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Clinical Signs and Diagnosis of the Canine Primary Glaucomas

Paul E. Miller, DVM* and **Ellison Bentley, DVM**

Department of Surgical Sciences, School of Veterinary Medicine, University of Wisconsin-Madison, 2015 Linden Drive, Madison, WI 53706-1102, USA

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DEFINITION OF PRIMARY GLAUCOMA

A clinician's working definition of glaucoma determines which clinical signs and diagnostic values are considered important and pivotal in directing therapy. Unfortunately, there is no clear consensus on the definition of glaucoma or its various forms in human or veterinary medicine.^{1,2} For more than 100 years, glaucoma has been thought of as a "disease of elevated intraocular pressure (IOP)" and this parameter has been emphasized as the defining clinical sign, diagnostic variable, and therapeutic guide. This remains true for the vast majority of patients with glaucoma in veterinary medicine. Recent advances in both human and veterinary medicine, however, have demonstrated that damage to the optic nerve or associated tissues, such as the retinal nerve fiber layer (RNFL) can occur before IOP increases are documented or even after IOP has returned to normal values. This indicates that IOP alone is not the sole characteristic that defines the presence or absence of glaucoma and this fact has caused vision scientists to focus on the anatomic and molecular mechanisms that lead to the characteristic optic disc and visual field changes resulting in glaucomatous vision loss. The evolution of the definition of glaucoma to essentially a specific type of optic neuropathy has led to the proliferation of other diagnostic techniques that evaluate the posterior segment in more detail and tend to de-emphasize the role that IOP plays in this disorder.

For the purpose of this article, "primary glaucoma" is defined as a group of disorders that are typically bilateral, have a strong breed predisposition, are associated with increasing age, are documented or believed to have a genetic basis,^{3–5} result in characteristic changes to the optic nerve, and have no readily identifiable secondary ocular or systemic cause on routine ophthalmic examination. IOP is an important risk factor but not the sole risk factor for glaucomatous damage. The gonioscopic appearance of the iridocorneal angle (ICA) further categorizes primary glaucoma into "open" and "closed" forms. The term "primary angle closure glaucoma" (PACG) is used to reflect that the gonioscopic appearance of the ICA changes over time and eventually this structure appears closed.^{6,7} In clinical practice, PACG

*Corresponding author. millerp@svm.vetmed.wisc.edu.

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is many times more frequent than primary open angle glaucoma (POAG) in dogs and as such will be emphasized here.

PRIMARY OPEN ANGLE GLAUCOMA

This clinically rare disorder typically occurs in the beagle, where the ADAMTS10 gene has been implicated (Figs. 1 and 2).^{4,5} POAG is also sporadically observed in other breeds, including the Norwegian elkhound, which also has a mutation in the ADAMTS10 gene but at a different location from that in beagles.^{8,9} Because the clinical signs of this form of glaucoma mimic key elements of human POAG, dogs with this form of glaucoma have been used as a model of human POAG for more than 4 decades, resulting in a robust literature base even though the disease is clinically rare.⁸

Clinical signs in beagles include an initially open ICA that narrows as the disease progresses, slowly progressive increases in IOP that occur over months to years, mydriasis, lens luxation (which may be part of this genetic mutation), optic nerve atrophy, and vision loss.⁸ The disease is similar in Norwegian elkhounds, although it frequently is not diagnosed until the dog is middle-aged or older.⁹ With these distinct clinical features in mind, the remaining clinical signs and diagnostic evaluation is similar to that for dogs with PACG.

PRIMARY ANGLE CLOSURE GLAUCOMA

Figs. 3 and 4 demonstrate the typical clinical presentation of this disorder. This entity is typically associated with gonioscopically visible pectinate ligament dysplasia (PLD) in a large number of breeds (Figs. 5 and 6).^{7,8} In dandie dinmont terriers, it has been associated with a novel genetic locus on CFA8, although it is likely that multiple genes are involved in this disorder.³ Two genetic loci have been suggested as possible PACG risk-conferring variants in basset hounds.¹⁰ In one study of almost 100 bouvier des Flandres dogs in the United States, a single male dog was the father or grandfather of all affected dogs, even though affected dogs had 5 different mothers.¹¹ Although the vast majority of dogs who develop PACG have PLD, only a small fraction of dogs with PLD will develop PACG in their lifetime.¹¹ This strongly suggests that other factors are involved in the genesis of PACG and that the presence or absence of these factors is sufficiently important to determine whether an individual develops PACG or not.

Reverse Pupillary Block

A reverse pupillary block mechanism has been proposed by the authors as the pathophysiologic mechanism of PACG (Fig. 7).⁷ This hypothesis appears consistent with all known epidemiologic, anatomic, physiologic, and histologic features of PACG in dogs and can explain many of the clinical signs seen in this disorder. In brief, PLD is proposed to be the first “hit” in a multistep process in which the dysplastic ligament functions as a form of peripheral anterior synechia and holds the peripheral iris in close contact with the inner surface of the cornea. Stress or excitement puts the pupil into a midrange to dilated position and increases pulse pressure amplitudes in the choroid, thereby expanding and contracting the choroid in a pulsatile fashion to a greater degree than what occurs normally. These pulsatile forces are transmitted through the vitreous as a fluid wave to the posterior chamber

where small aliquots of aqueous humor are forced through the pupil into the anterior chamber. In humans, it has been calculated that a 5% change in the volume of the choroid would displace 25 μL of aqueous, which is more than enough to raise IOP outside of the normal range.¹² This fluid movement results in slightly higher pressure in the anterior chamber than in the posterior chamber/vitreous (based on calculations in the human eye IOP in the posterior chamber is normally 1 to 2 mm Hg greater than that in the anterior chamber¹²). Normally this increased pressure would force the ICA open,¹³ but this compensatory mechanism is abrogated by PLD, which prevents the angle from opening further allowing the additional aqueous to escape. Progressive closure of the ICA over time due to a variety of factors may further facilitate angle closure. The increased pressure in the anterior chamber presses the pupillary zone of the iris more tightly against the anterior lens capsule and creates a “ball-valve” effect at the pupil, which prevents the increased volume of aqueous in the anterior chamber escaping backward to the posterior chamber and normalizing anterior chamber IOP. Mid-range pupils (as seen with dim light and increased sympathetic tone) are more susceptible to pupil block, as they have greater contact with the anterior lens capsule than maximally dilated or very miotic pupils.^{12,14} This may be appreciated clinically on detailed slit-lamp bio-microscopy or on high-resolution ultrasonography in which the anterior iris surface assumes a sigmoid appearance and the area of contact between the posterior iris and anterior lens is increased. With subsequent systoles, additional aliquots of aqueous are forced through the pupil and entrapped in the anterior chamber, thereby further increasing IOP until it is counterbalanced by uveal/corneal/scleral resistance to compression/distention, usually in the 50 to 80 mm Hg range. This entire process can occur in the span of minutes and subsequently initiates posterior segment changes affecting the retina and optic nerve that can create a vicious cycle of glaucomatous degeneration.

CLINICAL FORMS OF PRIMARY ANGLE CLOSURE GLAUCOMA

The proposed reverse pupillary block mechanism can explain the various recognized clinical forms of PACG and their associated clinical signs.

Latent

In the *latent (occluded angle)* phase, the animal appears asymptomatic, but on gonioscopy the ICA is partially occluded by PLD (primary angle closure, see Fig. 6); however, IOP is within the normal range and glaucomatous damage to the optic disc is absent. The vast majority of animals with PLD fall into this category and only a small percentage will go on to develop glaucomatous damage in their lifetimes.¹¹ The pectinate ligament itself, even if dysplastic, may offer relatively little resistance to outflow. In one study of bouvier des Flandres dogs, aqueous outflow through the ICA of eyes affected with PLD was normal.¹⁵ Additionally, significant differences in IOP were not found in samoyeds with varying degrees of PLD.¹⁶ These studies and the common clinical observation of normal IOP even in the face of severe PLD strongly suggests that PLD itself typically offers relatively little resistance to outflow and that the location of the resistance to outflow (and hence the cause of the increased IOP) is likely located deeper within the ciliary cleft. However, sectioning of normal pectinate ligament fibers considerably opens the ICA and substantially increases

outflow, indicating that they serve as a “strut” that prevents the ICA from excessively opening or closing during normal physiologic changes in IOP.¹⁷

The appearance of PLD is not static and may change over time without an overtly detected increase in IOP.⁶ It is unclear, however, whether this change represents progressive thickening of the PLD with age, which is unusual for true dysplasias, or if this represents a form of peripheral anterior synechia that is occurring secondary to chronic apposition between the pectinate ligament and peripheral iris against the trabecular meshwork. In humans, frictional contact between the peripheral iris and the trabecular meshwork degrades the architecture and function of the trabecular meshwork, both in areas with overt peripheral anterior synechia and, more importantly, in areas without overt PAS.¹⁸ In another study, contact between the iris and trabecular meshwork and the peripheral anterior synechia were related to the degree of angle closure on gonioscopy.¹⁹ This suggests that this contact attenuates aqueous flow through the trabecular mesh-work, which in turn results in progressive dysfunction of the endothelium of the Schlemm canal, reduced trabecular meshwork mitochondrial function, fusion of trabecular beams, and eventual occlusion of the iridocorneal angle.¹⁹ Such a process may be involved in the apparent progression of PLD over time in dogs.

Intermittent

In this phase of the disease, the ICA becomes occluded (primary angle closure), resulting in transient increases in IOP that may or may not become overtly symptomatic or result in glaucomatous damage to the posterior segment (PACG). Often owners will comment that at night or under stressful conditions, the conjunctiva becomes hyperemic, the pupil may dilate, and the cornea may become somewhat hazy. Acute vision loss is not a prominent feature of this phase, although with chronic intermittent angle closure, episodic or persistent alterations in vision may occur, indicating that the dog has overt PACG and not just angle closure. It is hypothesized that in this phase a reverse pupillary block is established, but as the pupil dilates, this block is spontaneously broken as the iris slides down the more steeply curved peripheral lens and aqueous humor can once again more freely move through the pupil between the anterior and posterior chambers.⁷ Clinically this phase is manifested by acute increases in IOP that spontaneously resolve. However, repeated episodes of intermittent closure may be responsible for the ICA progressing to complete closure and sustained increases in IOP. Histologically (and clinically), evidence for this frictional change is seen as stripping of pigmented epithelial cells from the posterior iris (especially in the pupillary zone) and pigment on the anterior lens capsule and in the ICA, especially inferiorly.²⁰ In some instances the only means of identifying dogs affected with intermittent primary angle closure is to perform tonometry repeatedly over the course of the day and often evening and demonstrating an intermittent increase in IOP. The presence of notable amounts of pigment in the inferior angle or on the anterior lens surface is also very suggestive of intermittent primary angle closure. Dogs with this form often progress to acute congestive PACG.

Acute Congestive

This phase has the most florid symptoms and is the greatest threat to the maintenance of vision (see Fig. 3; Fig. 8). This may be the result of a single acute episode of pupil block,

although histologically and clinically there is often a suggestion that intermittent but spontaneously resolving rises in IOP may have occurred. Vision alterations are rapid in onset and common in this phase.

Post Congestive

This phase represents animals that have had an attack of acute congestive glaucoma that has resolved, usually through medical or surgical intervention. Clinical signs can be quite variable. IOP is within normal limits and in some instances the eye appears otherwise normal with no detectable vision loss or changes in the appearance of the optic disc. More frequently, however, there are residual signs of an acute attack that can range from mild episcleral injection to a grossly enlarged eye with massive intraocular changes.

Chronic Primary Angle Closure Glaucoma

This end-stage phase is common in dogs. Usually all of the ICA has become permanently closed by peripheral anterior synechia, the ciliary cleft is collapsed, and IOP is chronically elevated. This form may be the result of a prolonged attack of acute congestive glaucoma or repeated intermittent attacks. The latter form is the most common in eyes that are being treated with antiglaucoma drugs, as these tend to blunt the larger IOP spikes but do not completely eliminate the progressive damage to the ICA through frictional contact among the iris, dysplastic pectinate ligament, and trabecular meshwork. These patients tend to exhibit variable IOP measurements on serial examinations, often with sporadic instances of grossly abnormal values. In very advanced instances in which the eye is blind and typically buphthalmic, IOP may decline to normal or subnormal values (despite persistence of angle closure) as the ciliary body becomes atrophic. Severe reductions in aqueous humor production via this mechanism may lead to phthisis bulbi.

CLINICAL SIGNS OF PRIMARY ANGLE CLOSURE GLAUCOMA

Signalment is one of the most useful clinical features in the diagnosis of PACG in dogs. Although numerous breeds are at risk, and the major breeds affected vary by region of the United States and by country, some at-risk breeds dominate large-scale surveys more than others.²¹ These include American and English cocker spaniels, basset hound, miniature and toy poodles, great Dane, flat-coated retriever, chow chow, sharpei, Welsh springer spaniel, and bouvier des Flandres.²¹ These breed predispositions are believed to have a genetic basis. Additionally, in most breeds PACG has a significant female predisposition,²¹ perhaps due to a significantly smaller angle opening distance than male dogs²² or a shorter axial length as reported for Eurasier dogs.²³ Both a smaller angle opening distance and shorter axial length would lead to crowding of the ICA. Even small changes in angle opening distance are important, as aqueous humor flow through the trabecular meshwork is related to the radius of the opening distance to the fourth power in accordance with Poiseuille's law. Although any age can be affected, most dogs are middle to older aged,²¹ indicating that PLD (which is present at birth) is not, in and of itself, a common cause of PACG.

Historical features are also important factors in the diagnosis of PACG. Many intermittent and acute congestive attacks occur in dim light or under stressful circumstances, such as

being groomed or kenneled, moving to a new home, or the arrival of a new baby in the home. This is significant because these stressors result in a midrange pupil, which greatly increases its susceptibility to pupil block.¹⁴ Other historical features of intermittent angle closure also may be present on careful questioning of the client.

EARLY TO MIDSTAGE CLINICAL SIGNS

Pain

Although very mild increases in IOP (5–15 mm Hg) may not be associated with any ocular pain, severe pain is a common feature of most phases of PACG in dogs in which the IOP increase is marked. Owners, and occasionally veterinarians, frequently underestimate the degree of discomfort the animal is experiencing. Pain in acute PACG is often rapidly progressive and may be initially confined to the eye, but, as in humans, it appears to rapidly spread around the orbit and to be associated with frontal or generalized headaches that some humans liken to a migraine. Some dogs will in fact demonstrate blepharospasm in both eyes even though only one eye is affected, likely due to this generalized migraine sensation. This can mistakenly lead to a diagnosis of acute PACG in both eyes if a careful examination is not performed. The degree of pain is likely related to the magnitude of the IOP rise as well as its duration, and it should be assumed that all significant IOP elevations in dogs are associated with ocular pain until proven otherwise. The vast majority of owners will comment that the pet appears more energetic, lively, and youthful when an eye with chronically elevated IOP is enucleated, supporting the view that IOP elevations are painful in dogs.

Systemic Malaise

Dogs with acute congestive PACG appear unwell and may vomit or appear nauseous. Others may sleep more, hide in unusual locations, eat less, or have reduced tolerance for disturbances.

Alterations in Vision

Humans with PACG report colored halos around lights and blurred vision often at night, suggesting mild subacute attacks. These alterations rapidly progress to loss of peripheral vision and eventually complete vision loss if the attack does not spontaneously resolve. Once IOP is lowered, it may take several days to weeks for vision to return, if it returns at all.²⁴ Progressive vision loss due to an ongoing apoptotic cascade (see Definition, Classification, and Pathophysiology of Canine Glaucoma by Stefano Pizzirani, elsewhere in this issue, for more detailed discussion) is very common and even with successful IOP control vision is frequently lost over the ensuing months to years due to this process.²⁵

Episcleral Injection

Episcleral vascular congestion is a common clinical sign in PACG (see Fig. 8). It is not simply the result of increased IOP, as it frequently does not accompany postoperative IOP spikes in which comparably high levels of IOP lasting for hours are achieved or when IOP is experimentally increased by infusing saline into the anterior chamber.^{26–28} This suggests that episcleral vascular congestion is associated with poorly described vasodilatory factors or intraocular inflammatory pathways that are activated in acute congestive PACG. Episcleral

vascular congestion also can occur as drainage of aqueous humor and blood from the scleral venous plexus and vortex venous system is impaired, resulting in blood being shunted through the more superficial episcleral and conjunctival vessels.

Corneal Edema

As noted for episcleral congestion, corneal edema is a common clinical sign of PACG (see Fig. 8); however, it is also typically not observed in eyes with acute postoperative IOP spikes or with manometrically controlled marked IOP elevations, suggesting that it is not simply the result of increased IOP driving more aqueous humor into the cornea.^{26–28} With normal corneal endothelial function, increased IOP may initially compress the corneal stroma rather than making it edematous; however, persistently elevated IOP drives fluid across the corneal endothelium, creating edema of both the epithelium and stroma. Corneal microcystic changes (subepithelial corneal edema) may initially be observed without gross increases in corneal thickness. Although increased IOP alone does not disrupt the barrier function, a greater pressure gradient forces more fluid across an intact barrier and decreases the efficiency of the endothelial pump.²⁹ In chronic cases, the corneal endothelium may be damaged to the point that it can no longer maintain normal corneal clarity, even if IOP is restored to normal values.

Mild Aqueous Flare and Cell

These findings are regularly observed in dogs and humans^{20,30} and are attributable to pressure-associated anterior-segment ischemia. Flare and cell may worsen after a dramatic reduction in IOP as previously hypoxic tissues become reperfused. Anecdotally, the authors have observed a number of animals in which aqueous flare/cell were absent on detailed slit-lamp biomicroscopy when the eye was normotensive, only to observe mild to moderate flare/cell 1 to 3 days later during an acute attack of PACG. This strongly suggests that, like humans with PACG, not all canine eyes with aqueous flare and cell have secondary glaucoma.³⁰ This understanding becomes important when assessing the risk to the fellow eye in dogs with unilateral PACG and considering whether prophylactic therapy is warranted,³¹ as one should not mistake an eye with mild aqueous flare/cell and acute congestive PACG as having secondary glaucoma.

Pupil Alterations

Pupil abnormalities, such as midrange to dilated, sluggish to fixed, and irregularly shaped pupils, are common signs of primary glaucoma in dogs (see Figs. 1, 3, and 8). Peripheral anterior synechia can form rapidly (distorting the shape of the iris), and IOP-induced ischemia may produce sectorial or diffuse atrophy of the iris, especially the iris sphincter muscle. This results in a permanently fixed and midrange to dilated pupil. Such atrophy releases pigment and causes pigmentary dusting of the iris surface and corneal endothelium, which are observable both clinically and histologically.²⁰

The authors have noted the responsiveness of the pupil to miosis with latanoprost has prognostic value in dogs with acute PACG.³² Eyes that rapidly develop miosis (indicating relatively mild ischemia may be present) will typically have better short-term outcomes than eyes that do not develop miosis when exposed to fresh latanoprost, presumably because the

latter is indicative of greater anterior-segment ischemia, which likely indicates greater posterior segment ischemia as well. Additionally, on detailed slit-lamp biomicroscopy, it may be possible to appreciate the sigmoid appearance of the anterior iris surface (especially seen in the peripheral iris), suggesting reverse pupillary block is present.

Lens Changes

Age-related changes in lens thickness in samoyeds has been suggested to result in anterior chamber shallowing and an increased risk of pupil block in PACG.³³ These changes, however, are difficult to appreciate with slit-lamp biomicroscopy and are best detected on ultrasonography. *Glaukomflecken* are characteristic small anterior subcapsular lens opacities that occur secondary to lens epithelial cell necrosis in humans with PACG. Similar opacities may also develop as a result of ischemia, but are not routinely recognized in dogs.

Vitreous Alterations

Clinically useful clinical signs involving the vitreous are not recognized in dogs. The vitreous may elongate on ultrasonography, but this is not clinically appreciable.³³

Retina

During an acute attack, IOP may be high enough to cause retinal or choroidal vascular occlusion and ischemic retinal damage resulting in irregular wedge-shaped retinal lesions that have their apex directed toward the optic disc. Nerve fiber layer defects commonly seen in human PACG are typically difficult to clinically appreciate in dogs, but may be best appreciated by use of red-free (green) light and magnification (see later in this article).

Optic Disc Changes

Optic disc cupping occurs only in glaucoma (see Fig. 1; Fig. 9); however, early detection of optic disc changes in PACG in dogs is extremely difficult and confounded by the presence of potentially large amounts of myelin over the disc surface. This myelin can obscure the relationship between the optic cup and the surrounding neuroretinal rim and alter the typical cup/disc ratio (typically 0.3 in normal dogs) that is used to evaluate the optic disc for glaucomatous changes in humans. The authors have found that examination of the optic disc by indirect ophthalmoscopy alone is often insufficient in evaluating the disc for potential glaucomatous changes and prefer to use a pediatric gonioscope in which the center lens allows one to view the optic disc with a slit-lamp biomicroscope.

In the initial stages of acute congestive PACG, the optic disc often appears swollen with an adjacent peripapillary ring of retinal edema (see Fig. 3). The optic disc also may appear paler than normal, suggesting poor perfusion of disc tissue itself. With time, focal areas of disc atrophy may appear, although a more generalized concentric atrophy is more common in dogs. The “laminar dot sign,” in which the pores of the lamina cribrosa become visible, may develop in chronic cases, indicating loss of neuronal tissue. In advanced stages, myelin is completely lost, the entire disc is cupped, and the disc is often surrounded by a peripapillary ring of altered reflectivity that extends for one-third to one-half disc diameter around the disc (see Figs. 1 and 9).

Changes in the Lateral Geniculate Nucleus and Visual Cortex

There is accumulating evidence that glaucomatous damage to retinal ganglion cells also results in degenerative changes in the brain, including the lateral geniculate and the visual cortex.^{34,35} Histopathologic findings are even present in lateral geniculate layers driven by the unaffected fellow eye.^{34,35} This has significant implications on the therapy for glaucoma, especially those directed toward neuroprotection or neuro-regeneration, and indicates that this disorder affects more than the eye.

CHRONIC CLINICAL SIGNS

Most of these signs are poor prognostic indicators for vision (Fig. 10); however, animals with low scleral rigidity, such as very young dogs or the sharpei breed, may retain some degree of vision despite the presence of Haab striae and buphthalmia.

Haab Striae

These linear corneal lesions represent breaks in Descemet membranes that occur secondary to stretching of the globe. On detailed examination, the edge of these breaks are thickened and curled, and secondarily proliferate, whereas the area between the breaks is thin and smooth. If the cornea is clear, these breaks usually do not result in surrounding corneal edema despite the endothelial damage, presumably because epithelial fibrotic changes tightly seal the Descemet fracture.

Buphthalmos

Literally meaning “cow” or “ox” eye, this term refers to enlargement of the globe that occurs secondary to chronically elevated IOP (see Fig. 10). It is generally an indicator that vision is completely lost. In some instances, clients may comment that the eye appears to grossly change in size, indicating that this finding may fluctuate to some degree with changes in IOP, although once it has occurred, it tends to remain present. This disorder frequently leads to exposure keratitis, corneal ulceration, and other alterations, such as subluxation of the lens and occasionally scleral ectasia. Lens subluxation due to buphthalmia needs to be carefully differentiated from primary lens luxation that leads to secondary glaucoma. History and patient signalment usually readily allow this distinction to be made.

Reduced Episcleral Injection

With time, episcleral vascular injection tends to become less apparent in eyes with chronic glaucoma. The reason for this is unclear but may relate to shifts in blood flow within the eye or a reduction in ischemia-associated damage.

Phthisis Bulbi

This disorder may result in advanced cases of glaucoma, as the ciliary body ceases to produce aqueous humor. It is also a common sequelae to many antiglaucoma therapies that are directed at destroying aqueous humor production. It is also occasionally observed after gonio-implantation with excessive filtration.

DIAGNOSIS OF PRIMARY ANGLE CLOSURE GLAUCOMA

There are several diagnostic aides in addition to the presence of the previously described clinical signs and vision changes that can assist with the diagnosis of PACG in dogs. These techniques can generally be categorized by which aspect of glaucoma pathophysiology they seek to further define (ie, IOP, the iridocorneal angle, visual capabilities of the eye, optic disc, or nerve fiber layer).

TECHNIQUES THAT EVALUATE INTRAOCULAR PRESSURE

Tonometry

All currently available tonometers do not actually measure IOP but instead measure a physical feature of the cornea and use these measurements to *estimate* true IOP (Fig. 11). Therefore, all tonometers only provide approximations of IOP and these vary in accordance with a variety of anatomic and physiologic factors.

Indentation tonometry

With Schiotz tonometry, the parameter measured is the extent to which the cornea is indented by a known weight (see Fig. 11). Because of the gross distortion of the cornea and the requirement for perpendicular positioning, this instrument has the largest number of potential errors and is the most difficult to use correctly. Nevertheless, with careful adherence to manufacturer's recommendations, accurate estimates of IOP are possible in cooperative animals. Use of the human calibration table that comes with the instrument more closely mimics IOP estimates acquired with the applanation tonometers than canine-specific conversion tables.³⁶

Applanation tonometry

With the Tono-Pen XL, Tono-Pen Vet, or Avia (see Fig. 11) devices (Reichert Inc, Buffalo, NY, USA), the parameter measured is the force required to flatten (applanate) the corneal surface. The underlying physical principles for applanation tonometers, however, require that the surface be perfectly spherical, flexible, infinitely thin, and dry; features that the cornea only roughly approximates.²⁸ Corneal drying (after application of a topical anesthetic) or increased tear film viscosity (from mucoid ocular discharge or artificial tears/gels) can alter readings with these devices, although applanation tonometers are generally the least affected by abnormalities in the cornea itself.

Rebound tonometry

With the TonoVet (see Fig. 11), a blunted pinlike probe is bounced off of the corneal surface.²⁷ The motion parameters of the probe are then measured and converted by species-specific algorithms (that were derived by comparison to manometric measurements of IOP) to estimates of IOP.²⁷ The user can select between settings for cat/dog = d, horse = h, and other = p.²⁷

By careful calibration to manometrically determined IOP, the measurements obtained with any tonometer can be converted to estimates of IOP by the use of tables (in the case of the

Schiotz) or by the use of on-board microprocessors (in the case of the Tono-Pen and TonoVet). Each of these methods has their pros and cons, although when used correctly, all are sufficiently accurate to document elevated IOP in dogs. The authors prefer the Tono-Pen Vet or the TonoVet rebound tonometer because of their ease of use.

There are 3 main sources of error with all tonometers, and it is critical that the clinician fully understand these sources of potential errors.

Tonometer factors—Each device has an inherent 1 to 2 mm Hg variability according to the manufacturer, although in manometric studies, the authors have noted that all tonometers can occasionally provide IOP estimates that vary by 3 to 4 mm Hg when they are applied at exactly the same location at exactly the same manometrically controlled IOP. Therefore, the clinician should not overinterpret small (few mm Hg) changes in IOP over time as indicative of a trend in IOP.

It is also important to recognize that most tonometers (with the exception of the TonoVet rebound tonometer) are optimized and calibrated for the human eye. This means that the instruments tend to underestimate true IOP when used in animals.^{27,28,36} This error, however, is of limited clinical significance because the underestimation is generally linear over the range of IOP encountered in the clinics and so it is unnecessary to convert these tonometric values to true IOP values by corrective equations. It is critical, however, to recognize that because of this potential underestimation, normal values for one instrument cannot be transferred to another.^{27,28,36,37} For example, in one study, mean IOP with the TonoVet was 16.9 ± 3.7 mm Hg, whereas it was 11.6 ± 2.7 mm Hg with the Tono-Pen XL in the same set of dogs.³⁷ Therefore, it is imperative that normal values be determined for each tonometer, species, and potentially tonometrist.^{27,28,36,37} In general, however, if the instrument is properly maintained and instrument-specific normal values are used, instrument-related error has the least impact on IOP estimates in a clinical setting.

Tonometrist-controlled factors—This is often the greatest source of error in estimating IOP. Proper application of the device to the cornea is essential. The Schiotz tonometer must be placed perpendicular to the cornea and ground so that the full force of the attached weight is available to indent the cornea. The TonoVet must impact the cornea with the probe parallel to the ground to avoid the effects of gravity on the probe's reverberation characteristics. It also is critical to avoid confounding results secondary to technical errors, such as compressing the globe while holding the eyelids apart (Figs. 12 and 13), compressing the jugular veins with a tight collar,³⁸ corneal drying, or viscous materials present on the corneal surface. IOP estimates in eyes that have had intraocular surgery are also especially prone to erroneous overestimations of IOP because of reductions in ocular rigidity. In the authors' experience, tonometrist-controlled factors are the most frequent and largest source of error in a clinical setting. Corneal changes, such as thinning, neovascularization, and fibrosis, also can affect IOP readings, although typically to a lesser degree than errors in technique do.

Animal factors—IOP is essentially a physiologic parameter and as such it is influenced by the animal's ocular and systemic physiology (especially that related to the respiratory and cardiovascular system). Ideally, the animal should be resting quietly and its head should be

the same distance above the heart at each interval.³⁹ Resisting application of the tonometer by nervous or excited dogs, or dogs that are moving, often results in inaccurate readings and may cause the clinician to believe that increased IOP is present when in fact it is absent. In stressed or uncooperative animals, these errors can be very large.

The Effect of Corneal Thickness on Intraocular Pressure Measurements

Although not a major factor in a clinical setting, corneal thickness plays a role in tonometric estimates of IOP in animals. In a recent study in dogs, it was found that for every 100- μ m increase in corneal thickness, the IOP estimate was increased by 1 mm Hg for the Tono-Pen XL and 2 mm Hg for the TonoVet.³⁷

TECHNIQUES THAT EVALUATE THE IRIDOCORNEAL ANGLE

Gonioscopy

Because the sclera extends anteriorly in dogs, it is difficult to impossible to view the normal ICA directly. Although it sometimes is possible to visualize the ICA with an indirect ophthalmoscope and a condensing lens held at an extremely oblique angle to the eye, these structures can be more fully and consistently examined by use of a specialized gonioscopes. Careful evaluation of the iridocorneal angle plays an important role in identifying the type of glaucoma that is present and the likely location of the impediments to outflow. Gonioscopy requires specialized training to properly perform and interpret, and, as such, cases requiring gonioscopy should be referred to a specialist, if possible, to confirm the diagnosis of primary glaucoma and to localize where the impediment to outflow is. Identification and correction of all impediments to outflow are critical to the effective treatment of glaucoma. Because gonioscopy can alter IOP by compressing the cornea, tonometry should be performed before gonioscopy.

A number of gonioscopes are commercially available and can be broken down into those that directly view the iridocorneal angle by using the principle of total internal reflection (Koepe or Barkan, for example) and those that indirectly visualize it by use of one or more reflecting mirrors ("gonioprism," such as a Goldmann single-mirror or 3-mirror or Zeiss 4-mirror [Ocular Instruments Inc, Bellevue, WA, USA]; Fig. 14). The latter examines the angle opposite to where the mirror is located. The authors prefer use of indirect gonioscopy with a 3-mirror Goldmann-type diagnostic lens designed for infants, as it allows examination of the entire iridocorneal angle with a slit-lamp biomicroscope and much higher magnification than that achieved with a direct gonioscope (which does not allow use of a slit-lamp biomicroscope). Many of the mirrored gonioscopes also have a central viewing lens that permits the optic disc to also be examined with a slit-lamp biomicroscope, thereby facilitating identification of subtle glaucomatous changes to the optic disc. The examiner must be careful to avoid indentation of the cornea, as this will make the ICA appear narrower. In the early stages of glaucoma, it is possible to identify compaction of the anterior aspect of the ciliary cleft (seen as a posterior "slanting" of the trabecular meshwork).

Indentation gonioscopy uses a lens in which the area of contact with the cornea is smaller than the corneal diameter (such as a Zeiss 4-mirror gonioscope). With this technique, gentle pressure on the cornea will force the peripheral iris posteriorly. If the angle is closed because of simple apposition between the iris and cornea, the angle will be forced open, allowing visualization of the pectinate ligament and trabecular meshwork, whereas if it is closed by adhesions between the iris and cornea (peripheral anterior synechia), it will remain closed. In the authors' experience, appositional closure is uncommon in dogs and the vast majority of angles do not open with indentation gonioscopy. Indentation gonioscopy cannot be performed with lenses that cover most of the corneal surface.

The authors have found the grading scheme proposed by Ekesten and Narfström,¹⁶ which evaluates both the width of the iridocorneal angle and the presence or absence of PLD, to be the most useful system (Fig. 15). The authors have further modified this scheme by calculating an "angle index," which factors in the width of the ICA and the degree of sheeting of the angle.¹¹ With this technique, the width of the ICA and the extent of sheeting are evaluated and scored separately according to the scheme published by Ekesten and Narfström.¹⁶ These 2 values are then combined into 1 number that is related to the estimated overall capacity for outflow through the iridocorneal angle. This standardized value can be used for statistical analysis and for comparisons between eyes with varying percentages of angle width and PLD, but with different or similar restrictions on the apparent capacity for outflow through the ICA. The angle index is calculated by giving a closed angle a value of 0, a very narrow angle a value of 1, a mildly narrowed angle a value of 2, an open angle a value of 3, and a wide open angle a value of 4, per the previously described criteria.^{11,16} For scoring PLD, the percentage of the iridocorneal angle (for 360°) affected by sheeting is visually estimated. The angle index is then calculated by multiplying the angle width score by (1 – the percentage of sheeting). For example, if the iridocorneal angle width is scored as a "2" and 80% of the iridocorneal angle is sheeted closed by PLD, the angle index is $2 \times (1 - 0.80) = 2 \times 0.20 = 0.40$. With this scheme, the maximal angle index value is 4.0 and the minimum value is 0. Therefore, in the preceding example, an eye with an iridocorneal angle width of "2" and PLD sheeting affecting 80% of the circumference of the iridocorneal angle has only 0.4/4 or 10% of the estimated outflow capacity of a fully open iridocorneal angle with no PLD sheeting.

In an almost 9-year longitudinal study of approximately 100 bouvier des Flandres dogs, it was found that there was a strong association between the development of glaucoma and the sheeting corrected angle index ($P < .001$) with the odds of glaucoma doubling for each 0.20-unit decrease in the angle index value.¹¹ Dogs with an angle index of less than or equal to 1 had a 21% risk of developing PACG compared with a risk of 1.9% for other dogs.¹¹ Additionally, in this study, all dogs who developed PACG over an approximately 9-year period had PLD at the initial examination.¹¹

Ultrasonography

High-frequency ultrasound probes with frequencies ranging from 20 MHz (high-resolution ultrasound [HRUS]) to 60 MHz (ultrasound biomicroscopy [UBM]) have been developed that allow imaging at resolutions that are comparable to low-power microscopic views (20–

80 μ m). These techniques were developed to improve the visualization of anterior-segment structures and have significantly contributed to our understanding of the pathogenic mechanisms involved in glaucoma and in glaucoma management. They have led to the theory of reverse pupillary block in PACG and have highlighted the critical prognostic and diagnostic role the ciliary cleft plays in glaucoma.

On HRUS imaging of patients with overt PACG or in the normotensive fellow eye that is at risk of PACG, the most striking features are substantial contact between the posterior iris and anterior lens capsule, a sigmoidally shaped iris, and the status of the ciliary cleft (see Figs. 2 and 4). The latter may be open (roughly interpreted as the outer and inner walls diverge), narrowed (roughly interpreted as the outer and inner walls are parallel or the overall volume of the cleft is less than normal), or closed (the cleft is not visible). This increased iridolenticular contact is believed to allow for a reversal of the pressure gradients between the anterior and posterior chambers (reverse pupillary block) and is correlated with pigment loss from the posterior iris surface and its deposition in the inferior iridocorneal angle. The authors have come to regard this iris configuration and the presence of ciliary cleft abnormalities to be important diagnostic features of glaucoma.¹¹ In a recent study of almost 100 bouvier des Flandres dogs, it was determined that the rate of development of glaucoma in dogs with at least one eye with a narrow or closed cleft was 24% (8/33) compared with 1.8% (1/57) in dogs with bilaterally open clefts.¹¹

Anterior-Segment Optical Coherence Tomography

This technique uses light instead of sound (in contrast to the HRUS and UBM) to obtain cross-sectional in vivo images of the anterior (or with modifications the posterior segment, see Fig. 16). Near-infrared light with a wavelength of 830 nm was first used to acquire images of the anterior segment, but recently this technology has been adapted to use a longer wavelength (1310 nm), which allows for increased penetration of nontransparent tissues such as sclera and iris. Image acquisition is fast and comfortable for the patient (as there is no contact with the eye), and is comparable to those acquired with a UBM. However, as the technique involves light transmission through optically opaque tissues, such as iris and sclera, visualization of the lens and structures posterior to the iris is decreased compared with HRUS or UBM. Due to the large diameter the canine eye, anterior-segment optical coherence tomography (AS-OCT) images also do not span from limbus-to-limbus as they do in humans. The lack of contact with the ocular surface (and hence reduced chance for indentation of the cornea) with AS-OCT versus HRUS and UBM may offer a less distorted view of the ICA than other modalities; however, the UBM and HRUS are the only devices that allow for imaging of the ciliary cleft, and this tissue plays a major role in evaluating the risk for PACG in dogs.

TECHNIQUES THAT EVALUATE THE VISUAL CAPABILITIES OF THE EYE

Visual Field

In theory, directly assessing the patient's full range of vision is the ideal clinical technique for estimating the functional impact of glaucoma on the patient's vision.⁴⁰ Manual or automated perimetry tests the light-difference sensitivity across the visual field by asking

patients to push a button when they observe a variably sized white target on a white background (so-called standard achromatic perimetry). Although automated perimetry (Humphrey Field Analyzer, for example) is the current gold standard for assessing visual field defects and disease progression in humans, its requirement for the patient to follow verbal instructions, maintain fixation on one point in space, and to push a button when the target is observed renders it unsuitable for use in veterinary medicine. Clinicians may be able to crudely estimate a dog's visual field by covering one eye and attempting to get the animal to fixate on a single point in space. A novel and interesting target (such as a food treat) is then introduced from the periphery of the animal's visual field and it is noted when the dog first responds to the presence of the treat. Such techniques, however, are very crude and at best detect only massive changes in the animal's vision. Furthermore, confounding factors, such as scent, may confuse such an evaluation. However, even with standard automated perimetry in humans, visual field defects become apparent only after a substantial number of ganglion cells have been lost, indicating that it is missing early stages of the disease.⁴¹

In an effort to increase the ability of perimetry to detect glaucomatous changes in the visual field, variations on this technique also have been explored in humans. Although almost all ganglion cells can respond to white light, more specific functions of ganglion cells, such as contrast sensitivity, motion perception, and color vision, are encoded by different subsets of ganglion cells.⁴² It is theorized that by "teasing" out these subsets of ganglion cells, so-called function-specific perimetry may be more sensitive at detecting visual field changes before large numbers of ganglion cells are lost. Short-wavelength automated perimetry, which isolates the blue cone visual pathway (a pathway shown to be abnormal in early glaucoma), can be performed with most of the automated achromatic perimetry units. This technique differs from standard achromatic perimetry in that it uses a narrow-band blue-light stimulus on a yellow background, but it still requires the patient to cooperate with the procedure in the same way as for standard automated perimetry.⁴² Although this technique may allow detection of visual field changes before standard white-light automated perimetry, further study is required to confirm this.

Electrophysiologic Testing

Electrophysiologic testing is another method for trying to understand the effect of glaucoma on a patient's visual function.⁴³ The standard *full-field electroretinogram* (ERG), which is predominately driven by the outer retina, is generally not helpful in the diagnosis or treatment of glaucoma, especially PACG, in which the IOP increase may be very sudden.^{43–45} If IOP is very high, the full-field ERG may be extinguished, and although this has negative prognostic significance, in the authors' experience it is still possible for vision to be temporarily regained once IOP returns to normal and adequate perfusion to the retina is returned.^{24,43–45}

The *pattern ERG* (PERG) is thought to originate from the inner retina in response to patterned stimuli (instead of a white flash of light in standard electroretinography), and is considered one of the best electrophysiological tools for assessing retinal ganglion cell

function in a clinical setting.^{43–45} Initial testing in humans and dogs suggests that the PERG is more sensitive than the full-field ERG to IOP increases.^{43–45}

Another component of electrophysiologic testing, the *visual evoked potential* (VEP) is also generally agreed to be abnormal in glaucoma, either in terms of its amplitude or its latency.⁴³ Standard white light, pattern, or flicker-based VEPs have been investigated but the results are variable enough across studies to indicate that VEP does not perform well enough to be useful clinically.⁴³

Multifocal electroretinogram/visual evoked potential

With this instrumentation, very discrete stimuli (usually a preset number of hexagons that may flash or show a pattern) are projected onto the retina, and the local response of that region of retina is recorded.⁴³ The great advantage of this technique is that one can record a detailed multifocal ERG (mfERG) that shows a topographic distribution of the signal amplitudes instead of just a single mass response representing the average response across the entire retina. This technique allows for the detection of regional midperipheral retinal damage that occurs in the earlier stages of glaucoma and these correspond to regions of visual field loss.⁴³ In a sense, this is a more objective method for estimating visual field loss in animals than standard perimetry that requires the patient's cooperation. However, the application of mfERG testing to human glaucoma has thus far met with limited clinical success.⁴³ By changing the stimulus from white light to an alternating pattern of black and white triangular checks it becomes possible to record a pattern multifocal VEP.

TECHNIQUES THAT EVALUATE THE OPTIC DISC

Optic Disc Photography

Because changes to the optic disc are a hallmark of glaucoma, much effort has been spent on carefully evaluating the optic disc, especially over time. Photography of the disc offers a number of clinical advantages, and the recent introduction of simple fundus cameras and fundus adaptors for smart phones may facilitate identification of alterations in the optic disc in dogs with glaucoma (see Figs. 1, 3, and 9). This is especially true in dogs, in which a high variation in the amount of myelin exists in normal dogs of different breeds at the level of the optic nerve head. Images should include the optic disc and the adjacent peripapillary region. Images are very useful because the magnification is relatively high, the animal is not moving, the images are in full color, and they can be examined for an unlimited amount of time or compared across time. Evaluation of disc photos should include the size and shape of the optic disc, color of the optic disc, configuration and depth of the optic cup, the cup/disc-diameter ratio, the presence or absence of the laminar dot sign (small dark dots on the optic disc representing pores of the lamina cribrosa), the presence or absence of peripapillary chorioretinal atrophy, the visibility of the RNFL, the appearance of retinal blood vessels and those over the surface of the disc, and the nature of the myelin on the surface of the disc.

Advanced Optic Disc Imaging

These instruments provide the clinician with reproducible objective measurements of the optic nerve head that may be useful in detecting glaucomatous damage or progression over

time. However, any one of these tests is limited in its ability to detect glaucomatous damage and therefore they should be used in conjunction with careful clinical examination and ideally functional vision testing. This technology is rapidly evolving, and with additional studies over time they may demonstrate great utility in the diagnosis and treatment of patients with glaucoma.

Confocal Scanning Laser Ophthalmoscopy (Heidelberg Retina Tomograph)

This instrument uses a confocal scanning laser (670-nm diode laser) to obtain multiple measures of retinal height at various points on the fundus (Fig. 17).^{46,47} Multiple confocal slices are acquired at different focal planes, allowing for a detailed 3-dimensional reconstruction of the optic disc and adjacent peripapillary retina. Three consecutive scans are acquired in approximately 2 seconds, making this a very rapid method for evaluation of the optic disc. Once the image is acquired, a number of automated methods for data evaluation are possible.⁴⁶

Optical Coherence Tomography

This technology differs from confocal scanning laser ophthalmoscopy in that it provides a histologic representation of the tissues and is not subject to some of the polarization artifacts stemming from the anterior segment (Fig. 18). With some changes in configuration, this device also can examine the posterior segment as well as the anterior segment.^{48–50} It provides high-resolution cross-sectional images of the fundus, and the distances and sizes of tissues in the fundus are determined by the amount of time it takes for light to reflect from the different structures. In this sense, it functions much like an ultrasound unit but it uses light instead of sound waves and it provides a level of resolution that approximates histopathology.

Time-Domain Optical Coherence Tomography

Time-domain OCT assessment of the optic nerve head consists of 6 scans centered on the optic disc that radiate from the disc in a spokelike manner. With this technology, each data point in each A-scan is obtained by moving the reference mirror for each depth, a process that is relatively slow and creates practical problems due to eye movement. Tissues between these scans are interpolated between the 6 radial scans. A topographic image of the optic disc is constructed and this can be automatically analyzed in detail. The advantage of this technique is that it allows for not only evaluation of the optic disc but also for cross-sectional analysis of the RNFL (ie, its thickness) and the macula with a single instrument.^{48,50}

Spectral-Domain Optical Coherence Tomography

There are a number of commercially available units (unlike only a single unit for time-domain OCT), and these have largely replaced time-domain OCT.^{48–50} This technology is similar to that of time-domain OCT but keeps the reference mirror fixed and obtains the entire A-scan at once using spectrally (color) separated detectors. The resulting data are analyzed by a spectrometer using a Fourier transformation. This allows for very fast scanning (20,000 A-scans per second) and for multiple related A-scans to create a B-scan or cross-sectional images of the optic nerve head, RNFL, and macula with a higher resolution

(4–5 μm) than time-domain technology. Nevertheless, it is still essential that the eye be perfectly still for several seconds to capture useful images, and this is difficult to achieve in dogs without sedation. The high scanning speed reduces motion artifacts, and because multiple B-scans can be rapidly acquired, these can be combined to create a 3-dimensional representation of the fundus. The acquired images also can be automatically measured and evaluated. With some units, it is possible to measure choroidal, pre-lamina cribrosa and laminar structures in a living patient.

TECHNIQUES THAT EVALUATE THE RETINAL NERVE FIBER LAYER

Retinal Nerve Fiber Layer Photography

Because the axons of the retinal ganglion cells are one of the earliest structures damaged in glaucoma, evaluation of the RNFL is a critical component of the diagnosis and management of glaucoma. Damage to the RNFL occurs before detectable changes in the optic disc, and significant RNFL loss can occur before functional loss can be demonstrated on perimetry.⁴¹ The brightly reflective tapetum lucidum, however, makes this tissue difficult to consistently clinically identify in dogs. The healthy RNFL will appear as slightly opaque with visibly radiating striations emanating from the optic disc. Glaucomatous defects in the RNFL appear as slit-groove-shaped or wedge-shaped defects or diffuse generalized loss. Techniques for evaluating the RNFL layer are described in the following sections.

Ophthalmoscopy

A direct ophthalmoscope or a slit-lamp with a gonioscope that has a central viewing lens for examination of the fundus is especially useful for evaluation of the RNFL. Examination is facilitated with the use of red-free (green) light (available on most direct and indirect ophthalmoscopes). This is because the RNFL is invisible to red light but more easily visualized with shorter-wavelength (green) light that does not penetrate the RNFL and is reflected by the superficial layers of the retina. Good visualization of the RNFL requires very clear media (often not a possibility in dogs with PACG or some degree of cataract) and high contrast (which makes it difficult to observe in eyes with lightly pigmented fundi or a tapetum).

Red-Free Photography

This technique uses a fundus camera with a red-free filter and high-contrast black-and-white film or digitally acquired images that are converted to red-free and enhanced with various software packages to maximize contrast.

Confocal Scanning Laser Ophthalmoscopy and Optical Coherence Tomography

These previously discussed imaging techniques also are capable of evaluating the RNFL thickness and cross-sectional area values.

Scanning Laser Polarimetry

The RNFL is birefringent (like the cornea and to a lesser extent the lens).⁵¹ The anterior-segment signals must be removed and the latest commercially available scanning laser

polarimeter has a variable corneal compensator that allows for eye-specific compensation for anterior-segment birefringence and automated data analysis (Fig. 19). With this device, the images match the appearance of the RFNL in red-free fundus photographs, but its advantages over these techniques are its data analysis tools, especially its Nerve Fiber Layer Indicator (NFI), which provides a single number (range 1–100) that represents the overall integrity of the RFNL.

The diagnostic accuracy of the Gdx's (Laser Diagnostic Technologies, Inc, San Diego, CA, USA) NFI score in humans is very good, with a sensitivity of 91.7%, a specificity of 95%, and an overall accuracy of 93.2%.⁵² The Heidelberg retinal tomograph (Heidelberg Engineering, Heidelberg, Germany) and OCT also have been shown to provide similar accuracies for discrimination between healthy and glaucomatous eyes.⁵³ In some studies, automated analysis of measurements with the Gdx and the HRT may better discriminate between healthy and glaucomatous eyes than general ophthalmologists who subjectively grade the appearance of the optic nerve head on stereoscopic optic disc photographs.⁵⁴ A study of glaucomatous cocker spaniels also demonstrated that scanning laser polarimetry was capable of detecting changes in RNFL thickness in early stages of the disease and that it may have value in detecting progressive changes in this tissue in dogs.⁵⁵

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KEY POINTS

- Early diagnosis is critical in primary angle closure glaucoma (PACG) in dogs.
- Risk factors include breed, age, gender, presence of disease in related dogs, an abnormally formed iridocorneal angle, increased intraocular pressure, and a narrowed or closed ciliary cleft.
- Diagnosis depends on careful ophthalmic examination, particularly of the optic nerve and iridociliary angle if possible, tonometry, and other forms of imaging, such as anterior-segment ultrasound.
- PACG is a bilateral disease, so prophylactic therapy should be initiated immediately after diagnosis in the fellow, nonaffected eye of dogs with PACG.

Fig. 1.

Chronic POAG in a beagle. (A) Both pupils are dilated and IOP is increased in both eyes to approximately 50 mm Hg. (B) Fundus photograph of the same dog. The optic disc is depressed from the surface of the fundus (cupped), has little myelin and is darker than normal. The area surrounding the disc has altered reflectivity. (*From* Miller PE. The glaucomas. In: Maggs DJ, Miller PE, Ofri R, editors. *Slatter's fundamentals of veterinary ophthalmology*. 5th edition. St Louis (MO): Elsevier; 2013. p. 259; with permission.)

Fig. 2.

Primary open angle glaucoma in the beagle (same dog as in Fig. 1). (A) The iridocorneal angle is gonioscopically relatively open. (B) High-resolution ultrasound image of the anterior segment. Note that the iris does not have the same configuration as in PACG (see Fig. 3) and that the ciliary cleft is still open (*arrow*). (From Miller PE. The glaucomas. In: Maggs DJ, Miller PE, Ofri R, editors. *Slatter's fundamentals of veterinary ophthalmology*. 5th edition. St Louis (MO): Elsevier; 2013. p. 259; with permission.)

Fig. 3.

Acute PACG in an American cocker spaniel. (A) This disorder first manifests as a unilateral disease, but both eyes are typically ultimately affected. (B) A closed iridocorneal angle on gonioscopy. (C) In the acute stages, the optic disc is pale (poorly perfused) and there is subtle peripapillary edema (*arrows*). In the latter stages, it looks similar to that seen in Fig. 1. (From Miller PE. The glaucomas. In: Maggs DJ, Miller PE, Ofri R, editors. *Slatter's fundamentals of veterinary ophthalmology*. 5th edition. St Louis (MO): Elsevier; 2013. p. 258; with permission.)

Fig. 4.

(A) High-resolution ultrasound image of a normal eye. AC, anterior chamber; C, cornea; CB, ciliary body; I, iris; L, lens. White arrows outline the ciliary cleft. (B) An eye with acute PACG. Note the sigmoidal shape of the iris, increased contact of the peripheral iris with the cornea (*black arrow*) and collapse of the ciliary cleft (*white arrow*). (From Miller PE. The glaucomas. In: Maggs DJ, Miller PE, Ofri R, editors. *Slatter's fundamentals of veterinary ophthalmology*. 5th edition. St Louis (MO): Elsevier; 2013. p. 258; with permission.)

Fig. 5.

Goniophotograph of a normal dog. A, pupil; B, iris; C, pectinate ligament strands (*thin brown lines*); D, bluish-white zone of the trabecular meshwork; E, deep pigmented zone; F, superficial pigmented zone; G, cornea. (From Miller PE. The glaucomas. In: Maggs DJ, Miller PE, Ofri R, editors. *Slatter's fundamentals of veterinary ophthalmology*. 5th edition. St Louis (MO): Elsevier; 2013. p. 250; with permission.)

Fig. 6. Marked PLD characterized by broad sheets of tissue. Although IOP was within normal limits, aqueous humor can exit the eye only via a few small “flow holes” (*arrows*) in the sheets. (*From* Miller PE. The glaucomas. In: Maggs DJ, Miller PE, Ofri R, editors. Slatter’s fundamentals of veterinary ophthalmology. 5th edition. St Louis (MO): Elsevier; 2013. p. 251; with permission.)

Fig. 7.

Proposed reverse pupillary block theory of the mechanism of PACG in dogs. See text for complete description. PLD holds the peripheral iris in close contact with the peripheral cornea and prevents the angle from opening farther when anterior chamber pressures increase. Stress or excitement puts the pupil into the midrange to dilated position and also increases the choroidal pulse pressure. The increase in choroidal pulse pressure forces small aliquots of aqueous humor into the anterior chamber, which results in slightly higher pressure in the anterior chamber than in the posterior chamber (*arrows*). This additional fluid cannot escape via the drainage angle and the pressure differential forces the iris into tighter contact with the anterior lens capsule creating pupil block (A), which prevents aqueous from returning to the posterior chamber. Prolonged increases in IOP lead to peripheral anterior synechia (B) and a further impediment to aqueous outflow. (*From Miller PE. The glaucomas. In: Maggs DJ, Miller PE, Ofri R, editors. Slatter's fundamentals of veterinary ophthalmology. 5th edition. St Louis (MO): Elsevier; 2013. p. 260; with permission.*)

Fig. 8.
Acute PACG in a great Dane. Notice the marked episcleral vascular congestion, diffuse corneal edema, and midrange to dilated pupil.

Fig. 9.

Optic disc cupping in PACG. Most retinal vessels disappear at the disc edge. The center of the disc is in focus below the level of the retinal surface and is grayish in color. There is also a peripapillary ring of altered retinal reflectivity. (*Courtesy of Christopher J. Murphy, DVM, PhD, University of California, Davis, Davis, CA.*)

Fig. 10. Chronic PACG in a dog. The eye is enlarged (buphthalmic), irreversibly blind, and has a subluxated lens.

Fig. 11. Tonometers commonly used in the diagnosis of PACG. Far left, Schiotz indentation tonometer; middle, Tono-Pen Vet applanation tonometer; far right, TonoVet rebound tonometer.

Fig. 12.
Incorrect technique for opening the eyelids for tonometry. The lids are being held open with pressure on the globe, thereby artificially increasing IOP.

Fig. 13.
Proper technique for holding the eyelids open. The lids are opened from over the boney orbital rim thereby avoiding pressure on the globe.

Fig. 14.

View through a Goldmann 3-mirror gonioprism. The central lens allows for viewing of the fundus with a slit-lamp biomicroscope. The 3 surrounding mirrors have different degrees of angulation so as to facilitate examination of different structures within the irido-corneal angle.

Fig. 15.

Schematic drawing of a grading scheme for the width of the iridocorneal angle. The ratio of the width of the anterior opening of the ciliary cleft (A) and the distance from the origin of the pectinate ligaments to the anterior surface of the cornea (B) is estimated. Also shown are the pupil (C), iris (D), pectinate ligament (E), deep pigmented zone (F), superficial pigmented zone (G), and cornea (H). (*From Ekesten B, Narfström K. Correlation of morphologic features of the iridocorneal angle to intraocular pressure in Samoyeds. Am J Vet Res 1991;52:1875; with permission.*)

Fig. 16.

AS-OCT image of a dog. This technique uses near-infrared light instead of sound to image the iridocorneal angle. As such, visualization of the ciliary body and lens are not as apparent as that observed on high-resolution ultrasound (see Figs. 2 and 4 for comparison). (*Courtesy of Carol Rasmussen, MS, University of Wisconsin-Madison, Madison, WI.*)

Fig. 17. Confocal Scanning Laser Ophthalmoscopy of a dog. A laser is used to image the optic disc (a), tapetum lucidum (b), nontapetal zone (c), retinal arterioles (d), and retina venules (e). (From Rosolen SG, Saint-Macary G, Gautier V, et al. Ocular fundus images with confocal scanning laser ophthalmoscopy in the dog, monkey and minipig. *Vet Ophthalmol* 2001;4(1): 42; with permission.)

Fig. 18.

Spectral-domain OCT image of a normal dog. This instrument provides high-resolution images of the posterior segment and includes an adjustable 3-dimensional view of the optic disc and surrounding retina (*upper left*), an ophthalmoscopic view of the optic disc denoting where line scans were obtained (*upper middle*), a cross-sectional view through the optic disc at the selected line scan (*upper right*), circular scans around the optic disc (*lower left*), cross-sectional views of the retina (*lower middle*), and color-coded thickness mapping of the optic disc or retina (*lower right*). (Courtesy of Carol Rasmussen, MS, University of Wisconsin-Madison, Madison, WI.)

Fig. 19.

Image from a normal eye with a scanning laser polarimeter (Gdx). Images include a fundus image from the scanned area and a color-coded thickness retardation map of the RNFL that shows thinner areas in blue and black and thicker areas in red, orange, and yellow. A variety of printouts are also presented. (*From Garcia-Sánchez GA, Gil-Carrasco F, Román JJ, et al. Measurement of the retinal nerve fiber layer thickness in normal and glaucomatous Cocker Spaniels by scanning laser polarimetry. Vet Ophthalmol 2007;10 Suppl 1:81; with permission.*)