360.
82. Kornegay JN. Cerebellar vermian hypoplasia in dogs. Vet Pathol 1986; 23:374-379.
83. Regnier AM, de Lahitte MJD, Delisle MB, et al. Dandy-Walker syndrome in a kitten. J Am Anim Hosp Assoc 1993; 29:514-518.
84. Antin IP. Dermoid sinus in a Rhodesian Ridgeback dog. J Am Vet Med Assoc 1970; 157:961-962.
85. Hofmeyr CFB. Dermoid sinus in the Ridgeback dog. J Small Anim Pract 1963; 4 (Suppl):5-8.
86. Gammie JS. Dermoid sinus removal in a Rhodesian Ridgeback dog. Can Vet J 1986; 27:250-251.
87. Lambrechts N. Dermoid sinus in a crossbred Rhodesian Ridgeback dog involving the second cervical vertebra. J S Afr Vet Assoc 1996; 67:155-157.
88. Marks SL, Harari J, Dernell WS. Dermoid sinus in a Rhodesian ridgeback. J Small Anim Pract 1993; 34:356-358.
89. Kasa F, Kasa G, Kussinger S. Dermoid sinus in a Rhodesian ridgeback. Case report. Tierarztl Prax 1992; 20:628-631.
90. Lord LH, Cawley AJ, Gilray J. Mid-dorsal dermoid sinuses in Rhodesian ridgeback dogs-a case report. J Am Vet Med Assoc 1957; 131:515-518.
91. Pratt JN, Knottenbelt CM, Welsh EM. Dermoid sinus at the lumbosacral junction in an English springer spaniel. J Small Anim Pract 2000; 41:24-26.
92. Booth MJ. Atypical dermoid sinus in a chow chow dog. J S Afr Vet Assoc 1998; 69:102-104.
93. Fatone G, Brunetti A, Lamagna F, et al. Dermoid sinus and spinal malformations in a Yorkshire terrier: diagnosis and follow-up. J Small Anim Pract 1995; 36:178-180.
94. Cornegliani L, Ghibaudo G. A dermoid sinus in a Siberian Husky. Vet Dermatol 1999; 10:47-49.
95. Penrith ML, van Schouwenburg S. Dermoid sinus in a Boerboel bitch. J S Afr Vet Assoc 1994; 65:38-39.
96. Selcer EA, Helman RG, Selcer RR. Dermoid sinus in a Shih Tzu and a boxer. J Am Anim Hosp Assoc 1984; 20:634-636.
97. Rochat MC, Campbell GA, Panciera RJ. Dermoid cysts in cats: two cases and a review of the literature. J Vet Diagn Invest 1996; 8:505-507.
98. Henderson JP, Pearson GR, Smerdon TN. Dermoid cyst of the spinal cord associated with ataxia in a cat. J Small Anim Pract 1993; 34:402-404.
99. Icenogle DA, Kaplan AM. A review of congenital neurologic malformations. Clin Pediatr (Phila) 1981; 20:565-576.
100. de Lahunta A. Veterinary Neuroanatomy and Clinical Neurology. 2nd ed. Philadelphia: WB Saunders Co, 1983; 6-29.
101. Greene CE, Gorgasz EJ, Martin CL. Hydranencephaly associated with feline panleukopenia. J Am Vet Med Assoc 1982; 180:767-768.
102. Carlson ME. Hydranencephaly and cerebrocortical hypoplasia in a four-month-old kitten. Feline Pract 1994; 22:10-12.
103. McGrath JR. Neurologic examination of the dog. 2nd ed. Philadelphia: Lea & Febiger, 1960; 91-107.
104. Hoerlein BF, Gage ED. Hydrocephalus. In: Hoerlein BF, ed. Canine neurology. 3rd ed. Philadelphia: WB Saunders, 1978; 733-760.
105. Shell LG. Congenital hydrocephalus. Feline Pract 1996; 24:10-11.
106. Summers B, Cummings J, de Lahunta A. Veterinary Neuropathology. St Louis: Mosby, 1995; 68-94.
107. de Lahunta A. Veterinary Neuroanatomy and Clinical Neurology. 2nd ed. Philadelphia: WB Saunders Co, 1983; 30-52.
108. Selby LA, Hayes HM, Jr., Becker SV. Epizootiologic features of canine hydrocephalus. Am J Vet Res 1979; 40:411-413.
109. Zook BC, Sostaric BR, Draper DJ, et al. Encephalocele and other congenital craniofacial anomalies in Burmese cats. Vet Med Small Anim Clin 1983; 78:695-701.
110. Van Winkle TJ, Fyfe JC, Dayrell-Hart B, et al. Polymicrogyria and asymmetrical hydrocephalus in four standard poodles. In: Proceedings of the 41st Annu Meet Am Coll Vet Pathol 1990; 144.

111. Johnston SD, Buoen LC, Weber AF, et al. Triploidy (117,XXX) in a stillborn canine pup conceived with frozen semen. J Am Vet Med Assoc 1989; 194:1446-1448.
112. Martin CL, Leipold HW. Aphakia and multiple ocular defects in Saint Bernard puppies. Vet Med Small Anim Clin 1974; 69:448-453.
113. Scott FW, LaHunta Ad, Schultz RD, et al. Teratogenesis in cats associated with griseofulvin therapy. Teratology 1975; 11:79-86.
114. Csiza CK, Scott FW, Gillespie JH, et al. Feline viruses. XIV. Transplacental infections in spontaneous panleukopenia of cats. Cornell Vet 1971; 61:423-439.
115. Krum S, Johnson K, Wilson J. Hydrocephalus associated with the noneffusive form of feline infectious peritonitis. J Am Vet Med Assoc 1975; 167:746-748.
116. Foley JE, Lapointe JM, Koblik P, et al. Diagnostic features of clinical neurologic feline infectious peritonitis. J Vet Intern Med 1998; 12:415-423.
117. Kline KL, Joseph RJ, Averill DR. Feline infectious peritonitis with neurologic involvement: clinical and pathological findings in 24 cats. J Am Anim Hosp Assoc 1994; 30:111-118.
118. Baumgartner WK, Krakowka S, Koestner A, et al. Ultrastructural evaluation of the acute encephalitis and hydrocephalus in dogs caused by canine parainfluenza virus. Vet Pathol 1982; 19:305-314.
119. Baumgartner WK, Krakowka S, Koestner A, et al. Acute encephalitis and hydrocephalus in dogs caused by canine parainfluenza virus. Vet Pathol 1982; 19:79-92.
120. Higgins RJ, Vandevelde M, Braund KB. Internal hydrocephalus and associated periventricular encephalitis in young dogs. Vet Pathol 1977; 14:236-246.
121. Wouda W, Vandevelde M, Kihm U. Internal hydrocephalus of suspected infectious origin in young dogs. Zentralblatt fur Veterinarmedizin 1981; 28:481-493.
122. Cantile C, Arispici M, Modenato M, et al. Hydrocephalus with periventricular encephalitis in the dog. J Vet Med (Series A) 1997; 44:595-601.
123. Palmer AC, Herrtage ME, Kaplan W. Cryptococcal infection of the central nervous system of a dog in the United Kingdom. J Small Anim Pract 1981; 22:579-586.
124. Davies TS. Comparative pathology of canine and feline methylmercury poisoning. Dissertation Abstracts International 1979; 39B (11):5162.
125. Pumarola M, van Niel MH. Obstructive hydrocephalus produced by parasitic granulomas in a dog. Zentralbl Veterinarmed A 1992; 39:392-395.
126. Slocombe RF, Arundel JH, Labuc R, et al. Cerebral coenuriasis in a domestic cat. Aust Vet J 1989; 66:92-93.
127. Cox NR, Shores A, McCoy CP, et al. Obstructive hydrocephalus due to neoplasia in a Rottweiler puppy. J Am Anim Hosp Assoc 1990; 26:335-338.
128. Chenier S, Quesnel A, Girard C. Intracranial teratoma and dermoid cyst in a kitten. J Vet Diagn Invest 1998; 10:381-384.
129. Targett MP, McInnes E, Dennis R. Magnetic resonance imaging of a medullary dermoid cyst with secondary hydrocephalus in a dog. Vet Radiol Ultrasound 1999; 40:23-26.
130. Steinberg H, Galbreath EJ. Cerebellar medulloblastoma with multiple differentiation in a dog. Vet Pathol 1998; 35:543-546.
131. Graham JC, O'Keefe DB, Wallig MA, et al. Lymphosarcoma causing acquired obstructive hydrocephalus in a dog. Can Vet J 1992; 33:669-670.
132. Tamke PG, Peterson MG, Dietze AE, et al. Acquired hydrocephalus and hydromelia in a cat with feline infectious peritonitis: a case report and brief review. Can Vet J 1988; 29:997-1000.
133. Knowles K, Alroy J, Castagnaro M, et al. Adult-onset lysosomal storage disease in a Schipperke dog: clinical, morphological and biochemical studies. Acta Neuropathol 1993; 86:306-312.
134. Carmichael S, Griffiths IR, Harvey MJ. Familial cerebellar ataxia with hydrocephalus in bull mastiffs. Vet Rec 1983; 112:354-358.
135. Johnson RP, Neer M, Partington BP, et al. Familial cerebellar ataxia with hydrocephalus in bull mastiffs. Vet Radiol Ultrasound 2001; 42:246-249.
136. Sacre BJ, Cummings JF, Lahunta Ad. Neuroaxonal dystrophy in a Jack Russel Terrier pup resembling human infantile neuroaxonal dystrophy. Cornell Vet 1993; 83:133-142.
137. Reichler IM, Hoerauf A, Guscetti F, et al. Primary ciliary dyskinesia with situs inversus totalis, hydrocephalus internus and cardiac malformations in a dog. J Small Anim Pract 2001; 42:345-348.
138. Jamne O, Nafstad P, Skancke E, et al. Primary ciliary dyskinesia. A case of respiratory problems in Bichon Frise dogs. Norsk Vet 1998; 110:199-202.
139. Dhein CR, Prieur DJ, Riggs MW, et al. Suspected ciliary dysfunction in Chinese Shar Pei pups with pneumonia. Am J Vet Res 1990; 51:439-446.
140. Jones BR, Alley MR, Batchelor B. Hydrocephalus and hypertrichosis in Golden Retriever dogs. N Z Vet J 1996; 44:38-39.
141. Thomas JB, Robertson D. Hereditary cerebellar abiotrophy in Australian Kelpie dogs. Aust Vet J 1989; 66:301-302.
142. Dodman NH, Bronson R, Gliatto J. Tail chasing in a Bull Terrier. J Am Vet Med Assoc 1993; 202:758-760.

143. DiBartola SP, Johnson SE, Johnson GC, et al. Hypodipsic hypernatremia in a dog with defective osmoregulation of antidiuretic hormone. J Am Vet Med Assoc 1994; 204:922-925.
144. Dow SW, Fettman MJ, LeCouteur RA, et al. Hypodipsic hypernatremia and associated myopathy in a hydrocephalic cat with transient hypopituitarism. J Am Vet Med Assoc 1987; 191:217-221.
145. Smith BA. Hydrosyringomyelia, hydrocephalus and scoliosis in a Rhodesian Ridgeback dog. Aus Vet Pract 1995; 25:79-86.
146. Schmahl W, Kaiser E. Hydrocephalus, syringomyelia, and spinal cord angiodysgenesis in a Lhasa-apso dog. Vet Pathol 1984; 21:252-254.
147. Silson M, Robinson R. Hereditary hydrocephalus in the cat. Vet Rec 1969; 84:477.
148. de Lahunta A, Cummings J. The clinical and electroencephalographic features of hydrocephalus in three dogs. J Am Vet Med Assoc 1965; 146:954-964.
149. Rivers WJ, Walter PA. Hydrocephalus in the dog: utility of ultrasonography as an alternate diagnostic imaging technique. J Am Anim Hosp Assoc 1992; 28:333-343.
150. Karkkainen M. Low- and high-field strength magnetic resonance imaging to evaluate the brain in one normal dog and two dogs with central nervous system disease. Vet Radiol Ultrasound 1995; 36:528-532.
151. Vite CH, Insko EK, Schotland HM, et al. Quantification of cerebral ventricular volume in English Bulldogs. Vet Radiol Ultrasound 1997; 38:437-443.
152. Vullo T, Korenman E, Manzo RP, et al. Diagnosis of cerebral ventriculomegaly in normal adult beagles using quantitative MRI. Vet Radiol Ultrasound 1997; 38:277-281.
153. Gage ED, Hoerlein BF. Surgical treatment of canine hydrocephalus by ventriculoatrial shunting. J Am Vet Med Assoc 1968; 153:1418-1431.
154. Gentle RL, Robins GM, Reynolds WT, et al. Case report-the surgical treatment of hydrocephalus in a Chihuahua. Aus Vet Pract 1983; 13:153-156.
155. Kay ND, Holliday TA, Hornof WJ, et al. Diagnosis and management of an atypical case of canine hydrocephalus, using computed tomography, ventriculoperitoneal shunting, and nuclear scintigraphy. J Am Vet Med Assoc 1986; 188:423-426.
156. Moissonnier P, Viateau V, Mollard M. Congenital hydrocephalus in a dog treated by means of a ventriculoatrial shunt surgery. Prat Med Chir Anim 1995; 30:675-682.
157. Ori J, Yamaguchi T, Komiya M, et al. Two cases of feline hydrocephalus treated by ventriculoperitoneal shunt. [Japanese]. J Jap Vet Med Assoc 1997; 50:599-602.
158. Johnson I, Gilday DL, Hendrick EB. Experimental effects of steroids and steroid withdrawal on cerebrospinal fluid absorption. J Neurosurg 1975; 42:690-695.
159. Greene CE, Vandevelde M, Braund K. Lissencephaly in two Lhasa Apso dogs. J Am Vet Med Assoc 1976; 169:405-410.
160. Zaki FA. Lissencephaly in Lhasa Apso dogs. J Am Vet Med Assoc 1976; 169:1165-1168.
161. Parker AJ, Cusick PK. Meningoencephalocele in a dog (a case history). Vet Med Small Anim Clin 1974; 69:206-207.
162. Khera KS. A teratogenicity study on hydroxyurea and diphenylhydantoin in cats. Teratology 1979; 20:447-452.
163. Khera KS. Teratogenic effects of methylmercury in the cat: note on the use of this species as a model for teratogenicity studies. Teratology 1973; 8:293-303.
164. Khera KS, Iverson F, Hierlihy L, et al. Toxicity of methylmercury in neonatal cats. Teratology 1974; 10:69-76.
165. Sponenberg DP, Graf-Webster E. Hereditary meningoencephalocele in Burmese cats. J Hered 1986; 77:60.
166. Noden DM, Evans HE. Inherited homeotic midfacial malformations in Burmese cats. J Craniofac Genet Dev Biol Suppl 1986; 2:249-266.
167. Till K. Hidden spinal malformations. West J Med 1978; 129:495-496.
168. Till K. Spinal dysraphism: a study of congenital malformations of the back. Dev Med Child Neurol 1968; 10:470-477.
169. Cornette L, Verpoorten C, Lagae L, et al. Closed spinal dysraphism: a review on diagnosis and treatment in infancy. Europ J Paediatr Neurol 1998; 2:179-185.
170. Tortori-Donati P, Rossi A, Cama A. Spinal dysraphism: a review of neuroradiological features with embryological correlations and proposal for a new classification. Neuroradiology 2000; 42:471-491.
171. Engel HN, Draper DD. Comparative prenatal development of the spinal cord in normal and dysraphic dogs: embryonic stage. Am J Vet Res 1982; 43:1729-1734.
172. McGrath JT. Spinal dysraphism in the dog. With comments on syringomyelia. Pathol Vet 1965; 2:1-36.
173. Confer AW, Ward BC. Spinal dysraphism: a congenital myelodysplasia in the Weimaraner. J Am Vet Med Assoc 1972; 160:1423-1426.
174. Broek AHMvd, Else RW, Abercromby R, et al. Spinal dysraphism in the Weimaraner. J Small Anim Pract 1991; 32:258-260.
175. McGrath JT. Animal models of human disease. Spinal dysraphism. Comp Pathol Bull 1976; 8:2,4.
176. Shelton MC. A possible mode of inheritance for spinal dysraphism in the dog with a more complete description of the clinical syndrome. MS Thesis. Iowa State University; 1977.
177. Geib LW, Bistner SI. Spinal cord dysraphism in a dog. J Am Vet Med Assoc 1967; 150:618-620.
178. Klaus B. [Picture report. Spinal dysraphism in a German shepherd]. Berl Munch Tierarztl Wochenschr 1973; 86:95.
179. Neufeld JL, Little PB. Spinal dysraphism in a Dalmatian dog. Can Vet J 1974; 15:335-336.

180. Draper DD, Kluge JP, Miller WJ. Neurologic, pathologic and genetic aspects of spinal dysraphism in dogs. Anat Histol Embryol 1975; 4:369.
181. Shell LG, Carrig CB, Sponenberg DP, et al. Spinal dysraphism, hemivertebra, and stenosis of the spinal canal in a Rottweiler puppy. J Am Anim Hosp Assoc 1988; 24:341-344.
182. Malik R, France MP, Allan GS, et al. Abnormal control of urination and defaecation in a dog with myelodysplasia. Aus Vet Pract 1991; 21:178-180.
183. Rishniw M, Wilkerson MJ, Lahunta Ad. Myelodysplasia in an Alaskan Malamute dog with adult onset of clinical signs. Prog Vet Neurol 1994; 5:35-38.
184. Engel HN, Draper DD. Comparative prenatal development of the spinal cord in normal and dysraphic dogs: fetal stage. Am J Vet Res 1982; 43:1735-1743.
185. Ruberte J, Anor S, Carretero A, et al. Malformations of the vertebral bodies and the ribs associated to spinal dysraphism without spina bifida in a Pekingese dog. J Vet Med (Series A) 1995; 42:307-313.
186. Watson AG, de Lahunta A, Evans HE. Dorsal notch of foramen magnum due to incomplete ossification of supraoccipital bone in dogs. J Small Anim Pract 1989; 30:666-673.
187. van Herpen H, Voorhout G. [Occipital dysplasia in a Pomeranian dog]. Tijdschr Diergeneeskd 1993; 118:327-328.
188. Parker AJ, Park RD. Occipital dysplasia in the dog. J Am Anim Hosp Assoc 1974; 10:520-525.
189. Parker AJ, Park RD. Unusual deformity of the occipital bone in a dog (a case report). Vet Med Small Anim Clin 1974; 69:438-441.
190. Kelly JH. Occipital dysplasia and hydrocephalus in a Toy Poodle. Vet Med Small Anim Clin 1975; 70:940-941.
191. Wright JA. A study of the radiographic anatomy of the foramen magnum in dgs. J Small Anim Pract 1979; 20:501-508.
192. Simoens P, Poels P, Lauwers H. Morphometric analysis of the foramen magnum in Pekingese dogs. Am J Vet Res 1994; 55:34-39.
193. Simoens P, Poels P, Vyt P, et al. Variability of the foramen magnum in dog breeds in relation to occipital dysplasia. [Dutch]. Vlaama Diergen Tijds 1994; 63:44-53.
194. Onar V, Mutus R, Kahvecioglu KO. Morphometric analysis of the foramen magnum in German Shepherd dogs (Alsatians). Ann Anat 1997; 179:563-568.
195. Bardens JW. Congenital malformation of the foramen magnum in dogs. Southwest Vet 1965; Summer:295-298.
196. Bagley RS, Harrington ML, Tucker RL, et al. Occipital dysplasia and associated cranial spinal cord abnormalities in two dogs. Vet Radiol Ultrasound 1996; 37:359-362.
197. Colter SB. Congenital anomalies of the spine. In: Bojrab MJ, ed. Disease Mechanisms in Small Animal Surgery. 2nd ed. Philadelphia: Lea & Febiger, 1993; 950-959.
198. Saunders L. Congenital optic nerve hypoplasia in collie dogs. Cornell Vet 1952; 42:67-80.
199. Gelatt KN, Leipold HW. Case report. Bilateral optic nerve hypoplasia in two dogs. Can Vet J 1971; 12:91-96.
200. Weisse I, Stotzer H. Hypoplasia of the optic nerve and coloboma of the optic disc in a young Beagle (case report). Berl Munch Tierarztl Wochenschr 1973; 86:1-2.
201. Ernest JT. Bilateral optic nerve hypoplasia in a pup. J Am Vet Med Assoc 1976; 168:125-128.
202. Vestre WA, Brightman AH. Congenital blindness due to optic nerve hypoplasia. Canine Practice 1980; 7:45-46.
203. Kern TJ, Riis RC. Optic nerve hypoplasia in three Miniature Poodles. J Am Vet Med Assoc 1981; 178:49-54.
204. Turnquist SE, Pace LW, Sardinas J. Unilateral optic nerve hypoplasia and hydrocephalus in a Pekingese. Cornell Vet 1991; 81:305-311.
205. Spiess B, Litschi B, Leber A, et al. Hypoplasia of the optic nerves in a Poodle puppy. Kleintierpraxis 1991; 36:173-178.
206. Termote S. What is your diagnosis? Congenital optic nerve hypoplasia in a dog. J Small Anim Pract 1998; 39:1, 39.
207. Turnquist SE, Pace LW, Sardinas J. Unilateral optic nerve hypoplasia and hydrocephalus in a Pekingese. Cornell Vet 1991; 81:305-311.
208. Belhorn RW. Survey of ocular findings in eight- to ten-month-old Beagles. J Am Vet Med Assoc 1974; 164:1114-1116.
209. MacMillan AD, Lipton DE. Heritability of multifocal retinal dysplasia in American Cocker Spaniels. J Am Vet Med Assoc 1978; 172:568-572.
210. Rensburg IBJv, Petrick SW, Lugt JJvd, et al. Multiple inherited eye anomalies including persistent hyperplastic tunica vasculosa lentis in Bouvier des Flandres. Progress in Veterinary & Comparative Ophthalmology 1992; 2:133-139.
211. Meyer W. Studies on morphology and reproduction in relation to merle colour. Thesis. Tierarztliche Hochschule Hannover; 1977.
212. Barnett KC, Grimes TD. Bilateral aplasia of the optic nerve in a cat. Br J Ophthalmol 1974; 58:663-667.
213. Boroffka SA, Verbruggen AM, Boeve MH, et al. Ultrasonographic diagnosis of persistent hyperplastic tunica vasculosa lentis/persistent hyperplastic primary vitreous in two dogs. Vet Radiol Ultrasound 1998; 39:440-444.
214. Spiess BM, Leber-Zurcher AC. Oscillating potentials on the B-wave of the ERG in the dog. Schweiz Arch Tierheilkd 1992; 134:431-443.
215. Hogan D, Williams RW. Analysis of the retinas and optic nerves of achiasmatic Belgian sheepdogs. J Comp Neurol 1995; 352:367-380.
216. Gee BR, Doige CE. Multiple cartilaginous exostoses in a litter of dogs. J Am Vet Med Assoc 1970; 156:53-59.
217. Dingwall JS, Pass DA, Pennock PW, et al. Case report. Multiple cartilaginous exostoses in a dog. Can Vet J 1970; 11:114-119.

218. Gambardella PC, Osborne CA, Stevens JB. Multiple cartilaginous exostoses in the dog. J Am Vet Med Assoc 1975; 166:761-768.
219. Prata RG, Stoll SG, Zaki FA. Spinal cord compression caused by osteocartilaginous exostoses of the spine in two dogs. J Am Vet Med Assoc 1975; 166:371-375.
220. Alden CL, Dickerson TV. Osteochondromatosis of the cervical vertebrae in a dog. J Am Vet Med Assoc 1976; 168:142-144.
221. Doige CE. Multiple cartilaginous exostoses in dogs. Vet Pathol 1987; 24:276-278.
222. Acton CE. Spinal cord compression in young dogs due to cartilagenous exostosis. Calif Vet 1987; 41:7-8,26.
223. Pool RR. Osteochondromatosis. In: Bojrab MJ, Smeak DD, Bloomberg MS, ed. Disease mechanisms in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1993; 821-833.
224. Jacobson LS, Kirberger RM. Canine multiple cartilaginous exostoses: unusual manifestations and a review of the literature. J Am Anim Hosp Assoc 1996; 32:45-51.
225. Chester DK. Multiple cartilaginous exostoses in two generations of dogs. J Am Vet Med Assoc 1971; 159:895-897.
226. Beck JA, Simpson DJ, Tisdall PL. Surgical management of osteochondromatosis affecting the vertebrae and trachea in an Alaskan Malamute. Aust Vet J 1999; 77:21-23.
227. Caporn TM, Read RA. Osteochondromatosis of the cervical spine causing compressive myelopathy in a dog. J Small Anim Pract 1996; 37:133-137.
228. Santen DR, Payne JT, Pace LW, et al. Thoracolumbar vertebral osteochondroma in a young dog. J Am Vet Med Assoc 1991; 199:1054-1056.
229. Ness MG. Osteochondroma causing progressive posterior paresis in a lakeland terrier puppy. Vet Rec 1993; 132:608-609.
230. Banks WC, Bridges CH. Multiple cartilaginous exostosis in a dog. J Am Vet Med Assoc 1956; 129:131-135.
231. Owen LN, Bostock DE. Multiple cartilaginous exostoses with development of a metastasizing osteosarcoma in a Shetland sheepdog. J Small Anim Pract 1971; 12:507-512.
232. Green EM, Adams WM, Steinberg H. Malignant transformation of solitary spinal osteochondroma in two mature dogs. Vet Radiol Ultrasound 1999; 40:634-637.
233. Pool RR, Carrig CB. Multiple cartilaginous exostoses in a cat. Vet Pathol 1972; 9:350-359.
234. Bhatti S, van Ham L, Putcuyps I, et al. Atlantoaxial exostosis causing spinal cord compression in a mature Bernese mountain dog. J Small Anim Pract 2001; 42:79-81.
235. Liu S-K. Tumoral calcinosis. In: Bojrab MJ, ed. Disease mechanisms in small animal surgery. 2nd ed. Philadelphia: Lea & Febiger, 1993; 923-924.
236. Pedersen NC, Wind AP, Morgan JP, et al. Multicentric periarticular calcinosis. In: Ettinger SJ, ed. Textbook of Veterinary Internal Medicine. 3rd ed. Philadelphia: WB Saunders Co, 1989; 2360-2361.
237. Pool RR. Tumoral calcinosis. In: Moulton JE, ed. Tumors in domestic animals. 3rd ed. Berkeley: University of California Press, 1990; 123-125.
238. Kitchen H, Murray RE, Cockrell BY. Animal model for human disease. Spina bifida, sacral dysgenesis and myelocele. Animal model: Manx cats. Am J Pathol 1972; 68:203-206.
239. Leipold HW, Huston K, Blauch B, et al. Congenital defects on the caudal vertebral column and spinal cord in Manx cats. J Am Vet Med Assoc 1974; 164:520-523.
240. James CC, Lassman LP, Tomlinson BE. Congenital anomalies of the lower spine and spinal cord in Manx cats. J Pathol 1969; 97:269-276.
241. Deforest ME, Basrur PK. Malformations and the Manx syndrome in cats. Can Vet J 1979; 20:304-314.
242. Robinson R. Expressivity of the Manx gene in cats. J Hered 1993; 84:170-172.
243. Tomlinson BE. Abnormalities of the lower spine and spinal cord in Manx cats. J Clin Pathol 1971; 24:480.
244. Martin AH. A congenital defect in the spinal cord of the Manx cat. Vet Pathol 1971; 8:232-238.
245. Woodside JR, Dail WG, McGuire EJ, et al. The Manx cat as an animal model for neurogenic vesical dysfunction associated with myelodysplasia: a preliminary report. J Urol 1982; 127:180-183.
246. Dickele G, Perrot P, Audrin JF. Sacral dysgenesis in a Pekinese resembling the Manx cat anomaly. Prat Med Chir Anim 1996; 31:149-152.
247. Wilson JW, Kurtz HJ, Leipold HW, et al. Spina bifida in the dog. Vet Pathol 1979; 16:165-179.
248. Camon J, Sabate D, Franch J, et al. Associated multiple congenital malformations in domestic animals. Contribution of four cases. Zentralbl Veterinarmed A 1990; 37:659-668.
249. Yamada S, Iacono RP, Andrade T, et al. Pathophysiology of tethered cord syndrome. Neurosurg Clin N Am 1995; 6:311-323.
250. Ikai T. [Effects of caudal traction of the spinal cord on evoked spinal cord potentials in the cat]. Nippon Seikeigeka Gakkai Zasshi 1993; 67:275-288.
251. Fingeroth JM, Johnson GC, Burt JK, et al. Neuroradiographic diagnosis and surgical repair of tethered cord syndrome in an English bulldog with spina bifida and myeloschisis. J Am Vet Med Assoc 1989; 194:1300-1302.
252. Brunetti A, Fatone G, Cuomo A, et al. Meningomyelocele and hydrocephalus in a Bulldog. Prog Vet Neurol 1993; 4:54-59.
253. Wilson JW. Spina bifida in the dog and cat. Compend Contin Educ Pract Vet 1982; 4:626-636.

254. Khera KS, Iverson F. Toxicity of ethylenethiourea in pregnant cats. Teratology 1978; 18:311-313.
255. Furneaux RW, Doige CE, Kaye MM. Syringomyelia and spina bifida occulta in a Samoyed dog. Can Vet J 1973; 14:317-321.
256. Chesney CJ. A case of spina bifida in a Chihuahua. Vet Rec 1973; 93:120-121.
257. Clayton HM, Boyd JS. Spina bifida in a German shepherd puppy. Vet Rec 1983; 112:13-15.
258. Langeland M, Indrebo A. Radiography as a modality for screening of hemivertebrae in the Pug. Norsk Vet 2001; 113:71-76.
259. Bailey CS. An embryological approach to the clinical significance of congenital vertebral and spinal cord abnormalities. J Am Anim Hosp Assoc 1975; 11:1975.
260. Parker AJ, Park RD, Byerly CS, et al. Spina bifida with protrusion of spinal cord tissue in a dog. J Am Vet Med Assoc 1973; 163:158-160.
261. Hall JA, Fettman MJ, Ingram JT. Sodium chloride depletion in a cat with fistulated meningomyelocele. J Am Vet Med Assoc 1988; 192:1445-1448.
262. Plummer SB, Bunch SE, Khoo LH, et al. Tethered spinal cord and an intradural lipoma associated with a meningocele in a Manx-type cat. J Am Vet Med Assoc 1993; 203:1159-1161.
263. Taga A, Nakayama M, Tanaka H, et al. Myelography and magnetic resonance imaging of spina bifida cystica in a dog. [Japanese]. J Jap Vet Med Assoc 1998; 51:81-84.
264. Shamir M, Rochkind S, Johnston D. Surgical treatment of tethered spinal cord syndrome in a dog with myelomeningocele. Vet Rec 2001; 148:755-756.
265. Hall P, Turner M, Aichinger S, et al. Experimental syringomyelia: the relationship between intraventricular and intrasyrinx pressures. J Neurosurg 1980; 52:812-817.
266. Williams B, Bentley J. Experimental communicating syringomyelia in dogs after cisternal kaolin injection. Part 1. Morphology. J Neurol Sci 1980; 48:93-107.
267. Tachibana S, Kitahara Y, Iida H, et al. Spinal cord intramedullary pressure. A possible factor in syrinx growth. Spine 1994; 19:2174-2178; discussion 2178-2179.
268. Rossier AB, Foo D, Shillito J, et al. Posttraumatic cervical syringomyelia. Incidence, clinical presentation, electrophysiological studies, syrinx protein and results of conservative and operative treatment. Brain 1985; 108:439-461.
269. Levitski RE, Lipsitz D, Chauvet AE. Magnetic resonance imaging of the cervical spine in 27 dogs. Vet Radiol Ultrasound 1999; 40:332-341.
270. Cauzinille L, Kornegay JN. Acquired syringomyelia in a dog. J Am Vet Med Assoc 1992; 201:1225-1228.
271. Itoh T, Nishimura R, Matsunaga S, et al. Syringomyelia and hydrocephalus in a dog. J Am Vet Med Assoc 1996; 209:934-936.
272. Johnson L, Rolsma M, Parker A. Syringomyelia, hydromyelia and hydrocephalus in two dogs. Prog Vet Neurol 1992; 3:82-86.
273. Taga A, Taura Y, Nakaichi M, et al. Magnetic resonance imaging of syringomyelia in five dogs. J Small Anim Pract 2000; 41:362-365.
274. Morgan JP. Congenital anomalies of the vertebral column of the dog: A study of the incidence and significance based on a radiographic and morphometric study. J Am Vet Radiol Soc 1968; 9:21-29.
275. Done SH, Drew RA, Robins GM, et al. Hemivertebra in the dog: clinical and pathological observations. Vet Rec 1975; 96:313-317.
276. Drew RA. Possible association between abnormal vertebral development and neonatal mortality in Bulldogs. Vet Rec 1974:480-481.
277. Kirberger RM. Congenital malformation and variation of the lumbar vertebrae in a dog. J S Afr Vet Assoc 1989; 60:111-112.
278. Chauvet AE, Darien DL, Steinberg H. What is your neurologic diagnosis? Spinal abnormalities and syringomyelia of the lumbar spinal cord. J Am Vet Med Assoc 1996; 208:1387-1389.
279. Kramer JW, Schiffer SP, Sande RD, et al. Characterization of heritable thoracic hemivertebra of the German Shorthaired Pointer. J Am Vet Med Assoc 1982; 181:814-815.
280. van den Brande P, Dennis R. Congenital anomaly of the cervical vertebral column of a dog. Vet Rec 1994; 135:436.
281. Vernau KM, Kortz GD, Koblik PD, et al. Magnetic resonance imaging and computed tomography characteristics of intracranial intra-arachnoid cysts in 6 dogs. Vet Radiol Ultrasound 1997; 38:171-176.
282. Parker AJ, Park RD, Stowater JL. Cervical kyphosis in an Afghan hound. J Am Vet Med Assoc 1973; 162:953-955.
283. Tellhelm B, Brass W. Case reports on the HD-evaluation - sacralization. [German]. Kleintierpraxis 1994; 39:281-282.
284. Morgan JP, Bahr A, Franti CE, et al. Lumbosacral transitional vertebrae as a predisposing cause of cauda equina syndrome in German shepherd dogs: 161 cases (1987-1990). J Am Vet Med Assoc 1993; 202:1877-1882.
285. Morgan JP. Transitional lumbosacral vertebral anomaly in the dog: a radiographic study. J Small Anim Pract 1999; 40:167-172.
286. Schultz VA, Watson AG. Lumbosacral transitional vertebra and thoracic limb malformations in a Chihuahua puppy. J Am Anim Hosp Assoc 1995; 31:101-106.
287. Jones JC, Inzana KD. Subclinical CT abnormalities in the lumbosacral spine of older large- breed dogs. Vet Radiol Ultrasound 2000; 41:19-26.

288. de Lahunta A. Veterinary Neuroanatomy and Clinical Neurology. 2nd ed. Philadelphia: WB Saunders Co, 1983; 175-214.
289. Stigen O, Hagen G, Kolbjornsen O. Stenosis of the thoracolumbar vertebral canal in a Basset Hound. J Small Anim Pract 1990; 31:621-623.
290. Wheeler SJ. Vertebral abnormalities in dogs. J Small Anim Pract 1991; 32:149-150.
291. Tarvin G, Prata RG. Lumbosacral stenosis in dogs. J Am Vet Med Assoc 1980; 177:154-159.
292. Malik R, Allan GS, Howlett CR, et al. Osteochondrodysplasia in Scottish Fold cats. Aust Vet J 1999; 77:85-92.
293. Vernau KM, Kortz GD, Koblik PD, et al. Magnetic resonance imaging and computed tomography characteristics of intracranial intra-arachnoid cysts in 6 dogs. Vet Radiol Ultrasound 1997; 38:171-176.
294. Knipe MF, Sturges BK, Vernau KM, et al. Atlantoaxial instability in 17 dogs. J Vet Intern Med 2002; 16:368.
295. Schatzberg SJ, Haley NJ, Bar SC, et al. Polymerase chain reaction amplification of parvoviral DNA from the brains of dogs and cats with cerebellar hypoplasia. J Vet Intern Med 2002; 16:331.
296. Saito M, Olby NJ, Munana KR, et al. Assessment of canine hydrocephalus using cerebrovascular resistance index. J Vet Intern Med 2002; 16:332.
297. Rylander H, Lipsitz D, Berry WL, et al. Retropective analysis of spinal arachnoid cysts in 14 dogs. J Vet Intern Med 2002; 16:690-696.
298. Rusbridge C, Wilkins P. Neuronal heterotopia in a Lagotto Romagnola dog. In: Proceedings of ESVN 15th Annu Sympo 2002.
299. Rusbridge C, Knowler SP. Syringohydromyelia secondary to occipital bone hypoplasia (Chiari malformation) in Cavalier King Charles Spaniels. In: Proceedings of ESVN 15th Annu Sympo 2002.
300. Lu D, Lamb CR, Pfeiffer DU, et al. Clinical and MRI findings in 40 Cavalier King Charles Spaniels with Chiari I malformation. In: Proceedings of ESVN 15th Annu Sympo 2002.
301. Fyfe JC, Goldowitz D, Henthorn PS. Neuropathic fetal akinesis deformation sequence in dogs: a model of pontocerebellar hypoplasia type I? In: Proceedings of ESVN 15th Annu Sympo 2002.
302. Barth PG. Pontocerebellar hypoplasias. An overview of a group of inherited neurodegenerative disorders with fetal onset. Brain Dev 1993; 15:411-422.
303. Anderson DM, White RA. Nasal dermoid sinus cysts in the dog. Vet Surg 2002;31:303-308.
304. Dewey CW. External hydrocephalus in a dog with suspected bacterial meningoencephalitis. J Am Anim Hosp Assoc 2002;38:563-567.
305. Tani K, Taga A, Itamoto K, et al. Hydrocephalus and syringomyelia in a cat. J Vet Med Sci 2001;63:1331-1334.
306. Franklin RJ, Ramsey IK, McKerrell RE. An inherited neurological disorder of the St Bernard dog characterised by unusual cerebellar cortical dysplasia. Vet Rec 1997;140:656-657.
307. Nykamp S, Scrivani P, DeLahunta A, et al. Chronic subdural hematomas and hydrocephalus in a dog. Vet Radiol Ultrasound 2001;42:511-514.
308. Saito M, Olby NJ, Spaulding K. Identification of arachnoid cysts in the quadrigeminal cistern using ultrasonography. Vet Radiol Ultrasound 2001;42:435-439.
309. Saito M, Sharp NJ, Kortz GD, et al. Magnetic resonance imaging features of lissencephaly in 2 Lhasa Apsos. Vet Radiol Ultrasound 2002;43:331-337.
310. Cantile C, Chianini F, Arispici M, et al. Necrotizing meningoencephalitis associated with cortical hippocampal hamartia in a Pekingese dog. Vet Pathol 2001;38:119-122.
311. Silver GM, Bagley RS, Gavin PR, et al. Radiographic diagnosis: cartilaginous exostoses in a dog. Vet Radiol Ultrasound 2001;42:231-234.
312. Rusbridge C, Knowler SP. Inheritance of occipital bone hypoplasia (Chiara type I malformation) in Cavalier King Charles Spaniels. J Vet Intern Med 2004; 18: 673-678.