Published in final edited form as:

Vet Ophthalmol. 2013 March ; 16(2): 111–118. doi:10.1111/j.1463-5224.2012.01038.x.

Validation of the TonoVetR Rebound Tonometer in Normal and Glaucomatous Cats

Gillian J McLellan^{a,b,c}, Jeremy P. Kemmerling^a, and Julie A Kiland^a

^aDept. of Ophthalmology & Visual Sciences, University of Wisconsin - Madison, WI 53792, USA

^bDept. of Surgical Sciences, University of Wisconsin - Madison, WI 53792, USA

^cEye Research Institute, University of Wisconsin - Madison, WI 53792, USA

Abstract

Objective—To validate intraocular pressure (IOP) readings obtained in cats with the TonoVet[®] tonometer.

Animal Studied—IOP readings obtained with the TonoVet[®] were compared to IOP readings determined by manometry and by the Tono-Pen XL in 1 normal cat and 2 glaucomatous cats. TonoVet[®] and Tono-Pen XL readings were also compared in a further 6 normal and 9 glaucomatous cats.

Procedures—The anterior chambers of both eyes of 3 anesthetized cats were cannulated and IOP was varied manometrically, first increasing from 5 to 70 mm Hg in 5 mm Hg increments, then decreasing from 70 to 10 mm Hg in 10 mm Hg decrements. At each point, two observers obtained three readings each from both eyes, with both the TonoVet[®] and Tono-Pen XL. IOP was measured weekly for 8 weeks with both tonometers in 6 normal and 9 glaucomatous unselected cats. Data were analyzed by linear regression. Comparisons between tonometers and observers were made by paired student t-test.

Results—The TonoVet[®] was significantly more accurate than the Tono-Pen XL ($p=0.001$), correlating much more strongly with manometric IOP. In the clinical setting, the Tono-Pen XL, underestimated IOP when compared with the TonoVet[®].

Conclusions—Both the TonoVet[®] and Tono-Pen XL provide reproducible IOP measurements in cats, however the TonoVet[®] provides readings much closer to the true IOP than the Tono-Pen XL. The TonoVet[®] is superior in accuracy to the Tono-Pen XL for detection of ocular hypertension and/or glaucoma in cats in a clinical setting.

Keywords

Intraocular pressure; Glaucoma; Cat; Tono-Pen XL; TonoVet; manometry

Introduction

The “glaucomas” represent a group of disorders of diverse causes that are characterized by a loss of vision due to damage to the optic nerve. Glaucoma in cats is most often secondary to other intraocular disease, particularly uveitis or neoplasia.¹ Feline glaucoma is generally insidious in onset and affected cats are often presented late in the course of the disease and it is likely that glaucoma is under-diagnosed in this species.^{2–6}

High intraocular pressure (IOP) is the most significant risk factor for the development of glaucoma in both humans and cats¹ and appears to be predictive of disease progression; the higher the IOP, the greater the likelihood for progressive optic nerve damage to occur.⁷ Despite advances in our understanding of the pathogenesis of glaucoma, there is currently no cure for the disease and therapies directed at lowering IOP remain the standard of care for animals and humans with glaucoma.¹ To allow the diagnosis of ocular hypertension and glaucoma, as well as monitor IOP in response to treatment and progression of disease, it is important that devices are available that provide accurate and precise measurements of IOP. Unfortunately, some commonly used tonometers have significant limitations in cats.

Over the past 25 years, portable hand-held tonometers such as the Tono-Pen XL have been created that are readily applicable to humans, veterinary patients, and laboratory animals. The Tono-Pen operates on the same basic principle as Goldmann applanation tonometry⁸ and in a study in horses has been shown to have comparable accuracy both clinically and *in vitro* to larger applanation tonometers such as the MacKay-Marg.⁹ However, in a study involving isolated cat eyes, the MacKay-Marg tonometer was found to be more accurate at estimating IOP within the normal range than the Tono-Pen.¹⁰ Two independent studies in cats concluded that the Tono-Pen XL, a later iteration of the TonoPen, substantially underestimated actual IOPs at all pressure settings when compared with manometry.^{11,12} A recent study by Rusanen et. al. found that the Tono-Pen XLTM underestimated IOPs cat eyes *in vitro* at manometrically measured pressures >30mm Hg.¹³ Despite these limitations, the Tono-Pen XL has been widely adopted by veterinary clinicians for IOP measurement in cats.

More recently, hand-held rebound (“induction-impact”) tonometers such as the TonoVet[®] and ICare[®] have become available. Rebound tonometry calculates IOP based on the deceleration of a moving pin as it comes into contact with the cornea. The pin’s motion is monitored by a solenoid in the tonometer, which also serves to propel the magnetic pin.¹⁴ Rebound tonometry has been found to provide reliable and accurate IOP measurements in humans^{15,16}, dogs^{17–19}, horses¹⁸, rabbits²⁰, mice²¹, birds of prey^{22,23}, monkeys^{24,25}, as well as cats.¹³

The TonoVet[®] is of particular value to veterinary clinicians and those using animal models in research because it is portable, user-friendly and, as the lightweight probe makes only very brief corneal contact, requires no topical anesthesia. Before adopting this tonometer to obtain IOP measurements in cats in a clinical or research setting, validation in normal and glaucomatous cats is essential. At the time our study was performed, results from testing in cats had yet to be published. To our knowledge there have been no published studies determining the validity of IOP measurements obtained using the TonoVet[®] in cats with glaucoma.

The current study was therefore designed and conducted to validate use of TonoVet[®] rebound tonometry to measure IOP in both normal cats and in cats with glaucoma.

Materials and Methods

Animals and Anesthesia

A total of six normal and nine glaucomatous adult cats were studied. All cats were part of a colony maintained for the study of a recessively inherited form of congenital glaucoma. Subjects had been acclimated to their surroundings, to frequent handling, and to weekly IOP measurements taken with both the Tono-Pen XLTM (Reichert, Depew, NY) and TonoVet[®] (Icare Finland Oy, Helsinki, Finland) for a minimum of 4 weeks prior to this study. Prior to inclusion in the study, cats were determined to be free of other ocular abnormalities by slit-

lamp biomicroscopy. All experiments were performed with approval of the Institutional Animal Care and Use Committee and in accordance with the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research.

For invasive testing *in vivo* (Tono-Pen XL and TonoVet® vs. manometric IOP measurements), cats were given anti-inflammatory medication (0.2mg/kg meloxicam subcutaneously) and were subsequently anesthetized with intramuscular injections of xylazine (1–2mg/kg) and ketamine (12.5–25mg/kg). Cats were placed in sternal recumbency throughout the procedure. Stable body temperature was maintained using a warm-water heating blanket. Heart rate and blood oxygen levels were monitored using a pulse oximeter. In contrast, cats were not sedated for clinical evaluation of the Tono-Pen XL vs. TonoVet®.

Validation of Tono-Pen XL™ and TonoVet® vs. Manometry

Validation of the TonoVet® tonometer and Tono-Pen XL versus manometry was carried out in 1 normal and 2 glaucomatous anesthetized cats according to published methods^{25,26} with some minor modifications. The anterior chamber of each eye was cannulated with a branched 26-gauge needle. One arm of each needle was attached, via polyethylene tubing, to a vertically adjustable reservoir filled with degassed Bárány's mock aqueous humor²⁷; the other arm was attached, also via polyethylene tubing, to a pressure transducer. The pressure transducer was connected to an amplifier and to a computer for voltage monitoring, and to a chart recorder. This allowed manometric IOP to be verified by the computer and chart recorder throughout the procedure. The reservoir of mock aqueous humor was raised and lowered to control the intraocular pressure. The IOP was set initially to 5 mm Hg and increased by 5 mm Hg increments to 70 mm Hg. IOP was then decreased by 10 mm Hg decrements back down to 10 mm Hg. Two separate unmasked operators each obtained three consecutive IOP readings in both eyes with the TonoVet® and then with the Tono-Pen XL at each 5 mm Hg increment and at each 10 mm Hg decrement so that a total of twelve readings were obtained at each increment or decrement. Readings were obtained from the axial cornea with the TonoVet® probe tip held ~4mm from the corneal surface. Care was taken to ensure that the point of contact was perpendicular to the corneal surface. (Figure 1) Only readings with 5% variance as indicated on the instrument display were recorded for the Tono-Pen XL™. Similarly, only readings within the range of acceptable standard deviation per the manufacturer (2.5 mmHg) for the TonoVet® (as indicated by no bar or one bar "down" on the instrument display) were recorded. At the conclusion of the experiment, needles were removed from the anterior chamber and ophthalmic ointment applied to each eye. Following recovery from anesthesia, animals were returned to the colony and were observed daily for 3 days following the procedure to ensure no signs of ocular inflammation were evident.

Microsoft Excel was used to carry out linear regression analyses, and Instat v.3.06 (Graphpad Software Inc., La Jolla, CA) was used for comparisons through t-tests, with a p value of 0.05 or less considered significant.

Clinical Evaluation of Tono-Pen XL™ vs. TonoVet®

In order to obtain a data set spanning a wide range of IOPs under clinically relevant conditions, IOP was measured weekly for 8 weeks in a further 7 glaucomatous and 5 normal cats. Triplicate IOP readings were obtained in each eye, by a single observer using both tonometers consecutively. TonoVet® readings were obtained first, followed by the TonoPen-XL™. Topical anesthetic(0.5% Proparacaine HCl, Bausch & Lomb, Inc., Tampa, FL) was instilled immediately prior to acquiring TonoPen-XL readings. Animals were gently manually restrained in a seated position or sternal recumbency. No attempt was made

to randomize the order of eyes tested, with readings typically obtained for the right eye first, and observers were not masked as to the glaucoma status of animals tested.

Results

Validation of Tono-Pen XL™ and TonoVet® vs. Manometry

The data collected showed linear trends for both the TonoVet® and Tono-Pen XL™ tonometers (Figure 2) when values were plotted against manometric IOP, however, the TonoVet® readings were significantly closer to the true IOP than readings obtained with the Tono-Pen XL™, especially at IOPs above 20 mm Hg [(mean±SD) slope for 3 cats=1.03±0.03 and 0.62±0.04, respectively; p=0.001] (Figure 2). No significant difference was observed when comparing data from left versus right eyes for either tonometer and slopes were consistent between individual cats, irrespective of disease status (data not shown). While no significant difference was observed when comparing TonoVet® readings obtained by different operators, readings obtained with the Tono-Pen XL™ by the more experienced operator (a board-certified veterinary ophthalmologist, GJM) were slightly more accurate (mean slope = 0.64±0.05) than those readings taken by the less experienced operator (a recently trained undergraduate student, JPK; mean slope =0.60±0.04; p=0.021). Regardless of level of experience, values obtained with the TonoVet® were significantly more accurate when compared to the readings taken with the TonoPen-XL™ (p=0.003 and p=0.001) for both operators. Data for right and left eyes, operators, and composite increments/decrements were pooled in subsequent statistical analyses for overall determination of precision and accuracy of the Tono-Pen XL™ and TonoVet®. While differences between the readings obtained as either increments or decrements were not significant for either tonometer, the performance of the TonoVet® tonometer was subtly improved during the decremental phase of the experiment, as IOP was progressively lowered from high values (Figure 3). Bland Altman plots demonstrated a slight trend towards increasing overestimation of IOP by the TonoVet® tonometer at higher IOPs, as well as increasing variance particularly between 40–60 mm Hg. (Figure 4)

Clinical Comparison of Tono-Pen XL™ and. TonoVet®

Overall the TonoVet® was easier to use and was better tolerated by un-sedated cats than the Tono-Pen XL™. No topical anesthetic was required for TonoVet® readings and readings were obtained in a shorter amount of time (within a few seconds) than with the Tono-Pen XL™, particularly at lower IOPs. The slope of the Tono-Pen XL™ vs. TonoVet® regression line (Figure 5a) was comparable to the slope of the Tono-Pen XL™ vs manometry regression line (0.61 vs. 0.62) obtained in the invasive phase of the study. The Tono-Pen XL™ data were corrected using the manometrically derived equation:

$$\text{IOP(mmHg)} = 1.607 \times (\text{Tono-Pen XL}^{\text{TM}} \text{ reading} - 1.418)$$

and were plotted against TonoVet® values obtained in the same eyes, yielding a regression line with a slope of 0.98 (Figure 5b). Over the course of the 8 week study period, fluctuations in IOP readings taken with the TonoVet® were more dramatic and peak IOP values much higher in many of the glaucomatous cats than were readings taken with the TonoPen-XL™ as shown in Figure 6.

Discussion

In summary, the TonoVet® provided IOP readings in cats that were significantly more accurate than IOP readings obtained with the Tono-Pen XL™. In both the normal and

glaucomatous cats in our study, the TonoVet® readings showed very close correlation with manometrically determined IOP, although readings were generally higher than actual IOP by 2–5 mm Hg. Ease of use is a major benefit of using the TonoVet® although, as the magnetized metal probe must lie in the horizontal plane, patient positioning is more critical than for the Tono-Pen XL™. We were able to demonstrate that an inexperienced operator can be readily trained to obtain valid IOP measurements using both the TonoVet® and Tono-Pen XL™ however, obtaining consistent IOP readings with the Tono-Pen XL™ proved to be a greater challenge and was more time-consuming for the inexperienced operator, particularly at low IOPs.

Overall, we found that the degree of precision, or reproducibility, was comparable for the TonoVet® and Tono-Pen XL™ ($r^2=0.92$ vs. $r^2=0.94$ respectively) though occasional readings with very high variance were obtained that could be considered “outliers” as can be clearly seen in figure 3. This was more apparent for the TonoVet® than the Tono-Pen XL™. In a clinical or research setting, at least 3 consistent readings should be obtained to minimize the impact of individual inconsistent values on the accuracy of IOP measurement. The TonoVet’s internal calculation obtains 6 readings that are considered acceptable and then the lowest and highest values are discarded by the software prior to calculation of the mean IOP value.

The Tono-Pen XL™ was significantly less accurate compared to the TonoVet® with large underestimations of pressure relative to manometry, especially at higher IOPs. The slope for the Tono-Pen XL™ relative to manometry obtained in our study is in agreement with the slope obtained for the Tono-Pen XL™ in a study conducted by Passaglia et. al.¹¹ which also found that the Tono-Pen XL™ significantly underestimated IOP relative to manometry *in vivo* in cats (mean slopes=0.62 and 0.64, respectively). This underestimation is also consistent with results of a study using enucleated cat eyes that was reported by Rusanen et. al.¹³ in which the TonoPen Vet® (which is essentially identical to the the Tono-Pen XL™) was found to significantly underestimate IOP compared with manometry, especially at pressures >30mm Hg. This same study also sought to establish a reference range for IOP in cats and reported that mean IOP measurements obtained in awake cats with the TonoVet® rebound tonometer were significantly higher compared with measurements acquired with the Tono-Pen Vet® (20.7mmHg vs. 18.4mmHg, respectively¹³) Although our intent was not to establish a reference range, but to ascertain the performance of the instrument across a wide range of IOPs in a clinical setting, we also found that measurements taken with the TonoPen-XL™ in unsedated cats were consistently lower than those taken with the TonoVet®. Although widely used in veterinary clinical practice, it is conceivable that this systematic underestimation of IOP by the TonoPen Vet® or TonoPen-XL™ could contribute to under-diagnosis of glaucoma in feline clinical patients and could significantly impact the treatment decisions made in cats with ocular hypertension and/or glaucoma. This underestimation would likely impact results of studies done in feline subjects in research settings as well. In the current study, the data collected with the Tono-Pen XL™ in one cat included readings of 32 mm Hg across a manometrically determined IOP range of 45–55 mm Hg. An IOP of 32 mm Hg would be considered moderately high, requiring some intervention to lower the IOP, or at least subsequent re-evaluation, whereas an IOP in the 45–55 mm Hg range would be considered vision threatening and would warrant prompt medical or surgical intervention to substantially lower the IOP.

Clinical evaluation within our research colony, also identified much greater fluctuations in IOP over time using the TonoVet®, with the IOP measurements in one cat ranging between ~22 and 62mmHg, indicating a magnitude of diurnal fluctuation of up to 40 mm Hg. Although somewhat controversial, the magnitude of IOP fluctuation, as well as mean IOP, has been suggested to represent a significant risk factor for disease progression in

humans.^{28,29} The TonoVet[®] tonometer appears to offer greater sensitivity for the detection of the role played by IOP "spikes" in the progression of retinal and optic nerve disease in glaucomatous feline subjects and for monitoring efficacy of IOP-lowering treatment.

An element of inter-user variability was noted in our study, particularly with the TonoPen-XL[™], whereby IOP measurements taken by the more experienced observer were found to be slightly, but significantly more accurate than those taken by the less experienced observer. User error or differences in user technique are some drawbacks of using handheld tonometers, and the Tono-Pen applanation tonometers arguably are more prone to inaccuracy due to incorrect technique. Many variables, such as site of contact on the cornea, angle of impact on the cornea, position of the patient, use of appropriate restraint technique, hysteresis of the eye, and distance from the cornea (for the TonoVet[®]), can affect the IOP values obtained. Operators can attempt to control for some of these variables with good, consistent technique however, not all of these confounding variables can be completely mitigated at all times. IOP measurements in humans using the handheld ICare[®] rebound tonometer were found to be less precise or reproducible than measurements taken with the stationary Goldmann applanation tonometer.³⁰ Similarly, IOP measurements taken the TonoVet[®] were found to be slightly, but significantly less precise than those done with the Goldmann applanation tonometer when compared to manometry in cynomolgus monkeys, though both the TonoVet[®] and Goldmann tonometers were found to have comparable accuracy relative to manometrically determined IOP.²⁵ Maintaining consistent technique may present even more of an issue in conscious animals, particularly when using the Tono-Pen tonometers that rely on accurate manual application of an applanating rather than indenting force to the cornea.

Despite the lower reproducibility of readings, the TonoVet[®] still represents a valid and practical option for obtaining IOP readings in cats in veterinary clinical practice. However, the accuracy of rebound tonometry remains to be determined in situations where applanation tonometry has been shown to have significant limitations, such as in patients with corneal edema, scarring, and/or corneal surface irregularities.³¹

We found that the TonoVet[®] slightly overestimated intraocular pressure compared with manometry, in both normal and glaucomatous cats, though not significantly. This finding is not consistent with results from the Rusanen et. al. study which found that the TonoVet[®] correlated well with manometrically determined IOP in cats eyes *in vitro*, in the 25–50mm Hg range and underestimated IOP below 25mm Hg. This discrepancy could be due to a number of factors such as differences in the properties of cat eyes *in vivo* vs enucleated cat eyes, *ex vivo*, differences in TonoVet[®] or manometer calibration, differences in the operators' measurement techniques or other differences in experimental design and technique. Corneal hysteresis has been reported to affect the measurements taken using rebound tonometry.³² In our study both tonometers were evaluated consecutively at each IOP increment and decrement, whereas in the Rusanen et. al. study, each tonometer was evaluated separately as IOP was decreased from an initial value of 70mm Hg so that each eye was subject to extremely high IOP on 2 occasions during their experiment. It is conceivable that overall underestimation of the IOP by the TonoVet observed in that study may have been due to alterations in corneal biomechanics/hysteresis.¹³ In our study IOP readings taken with the TonoVet[®] during decrements in IOP were slightly lower than those taken during increments though not significantly. This subtle difference could also be related to alterations in corneal hysteresis or thickness following the extreme elevation in IOP. Repeated application of the Tono-Pen XL[™] tonometer could also have affected corneal hysteresis if external indenting pressure, rather than applanating force was applied to the eye.

In conclusion, the TonoVet[®] rebound tonometer provides IOP readings in both normal and glaucomatous cats that are accurate, relatively precise and reproducible, with low inter-observer variability. If the Tono-Pen XL[™] is used, an equation may be applied to correct values and provide a better estimate of actual IOP. On the basis of our findings, the TonoVet[®] appears to represent a more appropriate choice of instrument for measuring IOP in the cat in a clinical setting than the Tono-Pen XL[™], particularly in any cats that show clinical signs that could be consistent with glaucoma.

Acknowledgments

Supported by NIH grant number K08EY018609 to Dr McLellan and conducted in the laboratory of Dr Paul Kaufman supported by NEI core grant P30EY0016665, and by an unrestricted award from Research to Prevent Blindness to the Department of Ophthalmology and Visual Sciences, University of Wisconsin-Madison.

References

1. McLellan GJ, Miller PE. Feline glaucoma-a comprehensive review. *Vet Ophthalmol.* 2011; 14:15–29. [PubMed: 21923820]
2. Kroll MM, Miller PE, Rodan I. Intraocular pressure measurements obtained as part of a comprehensive geriatric health examination from cats seven years of age or older. *J Am Vet Med Assoc.* 2001; 219:1406–1410. [PubMed: 11724179]
3. Ridgway MD, Brightman AH. Feline glaucoma: a retrospective study of 29 animal cases. *J Am Animal Hosp Assoc.* 1989; 25:485–490.
4. Blocker T, van der Woerd A. The feline glaucomas: 82 cases (1995–1999). *Vet Ophthalmol.* 2001; 4:81–85. [PubMed: 11422987]
5. Walde I, Rapp E. Feline glaucoma. Clinical and morphological aspects (a retrospective study of 38 cases). *Eur J Comp Animal Pract.* 1993; 4:87–105.
6. Dietrich U. Feline glaucomas. *Clin Tech Sm Animal Pract.* 2005; 20:108–116.
7. Wilensky, JT. Epidemiology of open-angle glaucoma. In: Kaufman, PL.; Mittag, TV., editors. *Textbook of Ophthalmology: Volume 7 (Glaucoma)*. London, England: Mosby; 1994. p. 29–33.
8. Kaufman PL, Davis GE. Minified Goldmann applanating prism for tonometry in monkeys and humans. *Arch Ophthalmol.* 1980; 98:542–546. [PubMed: 6767468]
9. Miller PE, Pickett JP, Majors LJ. Evaluation of two applanation tonometers in horses. *Am J Vet Res.* 1990; 51:935–937. [PubMed: 2368953]
10. Miller PE, Pickett JP, Majors LJ, et al. Evaluation of two applanation tonometers in cats. *Am J Vet Res.* 1991; 52:1917–1921. [PubMed: 1785739]
11. Passaglia CL, Guo X, Chen J, et al. Tono-Pen XL[®] calibration curves for cats, cows, and sheep. *Vet Ophthalmol.* 2004; 7:261–264. [PubMed: 15200622]
12. Stoiber J, Fernandez V, Lamar PD, et al. Ex vivo evaluation of Tono-Pen and pneumotonometry in cat eyes. *Ophthalmic Res.* 2006; 38:13–18. [PubMed: 16192743]
13. Rusanen E, Florin M, Hässig M, et al. Evaluation of a rebound tonometer (Tonovet[®]) in clinically normal cat eyes. *Vet Ophthalmol.* 2010; 13:31–36. [PubMed: 20149173]
14. Kontiola AI. A new induction-based impact method for measuring intraocular pressure. *Acta Ophthalmol Scand.* 2000; 78:142–145. [PubMed: 10794245]
15. Abraham LM, Epasinghe NCR, Selva D, et al. Comparison of the ICare[®] rebound tonometer with the Goldmann applanation tonometer by experienced and inexperienced tonometrists. *Eye (Basingstoke).* 2008; 22:503–506.
16. Filippopoulos T, Matsubara A, Danias J, et al. Predictability and limitations of non-invasive murine tonometry: Comparison of two devices. *Exp Eye Res.* 2006; 83:194–201. [PubMed: 16564045]
17. Görg C, Coenen RTI, Stades FC, et al. Comparison of the use of new handheld tonometers and established applanation tonometers in dogs. *Am J Vet Res.* 2006; 67:134–144. [PubMed: 16426223]

18. Knollinger AM, Croix NCI, Barrett PM, et al. Evaluation of a rebound tonometer for measuring intraocular pressure in dogs and horses. *J Am Vet Med Assoc.* 2005; 227:244–248. [PubMed: 16047660]
19. Leiva M, Naranjo C, Pena MT. Comparison of the rebound tonometer (ICareR) to the applanation tonometer (Tonopen XLR) in normotensive dogs. *Vet Ophthalmol.* 2006; 9:17–21. [PubMed: 16409240]
20. Kalesnykas G, Uusitalo H. Comparison of simultaneous readings of intraocular pressure in rabbits using Perkins handheld, Tono-Pen XL, and TonoVet tonometers. *Graefe's Arch Clin Exp Ophthalmol.* 2007; 245:761–762. [PubMed: 17120000]
21. Kim CY, Kuehn MH, Anderson MG, et al. Intraocular pressure measurement in mice: a comparison between Goldmann and rebound tonometry. *Eye (Basingstoke).* 2007; 21:1202–1209.
22. Jeong M, Kim Y, Yi N, et al. Comparison of the rebound tonometer (TonoVet) with the applanation tonometer (TonoPen XL) in normal Eurasian Eagle owls (*Bubo bubo*). *Vet Ophthalmol.* 2007; 10:376–379. [PubMed: 17970999]
23. Reuter A, Müller K, Arndt G, et al. Accuracy and reproducibility of the TonoVet rebound tonometer in birds of prey. *Vet Ophthalmol.* 2010; 13 (Suppl 1):80–85. [PubMed: 20840094]
24. Yu W, Cao G, Qiu J, et al. Evaluation of monkey intraocular pressure by rebound tonometer. *Mol Vis.* 2009; 15:2196–2201. [PubMed: 19898690]
25. Elsmo EJ, Kiland JA, Kaufman PL, et al. Evaluation of rebound tonometry in non-human primates. *Exp Eye Res.* 2011; 92:268–273. [PubMed: 21315069]
26. Peterson JA, Kiland JA, Croft MA, et al. Intraocular pressure measurement in cynomolgus monkeys. Tono-Pen versus manometry. *Invest Ophthalmol Vis Sci.* 1996; 37:1197–1199. [PubMed: 8631634]
27. Bárány EH. Simultaneous measurement of changing intraocular pressure and outflow facility in the vervet monkey by constant pressure infusion. *Invest Ophthalmol.* 1964; 2:135–143. [PubMed: 14166270]
28. Bergea B, Bodin L, Svedbergh B. Impact of intraocular pressure regulation on visual fields in open-angle glaucoma. *Ophthalmol.* 1999; 106:997–1004.
29. Asrani S, Zeimer R, Wilensky J, et al. Large diurnal fluctuations in intraocular pressure are an independent risk factor in patients with glaucoma. *J Glaucoma.* 2000; 9:134–142. [PubMed: 10782622]
30. Davies LN, Bartlett H, Mallen EA, et al. Clinical evaluation of rebound tonometer. *Acta Ophthalmol Scand.* 2006; 84:206–209. [PubMed: 16637838]
31. Whitacre MM, Stein R. Sources of error with use of Goldmann-type tonometers. *Surv Ophthalmol.* 1993; 38:1–30. [PubMed: 8235993]
32. Chui WS, Lam A, Chen D, et al. The influence of corneal properties on rebound tonometry. *Ophthalmol.* 2008; 115:80–84.

Fig. 1.
Photograph of the TonoVetR rebound tonometer (Icare Oy, Finland) as used to obtain intraocular pressure readings in cats.

Fig. 2.

Composite plot of pooled data from both eyes and observers for all three cats. Controlled, manometrically determined IOP values are represented on the x-axis. TonoVet® (TV) and Tono-Pen XL™ (TP) tonometer readings are represented on the y-axis. The best fit line for each tonometer is presented for comparison with the “ideal” line $y=x$. Some data points are superimposed.

Fig. 3.

IOP measurements taken with the TonoVetR for all three cats by both observers demonstrated no statistically significant difference between increments and decrements. The values obtained for the increments had a tendency to slightly overestimate IOP to a greater extent than those obtained for the decrements. Some data points are superimposed.

Fig. 4.

Bland-Altman plot illustrating that the TonoVet[®] shows only a slight trend to increasing overestimation of IOP at higher pressures. Variance also progressively increases at higher IOPs. IOP difference (TonoVet[®]-Manometric values) plotted against average IOP ((TonoVet[®] + Manometric)/2). Data are pooled for 3 cats each contributing 2 eyes. Some data points are superimposed.

Fig. 5.

Fig. 5a. Representative linear correlation plot of the mean of triplicate Tono-Pen XL IOP readings obtained over a period of 8 weeks from a single eye of a glaucomatous cat plotted against the mean of triplicate readings obtained from the same eye using the TonoVet. **Fig. 5b.** The slope of the regression line approaches the ideal of 1 when Tono-Pen XL values above are corrected by means of the manometry derived equation: manometric IOP = $1.607 \times$ (Tono-Pen XL reading - 1.418), this suggests that the performance of both tonometers in a clinical setting approaches that observed under strictly controlled experimental conditions. On each occasion the TonoVet was used first.

Fig. 6.

Representative plot of weekly IOP measurements obtained over the study period in a single glaucomatous adult cat. With the Tono-Pen XL, mild to moderate elevation in IOP is evident, with just 2 peaks observed between 30 and 40mmHg. The TonoVet however indicates much greater, highly clinically significant, fluctuations in IOP over the course of the study (IOP ranging from about 22mmHg to about 62mmHg).