Intraocular pressure measurements obtained as part of a comprehensive geriatric health examination from cats seven years of age or older

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**Objective**—To determine intraocular pressure (IOP) in cats ≥ 7 years of age undergoing a routine comprehensive geriatric health examination.

**Design**—Prospective study.

**Animals**—538 cats (1,068 eyes).

**Procedure**—IOP was measured by applanation tonometry following instillation of 0.5% proparacaine.

**Results**—Mean ± SD IOP for all eyes was 12.3 ± 4.0 mm Hg (range, 4 to 31 mm Hg). Mean age was 12.3 ± 2.9 years. Intraocular pressure did not vary significantly cross-sectionally with age. However, in 78 cats, IOP was measured more than once, and follow-up measurements were significantly less than initial measurements (mean time between measurements, 9.4 ± 3.0 months). The most useful tonometric criteria for identifying ocular abnormalities on the basis of IOP was an IOP ≥ 25 mm Hg (mean ± 3 SD) or a difference in IOP between eyes ≥ 12 mm Hg. Eight cats met these criteria, and 5 of these cats had ophthalmic abnormalities. Low IOP was a nonspecific indicator of the presence of ocular abnormalities, as 111 cats had an IOP ≤ 8 mm Hg, but only 2 had uveitis.

**Conclusions and Clinical Relevance**—Results suggest that IOP measurements can be a useful addition to a comprehensive geriatric health examination in cats ≥ 7 years of age, especially when combined with an ophthalmic examination. Cats without ocular abnormalities that have IOP ≥ 25 mm Hg or a ≥ 12 mm Hg difference in IOP between eyes should have tonometry repeated or be referred to an ophthalmologist for further evaluation before beginning antiglaucoma treatment. (J Am Vet Med Assoc 2001;219:1406–1410)

Glaucoma may be defined as partial or complete visual impairment secondary to damage of the optic nerve head by intraocular pressure (IOP)."Ophthalmoscopically, this damage is seen as posterior bowing or "cupping" of the optic nerve head as mechanical compression and ischemia of the optic nerve at the lamina cribrosa leads to retinal ganglion cell death. As these cells die, they may also release glutamate and other compounds that can induce a vicious cycle of apoptotic cell death in previously unaffected neighboring retinal ganglion cells, even if IOP returns to normal. Although in most patients distortion of the lamina cribrosa and degeneration of the optic nerve begin only when IOP is abnormally high, an unusually flexible lamina cribrosa may be distorted even by normal IOP thereby initiating the glaucomatous cascade of ganglion cell death and progressive vision loss (eg, normal-tension glaucoma). In yet other patients, the lamina cribrosa may be unusually resilient, allowing the optic nerve to tolerate an IOP in excess of the upper reference limit without vision loss (eg, ocular hypertension). Therefore, IOP is a major, but not the sole, risk factor for glaucomatous optic neuropathy, and the exact IOP at which damage occurs varies from individual to individual.

In cats, glaucoma is typically characterized by insidious increases in IOP with minimal, if any, overt clinical signs until the disease is quite advanced and severe vision loss has occurred. Unlike the case in dogs, however, acute ocular congestion is rare in cats with glaucoma, and the most common clinical signs are pupillary dilation, mild conjunctival hyperemia, subtle corneal edema, and buphthalmia if the increase in IOP is chronic. Both primary and secondary glaucoma reportedly can develop in cats, but secondary glaucoma, in which IOP usually slowly increases as a sequela of disorders such as chronic uveitis and intraocular neoplasia, far outrisps primary glaucoma in frequency. Recently, posterior misdirection of aqueous humor into the vitreal space with subsequent anterior shifting of the lens-iris diaphragm and slowly increasing IOP has also been reported as a cause of glaucoma in older cats. This condition is characterized clinically by relative pupillary dilation, an anterior chamber that appears abnormally shallow during slit-lamp biomicroscopy because of the anterior location of the lens and iris but without other evidence of anterior lens luxation, variable increases in IOP, and glaucomatous optic nerve head changes.

The slow and initially subtle increase in IOP associated with most forms of glaucoma in cats and the possibility that retinal ganglion cell death may become self-perpetuating if not identified early in the course of the disease suggest that it may be beneficial to include IOP screening as part of a routine comprehensive health examination in older cats. Additionally, although a preliminary report suggested IOP did not vary with age in cats, age significantly affects IOP in humans, and the effect of age on IOP in healthy older cats has not been definitively determined. Therefore, the purposes of the study reported here were to determine IOP in cats ≥ 7 years of age undergoing a routine comprehensive geriatric health examination, to identify clinically useful criteria for interpreting IOP mea-
Materials and Methods

Results of applanation tonometry performed on cats ≥ 7 years of age during comprehensive geriatric health examinations at a private practice in Madison, Wis, between March 1999 and July 2000 were used in the study. Tonometry was performed by trained technical staff members at the practice with a commercially available tonometer in accordance with the manufacturer’s recommendations. All measurements were performed between 8 AM and 7 PM and were obtained after application of 0.5% proparacaine. Completion of a geriatric health examination was recommended to owners of all cats ≥ 7 years of age examined at the practice, regardless of the physical health of the cats. In addition to tonometry, the geriatric health examination included a complete physical examination, CBC, serum biochemical analyses (19 tests), measurement of serum thyroxine concentration, urinalysis, and measurement of systemic blood pressure. Cats that required chemical restraint to be examined and cats receiving antiglaucoma medications were excluded. Cats in which IOP was outside of the previously reported reference range for the original model of this tonometer and in which results of an ophthalmic examination were abnormal were further examined by a board-certified veterinary ophthalmologist.

Analysis of variance was used to determine whether initial IOP measurements varied with age of the cats (cross-sectional analysis). A Student t-test was used to compare measurements between male and female cats. In 78 cats (154 eyes), follow-up IOP measurements were obtained several months or more after the initial measurements, and a paired Student t-test was used to compare follow-up measurements with initial measurements in these cats (longitudinal analysis). A paired Student t-test was also used to compare measurements from the right and left eyes of each cat. For all analyses, values of P < 0.05 were considered significant.

Results

Intraocular pressure was measured in 1,068 eyes of 538 cats ≥ 7 years of age (Fig 1), including 236 castrated male and 302 spayed female cats. Mean ± SD age of the cats was 12.3 ± 2.9 years (median, 12 years; range, 7 to 22 years), and mean age of the female cats (12.3 ± 3.0 years) was not significantly different from that of the male cats (12.4 ± 2.8 years). Mean IOP for the female cats (mean ± SD, 12.8 ± 4.1 mm Hg) was significantly (P < 0.001) greater than that for the male cats (11.7 ± 3.7 mm Hg); however, this difference was clinically negligible and within the expected variation for this tonometer. Mean IOP in the right eye was not significantly different from that of the left eye (11.9 ± 3.8 mm Hg vs 11.5 ± 3.7 mm Hg for males; 12.9 ± 4.1 mm Hg vs 12.7 ± 4.1 mm Hg for females). Mean ± SD IOP for all cats was 12.3 ± 4.0 mm Hg (median, 12 mm Hg; range, 4 to 31 mm Hg), and IOP in the right eye (12.4 ± 4.0 mm Hg) was not significantly different from that of the left eye (12.1 ± 3.9 mm Hg).

Mean IOP did not vary significantly with age of the cat (Table 1). However, follow-up IOP measurements were obtained in 78 cats (154 eyes) a mean of 9.4 ± 3.0 months after the first measurements, and follow-up measurements (10.9 ± 4.0 mm Hg) for these cats were significantly (P < 0.001) less than initial measurements (12.9 ± 4.0 mm Hg). For many of these 78 cats, follow-up IOP measurements were obtained because the cats had 1 or more chronic systemic diseases that required in-depth monitoring.

Various criteria based on IOP alone were examined to determine whether they could be used to identify cats with ophthalmic abnormalities. The following criteria were examined: IOP outside of the previously reported reference range for the original model of the tonometer (this reference range was established using generally younger, healthy cats); IOP greater than the mean + 2 SD or less than the mean − 2 SD for all cats in the study (ie, so-called age- and tonometer-adjusted reference values); IOP greater than the mean + 3 SD or less than the mean − 3 SD for all cats in the study; difference in IOP between the right and left eyes; and various combinations of the above criteria.

Of the 538 cats included in the study, 6 (9 eyes) had ophthalmic abnormalities and met 1 or more of the previously described IOP-based criteria. One cat (cat 1) had a unilateral complete resorbing cataract and presumed subclinical lens-induced uveitis (IOP, 6 mm Hg); the other eye appeared normal (IOP, 14 mm Hg). One cat (cat 2) had unilateral panuveitis and retinal detachment (IOP, 7 mm Hg) in 1 eye and aqueous humor misdirection with a uniformly shallow anterior chamber (IOP, 14 mm Hg).

Table 1—Intraocular pressures (IOP) obtained during comprehensive geriatric health examinations of 538 cats ≥ 7 years of age. The IOP did not significantly vary with age when analyzed cross-sectionally. Longitudinal analysis of repeated measurements from 78 cats, however, indicated that IOP decreased with age (P < 0.001)

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>No. of eyes (No. of cats)</th>
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<tr>
<td>7</td>
<td>21 (11)</td>
<td>11.4 ± 4.02</td>
</tr>
<tr>
<td>8</td>
<td>48 (24)</td>
<td>13.0 ± 3.89</td>
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<tr>
<td>9</td>
<td>96 (48)</td>
<td>12.1 ± 3.37</td>
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<td>10</td>
<td>171 (88)</td>
<td>12.1 ± 4.00</td>
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<td>11</td>
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<td>12</td>
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<td>12.6 ± 3.80</td>
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<td>12.2 ± 3.55</td>
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<td>22</td>
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</tr>
<tr>
<td>Total</td>
<td>1,068 (538)</td>
<td>12.3 ± 4.00</td>
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Figure 1—Intraocular pressure (IOP) in 1,068 eyes of 538 cats ≥ 7 years of age undergoing a comprehensive geriatric health examination. Mean ± SD IOP was 12.3 ± 4.0 mm Hg.
chamber but no evidence of lens luxation in the other eye (IOP 19 mm Hg). Two cats (cats 3 and 4) had bilateral aequous humor misdirection (IOP, 17 and 26 mm Hg in cat 3; 21 and 28 mm Hg in cat 4), and 1 cat (cat 5) had unilateral aequous humor misdirection (IOP 24 mm Hg in the affected eye and 12 mm Hg in the other eye). One cat (cat 6) had a chronic resorbing subluxated cataract with a large amount of vitreous in the anterior chamber and drainage apparatus (IOP, 31 mm Hg); the other eye appeared normal (IOP, 18 mm Hg).

Cats with IOP outside the reported reference range (9 to 31 mm Hg)—Overall, 158 eyes of 111 cats (20.6% of all cats) had an initial IOP ≤ 8 mm Hg, 84 eyes of 60 cats (11.2%) had an initial IOP ≤ 7 mm Hg, 51 eyes of 35 cats (6.9%) had an initial IOP ≤ 6 mm Hg, 19 eyes of 13 cats (2.4%) had an initial IOP ≤ 5 mm Hg, and 4 eyes of 4 cats (0.7%) had an initial IOP of 4 mm Hg (Fig 1). Ophthalmic examination of the 111 cats with IOP ≤ 8 mm Hg revealed 1 eye (cat 1; IOP, 6 mm Hg) that had a complete resorbing cataract and presumed subclincal lens-induced uveitis and another eye (cat 2; IOP, 7 mm Hg) that had overt panuveitis and retinal detachment. The remaining 109 cats were free of grossly detectable intracellular disorders except for nuclear sclerosis, senile iris atrophy, and inactive chorioretinal scars or incipient cataracts. An unspecified but large number of these cats, however, had a variety of chronic systemic metabolic disorders such as renal failure, hyperthyroidism, systemic hypertension, and idiopathic inflammatory bowel disease. None of the cats in the study had an initial IOP > 31 mm Hg, and this criterion did not identify cats 3, 4, 5, and 6 as abnormal.

Cats with IOP outside the range of mean ± 2 SD or mean ± 3 SD—for all cats in the study, mean IOP + 2 SD was 21 mm Hg, and 42 eyes of 30 cats (5.6%) had an IOP ≥ 21 mm Hg. Of these 30 cats, 26 (33 eyes) did not have any ophthalmic abnormalities. This criterion correctly identified as normal 3 cats (4 eyes; cats 3, 4, and 5) with aqueous humor misdirection and 1 cat (1 eye; cat 6) with a chronic resorbing subluxated cataract with a large amount of vitreous in the anterior chamber and drainage apparatus (IOP 31 mm Hg). One cat (cat 2) with panuveitis in 1 eye and aqueous humor misdirection in the other eye (IOP, 19 mm Hg) was not identified with this criterion. In addition, 1 eye (IOP, 17 mm Hg) in 1 cat (cat 3) with bilateral aqueous humor misdirection was not identified with this criterion, but the IOP of 17 mm Hg would not be expected to threaten vision in this eye, and the cat was correctly identified as having ophthalmic abnormalities, because IOP was 26 mm Hg in the other eye.

Mean IOP + 3 SD was 25 mm Hg, and 6 eyes of 6 cats (1.1%) had an IOP ≥ 25 mm Hg. Of these 6 cats, 3 (3 eyes) did not have any ophthalmic abnormalities. In all 3 cats, subsequent IOP measurements were ≤ 20 mm Hg, and the eyes remained ophthalmically normal. Two cats (2 eyes; cats 3 and 4) had aqueous humor misdirection; the condition was bilateral in both cats (IOP, 26 and 17 mm Hg in 1 cat and 28 and 21 mm Hg in the other). The third cat (1 eye; cat 6) had a chronic resorbing subluxated cataract with a large amount of vitreous in the anterior chamber and drainage apparatus (IOP 31 mm Hg in the affected eye).
and 18 mm Hg in the other eye). The criterion of an IOP difference ≥ 12 mm Hg between the 2 eyes did not identify cats 1, 3, and 4 as abnormal.

Combinations of criteria—Eight (1.5%) cats had an IOP ≥ 25 mm Hg (mean + 3 SD) or a pressure difference between eyes ≥ 12 mm Hg. Three of the 8 were ophthalmically normal and had initial IOP of 15 and 27, 25 and 22, and 27 and 23 mm Hg. All 3 of these cats were ophthalmically normal during follow-up examinations, and subsequent IOP measurements were ≤ 20 mm Hg. Two of the 8 cats (cats 3 and 4) had bilateral aqueous humor misdirection (IOP, 28 and 21 and 26 and 17 mm Hg), and 1 (cat 5) had unilateral aqueous humor misdirection (IOP, 24 and 12 mm Hg). One cat (cat 6) had a unilateral chronic resorbing subluxated cataract with a large amount of vitreous in the anterior chamber and drainage apparatus. One cat (cat 2) had panuveitis and retinal detachment in 1 eye (IOP, 7 mm Hg) and a uniformly shallow anterior chamber secondary to aqueous humor misdirection (IOP, 19 mm Hg) in the other eye. The cat (cat 1) with a unilateral complete resorbing cataract and panuveitis was not identified with this combination of criteria.

Overall, 6 eyes of 4 cats (0.74%) had aqueous humor misdirection. In these eyes, the initial IOP ranged from 17 to 28 mm Hg, and subsequent IOP was higher, unless antiglaucoma treatment was given. Tonometry readily permitted cats with mydriasis secondary to senile iris atrophy to be differentiated from cats with abnormally high IOP.

Discussion
Results of the present study suggest that measurement of the IOP can be a useful addition to a comprehensive geriatric health examination in cats ≥ 7 years of age, especially when combined with an ophthalmic examination. Using a combination of IOP ≥ 25 mm Hg (mean + 3 SD) or difference in IOP between eyes ≥ 12 mm Hg would have allowed us to identify 5 of the 6 cats with ophthalmic abnormalities that would alter IOP. The cat that was not identified had abnormally low IOP secondary to presumed lens-induced uveitis and did not have an abnormally high IOP. Although tonometry alone would not have been useful in identifying as abnormal cats with ocular diseases such as conjunctivitis and some keratopathies that do not alter IOP, it did allow more serious vision-threatening IOP increases to be ruled out in these animals with “red eyes.” The combined screening criteria also correctly identified all 5 cats (cats 2 to 6) as having abnormally high IOP prior to vision loss and thereby allowed careful monitoring and earlier therapeutic intervention in these cats. This afforded the clinician the opportunity to intervene before the glaucomatous apoptotic cell death cascade was initiated and irreversible vision loss occurred. The slightly higher IOP in female versus male cats was similar to findings in humans, but the difference was so small as to be of little clinical consequence in developing screening criteria.

The most common ophthalmic abnormality in this study was aqueous humor misdirection, which affected 4 of the 538 cats (6 eyes). In contrast to cats with spurious IOP elevations, the IOP remained high or increased in cats with aqueous humor misdirection. Tonometry allowed pupillary dilation secondary to glaucoma or aqueous humor misdirection to be differentiated from mydriasis attributable to apprehension or senile iris atrophy. The latter was particularly common in the cats in this study, and without tonometry it would have been difficult to differentiate these innocuous causes of mydriasis from mydriasis secondary to glaucoma. Therefore, not only did tonometry allow cats at risk of vision loss because of high IOP to be recognized and treated early, it also allowed glaucoma to be ruled out in many more cats with clinical signs, such as mydriasis, anisocoria, and reduced pupillary light reflexes, that were otherwise consistent with glaucoma.

Intraocular pressure was artificially high (≥ 25 mm Hg) in 3 cats in this study without any ophthalmic abnormalities, indicating that a single abnormal IOP measurement in the absence of other ophthalmic abnormalities is insufficient for a diagnosis of glaucoma in cats. Undoubtedly these spurious elevations were attributable to the fractious nature of the cats or to errors in technique that resulted in application of excessive tension on the globe, eyelids, or neck. It is also possible that IOP measurements varied slightly among the technicians who performed the procedure or with the individuals restraining the cats for the procedure. Therefore, cats that have an IOP ≥ 25 mm Hg or a difference in IOP between eyes ≥ 12 mm Hg but do not have any ophthalmic abnormalities or changes in the optic nerve head may have ocular hypertension or a falsely high IOP. Such cats should undergo a detailed ophthalmic examination, including scrutiny of the optic nerve head for glaucomatous changes, and tonometry should be repeated within a few weeks. If the IOP elevation persists or a detailed ophthalmic examination is not possible, referral to an ophthalmologist for a more in-depth assessment before initiating antiglaucoma treatment would be warranted.

Mean IOP (12.3 mm Hg) for cats in the present study, all of which were ≥ 7 years of age, was lower than IOP measured with an earlier model of the same tonometer, previously reported for younger healthy cats (approx 20 mm Hg). This suggests that IOP decreases with age in cats or that the 2 models of the tonometer yield very different estimates of IOP. However, in view of the accuracy of these tonometers, it would seem unlikely that the 2 models would differ to such a large degree. We did not find a significant difference in IOP among cats of various ages in the cross-sectional analysis in the present study, which was similar to results of a previous study. However, in the longitudinal analysis in the present study, in which IOP was measured a second time a mean of 9.4 months after the initial measurement, IOP did change significantly with age. A similar longitudinal decrease in IOP with age has been reported for humans, even though cross-sectional analyses in humans suggest that IOP may remain stable or actually increase up to 60 to 70 years of age. This discrepancy is believed to be the result of the general decrease in IOP with age in most
individuals being masked by a substantial increase in IOP in a subpopulation of older people with systemic hypertension or obesity. A similar masking may occur in cats, as IOP in cats in the present study was not normally distributed but skewed toward high IOP measurements in a small subset of cats.

It is unlikely that the reduction in IOP over time in the cats in the present report represents a statistical artifact such as regression toward the mean, because the trend was away from the mean IOP, not toward it. Although it is possible that the decrease in IOP with age in individual cats represents a drift in the internal calibration standard of the tonometer over time, the instrument indicated that it was calibrated properly prior to use, and this type of error has not been previously reported for this tonometer. It is also unlikely that this represents an improvement in tonometric technique of the staff members, because initial measurements made contemporaneous with follow-up measurements were not different from initial measurements made in cats that were followed-up. Importantly, many of the cats that were examined more than once were followed-up because of 1 or more systemic health problems that were identified during the first examination. It is unknown whether the decrease in IOP over time in this subset of cats simply reflects normal aging changes or otherwise poor systemic health, but overt uveitis was not detected in these cats.

Tonometry was a poor method of identifying anterior uveitis in these older cats, perhaps because IOP normally decreases with age in cats. A substantial number of cats ≥ 7 years of age in this study had IOP < 8 mm Hg, and in some cats the IOP was as low as 4 or 5 mm Hg without any overt signs of anterior uveitis. Low IOP presumably secondary to mild uveitis was seen in 2 cats (1 cat with an IOP of 6 mm Hg and a resorbing cataract and another cat with an IOP of 7 mm Hg and overt unilateral panuveitis), but overt uveitis was not detected in the remaining cats with IOP ≤ 7 mm Hg. Therefore, low IOP in and of itself should not be regarded as a specific feature of clinically relevant uveitis in older cats.

Tono-Pen XL, Mentor Ophthalmics, Norwell, Mass.

References