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Effect of Pneumatic Suction Ring Placement on Intraocular Pressure in Cats

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Key Words
Cat · Intraocular pressure · Pneumatic suction ring

Abstract
Purpose: To determine the effect of placing a pneumatic suction ring on intraocular pressure (IOP) in the cat and to design an improved method to generate a stable elevation of IOP. ***Methods:*** A pneumatic suction ring was applied to the eye in cats while the IOP was monitored. Three groups of animals (10 per group) were used. A vacuum pressure of 450 mbar was applied in one step to eyes of group 1 (anesthetized) and to group 2 (euthanized) cats. In group 3 (anesthetized) cats, an initial vacuum pressure of 250 mbar was applied, followed by a vacuum of slowly increasing pressure at a rate of 5 mbar/min for a total of 40 min to 450 mbar. ***Results:*** After the one-step application of a vacuum (450 mbar) to the eyes of anesthetized cats (group 1), IOP peaked within the first minute from a basal value of 25 ± 2 mm Hg (mean ± SD) to 90 ± 7 mm Hg. It then rapidly decreased to 69 ± 2 mm Hg 5 min later and continued to decrease to 39 ± 4 mm Hg 40 min later. This sharp peak and decline of IOP were also observed in eyes of euthanized cats (group 2). The basal IOP of these eyes was 8 ± 1 mm Hg. It rose to 18 ± 2 mm Hg immediately after the application of vacuum pressure (450 mbar) and returned to the basal level 5 min later. In contrast, the eyes of group 3 receiving an initial vacuum of 250 mbar followed by a 5 mbar/min vacuum increment exhibited a rapid increase in IOP and a very stable plateau (mean IOP = 62–68 mm Hg), lasting the whole study period (40 min). ***Conclusion:*** IOP after a one-step application of a vacuum via a pneumatic suction ring is self-adjusting and declines rapidly over time. This decline in IOP can be overcome by a supplementary increment in vacuum pressure.

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Pneumatic suction rings have been widely used to stabilize the globe during refractive surgery to obtain accurate and repeatable results. Suction cups and rings applied to the eye have been used to indirectly measure the outflow facility and the rate of aqueous humor formation [1, 2].

In refractive surgery, a pneumatic suction ring is designed not only to fixate the eye but also to pressurize it [3]. Basically, the vacuum pulls the sclera outward, decreasing the volume of the globe, which in turn elevates intraocular pressure (IOP). Increased IOP causes the cornea to become more taut and rigid. An IOP of 65 mm Hg provides adequate corneal rigidity for refractive surgery. Barraquer [4] discovered that by increasing IOP with a pneumatic fixation ring, an oscillating razor blade

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mounted like a carpenter's plane could shave a round, parallel-faced corneal disk from the anterior corneal stroma. He also recognized a relation between IOP and resection diameter that directly affects the compression of the cornea by the microkeratome. The greater the IOP and/or the greater the diameter of the resected disk, the more the cornea is compressed beneath the plane of the microkeratome resulting in a deeper resection.

A pneumatic fixation ring offers three functions. First, it fixates the patient's eye, which ensures smooth and accurate incisions or a lamellar cut. Second, it allows adjustment of the height of the microkeratome platform. Changing the height of the platform in relation to the cornea alters the amount of corneal tissue projecting above the platform, thereby allowing control of the diameter of the planed resection. Finally, the pneumatic fixation ring provides a grooved, geared track for passage of the motor-driven microkeratome across the cornea.

The effect of an external vacuum by the pneumatic suction ring on IOP is of clinical importance [5–7]. IOP tends to decrease during refractive surgery, causing the eye to soften considerably. Softening leads to the formation of an incomplete flap, a reduction of the depth, uniformity of straightness of the incisions during refractive surgeries. As depth of resection is reduced, the patient will have a less favorable response to the surgery.

In addition to being used in refractive surgeries, the pneumatic suction cup is also used in vacuum ophthalmodynamometry, which is a well-recognized clinical tool for aiding in the diagnosis of glaucoma and occlusive diseases of the carotid arterial system [1, 2]. To estimate various parameters of aqueous hydrodynamics, such as the rate of formation of aqueous humor, the resistance of outflow and the venous pressure, the IOP of the patient is raised usually for 10 min with a standard amount of vacuum pressure, and subsequently the pressure is released, at which time analysis of the rate of the fall of IOP toward its equilibrium value is used to derive the parameters in question. This method has a number of inherent disadvantages and potential errors. One of the drawbacks is that during the initial 10 min of vacuum application, the IOP is unstable and decreases with time, thus producing unnecessary and undesirable variability among patients.

As a diagnostic tool for occlusive diseases of the carotid arterial circulation, the pneumatic suction cup is used to elevate IOP and induce pulsation of the central retinal artery. Here the same principal of systemic blood pressure measurement is employed to estimate the intraocular blood pressure. However, a key difference is that, because the pulsation in the eye is a much weaker signal than that of the arm, it requires a much more careful measurement and thus a longer period to precisely perform such a measurement. An unstable IOP will significantly compromise the accuracy of the outcome.

In this paper, the dynamic change of IOP after the application of a vacuum using a pneumatic suction ring is described. The results reported here should provide a better understanding of the interaction between the surgical device and the eye. More importantly, a new method that can produce and maintain a stable elevated IOP is described. This method should improve the reproducibility of a deeper resection during refractive surgery, minimize interpatient variability during aqueous hydrodynamic estimations and allow for a more accurate evaluation of intraocular blood pressure.

Materials and Methods

Procedures used in this investigation conformed to the Association for Research in Vision and Ophthalmology Resolution on the Use of Animals in Research and were approved by the Animal Care Committee at the University of Oklahoma, where all studies were conducted. Thirty healthy cats of either sex weighing 3–3.5 kg were assigned to one of three groups (10 per group). In group 1 and group 3, experiments were performed on anesthetized cats. Anesthesia was induced using a mixture of ketamine (Parke-Davis, Morris Plains, N.J., USA) 35 mg/kg i.m. and xylazine (Miles, Shawnee Mission, Kans., USA) 6 mg/kg i.m. Supplemental doses of ketamine and xylazine were administered as needed. In group 2, the experiments were performed after the cats had been euthanized by an overdose of ketamine (>80 mg/kg, intracardial injection).

In all animals, the hair within approximately 3–4 cm of the eyes was shaved. This region was washed with povidone-iodine and then with alcohol three times. A lateral canthotomy was performed with a minimum cut of approximately 2.5 cm, which produced more available surface area of the eye for the suction ring. A Barraquer-type suction ring (Optical Radiation Corp., Irvine, Calif., USA) was centered on the pupil and attached concentrically to the limbus. The ring was connected via a plastic tubing to a vacuum pump. The amount of vacuum was expressed by negative pressure in millibars where 1 mbar equals 0.75 mm Hg. IOP was measured using an electronic pneumotonometer (Tono-Pen XL, Mentor O & O Inc., Santa Barbara, Calif., USA). The hand-held tonometer displays digital numeric values upon contact with the cornea. A single technician, well trained in the use of the instrument, made all of the measurements.

In groups 1 and 2 (n = 10), a vacuum pressure of 450 mbar was generated in a single step upon ring placement on the right eye. IOP was recorded every 5 min for 40 min. In group 3 (n = 10), after an initial one-step application of vacuum of 250 mbar on the right eye, the pressure was increased by 5 mbar/min for 40 min. IOP was recorded immediately before and after each increase in pressure (the data were then averaged). After the ring had been removed, IOP was measured under anesthesia at 1-hour intervals for 2 h and then daily for 7 days. Data are presented as means ± SD.

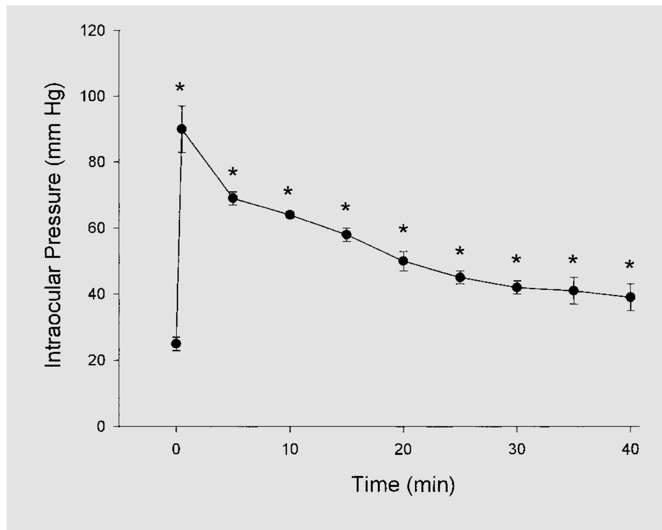

Fig. 1. Changes in IOP observed in anesthetized cats (group 1). A vacuum pressure of 450 mbar was applied in one step at time 0. Data are presented as means ± SD. * $p < 0.05$ versus basal level at 0 min by one-way ANOVA, then Dunnett's test.

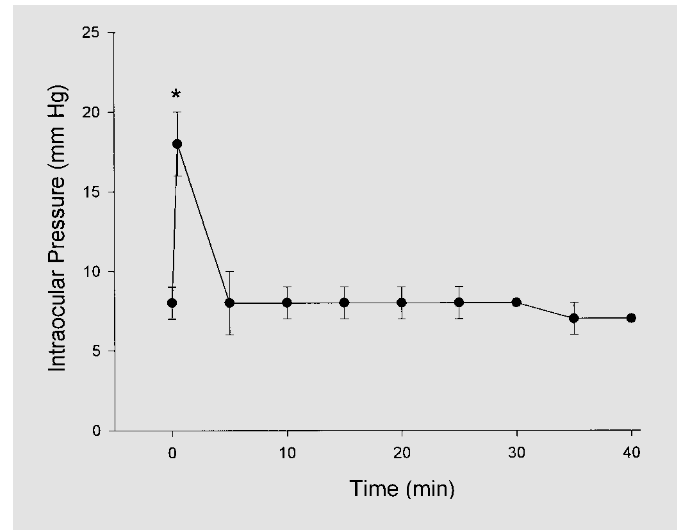

Fig. 2. Changes in IOP observed in euthanized cats (group 2). A vacuum pressure of 450 mbar was applied in one step at time 0. Data are presented as means ± SD. * $p < 0.05$ versus basal level at 0 min by one-way ANOVA, then Dunnett's test.

Results

IOP in the eyes of anesthetized cats (group 1) increased sharply after a one-step application of vacuum of 450 mbar (fig. 1). The peak IOP (90 ± 7 mm Hg) was approximately 360% of the baseline (25 ± 2 mm Hg). Even with the vacuum maintained, IOP declined over time after its peak. It decreased rapidly during the first 5 min at a rate of 4.5 mm Hg/min. IOP equaled 69 ± 2 mm Hg at 4.9 min. In the next phase, 5–19.9 min, IOP decreased at a slower rate of 1.2 mm Hg/min. IOP was 50 ± 4 mm Hg at 20 min. The final 20 min were marked by a very slow decrease of 0.48 mm Hg/min. Toward the end of the experiment, IOP (39 ± 4 mm Hg) leveled off at a value of 57% below its peak. Similar to the group 1 animals, the pressure curves observed in the euthanized cats' eyes increased at the onset of vacuum (fig. 2). However, the maximum IOP in group 2 averaged approximately 17 mm Hg, a 110% increase from baseline (8 mm Hg). Unlike in the eyes of the anesthetized cats, IOP of eyes from euthanized cats declined immediately to baseline, even with the vacuum maintained at 450 mbar (fig. 2).

To overcome the sharp decline in IOP and to maintain IOP at a relatively constant level during the entire procedure, a new method was developed, in which an additional vacuum of 5 mbar/min was applied after an initial vacuum of 250 mbar. In these animals (group 3), the initial vacuum increased IOP by 167% above the baseline pressure (from 26 ± 2 to 66 ± 7 mm Hg). This increase in IOP did not return rapidly toward baseline as that of groups 1 and 2. Instead, the IOP was maintained by the supplementary vacuum and was very stable, with a mean pressure between 62 and 68 mm Hg, throughout the whole study period of 40 min (fig. 3). The recovery of IOP after this, supplementary-vacuum, procedure was monitored for 2 h and then daily for 7 days. The IOP remained lower than that in the control eye until 5 days after application of the suction ring. The lowest IOP was 8 mm Hg. Approximately 50% of the readings were between 16 and 18 mm Hg (fig. 4).

Discussion

In this study, it was demonstrated that a one-step application of a vacuum pressure through a pneumatic suction ring induced a dramatic change in IOP in the cat eye (fig. 1). In the anesthetized animals, four distinctive phases of IOP change were observed: (1) a rapid and immediate increase in IOP, whose peak pressure correlated with the magnitude of the vacuum used – the higher the vacuum, the higher the spike; (2) a sharp decline of IOP (4.5 mm Hg/min) lasting from 0 to 4.9 min; (3) a slower decline (1.2 mm Hg/min) from 5 to 19.9 min, and

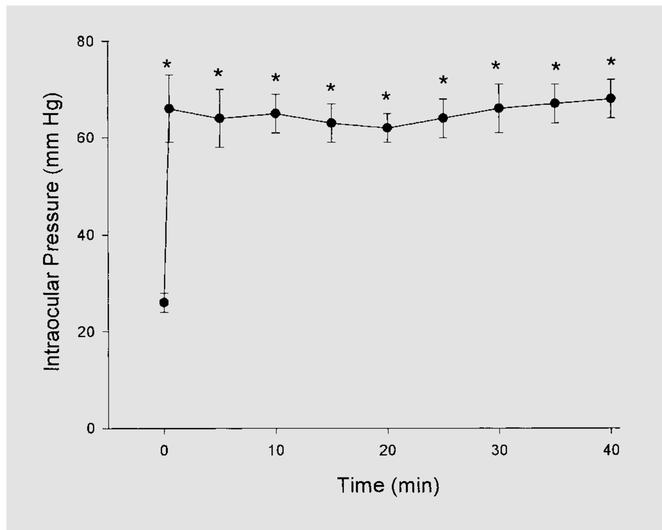

Fig. 3. Changes in IOP obtained in anesthetized cats (group 3). An initial vacuum of 250 mbar was applied at 0 min, followed by an incremental vacuum of 5 mbar/min for 40 min. Data are presented as means ± SD. * $p < 0.05$ versus basal level at 0 min by one-way ANOVA, then Dunnett's test.

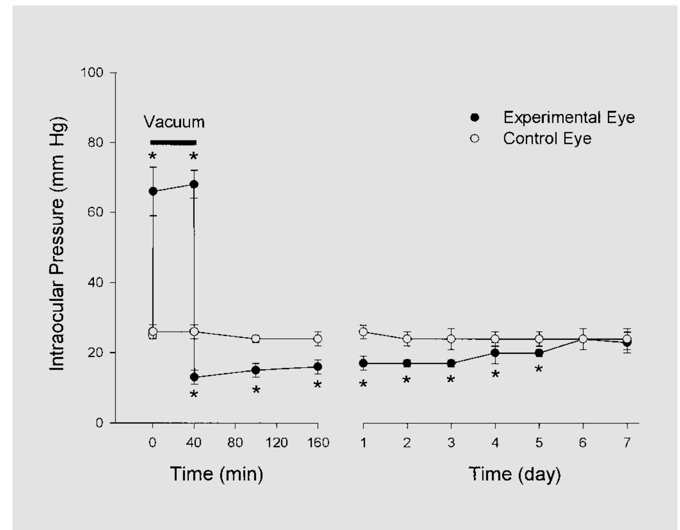

Fig. 4. Follow-up of changes in IOP obtained in cats of group 3. The bar above symbols of 0 and 40 min shows when the vacuum was on. Data are presented as means ± SD. * $p < 0.05$ versus the control eye value of the same time point by Student's t test.

(4) a relative IOP plateau (decline 0.48 mm Hg/min) from 20 to 40 min.

The sharp peak and rapid decline of IOP may compromise the outcome in refractive surgeries. During laser in situ keratomileusis, it has recently been reported [8] that the large initial IOP elevation precipitated optic nerve head ischemia in the patient. Surgeons apply a vacuum for various periods during the refractive surgeries; the rapid decline in IOP at a rate of 4.5 mm Hg/min will continuously soften the globe and change the mean corneal curvature during surgery. That likely affects the uniformity of the corneal flab thickness and incision depth, and could account for the occasional cases of iatrogenic uncorrupt adjusted corneal curvature, astigmatism and corneal wrinkling.

Similarly, the constant decline in IOP after suction cup application definitely affects the accurate estimation of the intraocular blood pressure or flow velocity values by vacuum ophthalmodynamometry and aqueous dynamic measurements. The mathematical derivations of various parameters depend on the assumed steady elevation of IOP during the initial 10 min of application of vacuum pressure. However, as shown above, the rapid decline of IOP within this time period will not support such an assumption, and thus will produce unnecessary uncertainties concerning clinical outcome. In addition, if the rate of decline varies in different patients, then the results will not be reproducible, which is the primary criticism of this method. So a steady IOP is even more critical for the measurement of retrobulbar hemodynamics [9].

This sharp peak and rapid decline of IOP induced by the suction ring are not unexpected, and similar findings in human patients have been previously reported [10]. A stable IOP is the result of a dynamic equilibrium between the formation and outflow of aqueous humor [11, 12]. The vacuum generated by the suction ring disrupted this equilibrium. The vacuum compressed the globe and reduced the volume of the anterior chamber, which immediately increased the pressure inside the eye and generated the sharp IOP peak. At that point, according to Poiseuille's law [13, 14] [$F = (P_o - P_v) \times C$, where F is the rate of aqueous outflow, P_o is the IOP, P_v is episcleral venous pressure and C is the outflow facility], the rate of aqueous outflow increases drastically, since only P_o, but not the other parameters, was increased in a short period of time. This sudden increase in outflow rate, coupled with the pressure-induced suppression of aqueous humor formation [15], caused the immediate decline of IOP. Eventually, the rates of aqueous formation and outflow reached a new equilibrium, and the plateau phase of IOP elevation was achieved. This explanation is supported by data collected in the euthanized cat: without a continuous production of aqueous humor, the suction-ring-induced IOP elevation quickly returned to the basal level (fig. 2).

If IOP changes are the result of this self-adjusting feedback system, it should then be possible to minimize the magnitude of the spike and the sharp decline of IOP with a low initial vacuum, followed by small vacuum increments at regular intervals. Indeed, in group 3 animals, IOP elevation had a smaller initial peak and a very stable plateau lasting for at least 40 min (fig. 3). The smaller initial peak has the added advantage of minimizing the risk of pressure-induced damage to the retina and optic nerve head. The vacuum (V_t) that provides a steady IOP at any time t (min) can be expressed in terms of an empirical equation: $V_t = V_o + Kt$, where V_o is the initial vacuum and K is the rate of vacuum increment. In our experiments reported in this paper, V_o = 250 mbar and K = 5 mbar/min. For a more precise level of IOP control, one may need a continuous increment of vacuum (instead of increments in steps shown here), with K a larger value at the beginning and smaller toward the end of the procedure.

A common feature found in all experimental cat eyes was hypotony after the application of the suction ring. IOP lower than its baseline can last for several days after the procedure (fig. 4). Very little is known about the mechanism. There are three likely hypotheses. First, it is possible that the suction induces a slight mechanical damage to the trabecular meshwork or other components of the outflow pathway so that the outflow resistance becomes abnormally low. Second, the elevation of IOP may induce a transient ischemia in the ciliary muscle or other structures of the outflow pathway [10], which again leads to a lower outflow resistance. Third, alternatively, the manipulation of the suction ring interferes with the blood flow to the ciliary body and causes a temporary impairment of aqueous humor formation. It is noteworthy that, although this study demonstrated in the animal model a statistically significant effect of the suction ring in reducing IOP for 1–6 days after application, it is not clear if this hypotony is relevant clinically.

The results reported here demonstrate that a one-step application of vacuum pressure via a pneumatic suction ring produces a sharp IOP peak, followed by a rapid decline of IOP in the cat. In contrast, the modified method generates a smaller IOP peak and a very stable plateau for at least 40 min. It is likely that the same phenomenon can be duplicated in human patients. If so, this improved technique should provide additional safety and accuracy for clinical procedures such as refractory surgery and vacuum ophthalmodynamometry.

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