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Author/s:
He, Z;Zhao, D;van Koeverden, AK;Nguyen, CT;Lim, JKH;Wong, VHY;Vingrys, AJ;Bui, BV

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Video Article

A Model of Glaucoma Induced by Circumlimbal Suture in Rats and Mice

Zheng He[1], Da Zhao[1], Anna K. van Koeverden[1], Christine T Nguyen[1], Jeremiah K. H. Lim[1], Vickie H. Y. Wong[1], Algis J. Vingrys[1], Bang V. Bui[1]

[1]Department of Optometry and Vision Sciences, University of Melbourne

Correspondence to: Bang V. Bui at bvb@unimelb.edu.au

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Abstract

The circumlimbal suture is a technique for inducing experimental glaucoma in rodents by chronically elevating intraocular pressure (IOP), a well-known risk factor for glaucoma. This protocol demonstrates a step-by-step guide on this technique in Long Evans rats and C57BL/6 mice. Under general anesthesia, a "purse-string" suture is applied on the conjunctiva, around the equator and behind the limbus of the eye. The fellow eye serves as an untreated control. Over the duration of our study, which was a period of 8 weeks for rats and 12 weeks for mice, IOP remained elevated, as measured regularly by rebound tonometry in conscious animals without topical anesthesia. In both species, the sutured eyes showed electroretinogram features consistent with preferential inner retinal dysfunction. Optical coherence tomography showed selective thinning of the retinal nerve fiber layer. Histology of the rat retina in cross-section found reduced cell density in the ganglion cell layer, but no change in other cellular layers. Staining of flat-mounted mouse retinae with a ganglion cell specific marker (RBPMS) confirmed ganglion cell loss. The circumlimbal suture is a simple, minimally invasive and cost-effective way to induce ocular hypertension that leads to ganglion cell injury in both rats and mice.

Video Link

The video component of this article can be found at https://www.jove.com/video/58287/

Introduction

Animal models provide an important platform for laboratory investigation of cellular processes underlying glaucoma pathogenesis, as well as to evaluate potential therapeutic interventions. Several inducible models have been developed to produce sustained intraocular pressure (IOP) elevation, the most important risk factor for glaucoma. Methods that have been applied to elevate IOP include: hypertonic saline injection in episcleral veins[1], laser photocoagulation of the trabecular meshwork[2] or of the limbal veins[3], and intracameral injection of substances such as ghost red blood cells[4], microbeads[5,6] and viscoelastic agents[7]. Each approach has its advantages and limitations.

A good model for glaucoma should mimic the disease process, with minimal complication such as trauma, inflammation and media opacities. These complications are frequently associated with the procedures used to induce IOP elevation, and can confound interpretation of outcomes. For example, paracentesis of the anterior chamber, even when foreign substances are not introduced, has been shown to cause trauma and inflammation that is not representative of typical glaucomatous change[8,9]. In addition to the importance of avoiding inflammation, maintaining optical clarity facilitates *in vivo* imaging and electrophysiology to monitor disease progression. Although it is unclear to what extent these complications may affect disease investigations, it may be better to avoid penetrating the eye during model induction. The circumlimbal suture approach avoids penetration of the globe and facilitates *in vivo* longitudinal assessment of retinal structure and function. More importantly, this model differs from previous ones in its capacity to return IOP to baseline values by removal of the suture when required. IOP normalization may be useful for studying the cellular and molecular correlates of reversible and irreversible ganglion cell injury[10,11,12,13,14].

This article focuses on the technique for model induction. Characterization of retinal injury induced by this model in rats and mice can be found in greater detail elsewhere[15,16,17,18,19].

Protocol

All experimental procedures were conducted according to the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes, set by the National Health and Medical Research Council in Australia. Ethics approval was obtained from the Howard Florey Institute Animal Ethics Committee (approval number 13-044-UM and 13-068-UM for rats and mice, respectively).

1. Intraocular Pressure Measurement in Conscious Rats

1. Set the laboratory rebound tonometer to the rat setting. Swaddle the awake rat in a piece of soft cloth to calm the animal. Expose the head and neck. Gently hold the torso in one hand, with the animal's back resting against the investigator's chest.

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NOTE: Topical anesthesia is not required.
2. Use the other hand to bring the rebound tonometer near the rat's eye, so that the tip of the IOP probe is approximately 2 - 3 mm away from and perpendicular to the corneal apex. Use the right hand to measure IOP in the animal's right eye, and left hand for the left eye.
3. Wait a few seconds for the rat to calm and press the measurement button once. Observe the tip of the IOP probe gently hit the corneal apex once; and hear the rebound tonometer beep once.
   NOTE: A single beep of the tonometer confirms successful measurement, which can be read from the LCD screen. A double beep indicates a measurement error. Measurement errors can arise from factors such as inappropriate working distance between the probe and the cornea, an excessive tilt in the orientation of the tonometer, or the probe striking the eyelid or a non-central part of the cornea. Refer to the rebound tonometer manual from the manufacturer for further detail regarding measurement errors.
4. Repeat step 1.3 ten times at an interval of 1 - 2 second, from these measurements derive an average IOP value for that time point. Reset the tonometer after the 5th reading.
5. For serial monitoring, measure IOP at the same time of the day and under consistent lighting conditions to minimize variation due to the diurnal IOP cycle[20,21].

2. Intraocular Pressure Measurement in Conscious Mice

1. Set the rebound tonometer to the mouse setting according to manufacturer's instruction.
2. To restrain the mouse by hand, place the mouse on a grill cage top and gently pull the tail backwards.
   NOTE: This will prompt the animal to grip onto the metal grill with its front legs and attempt to pull itself forward, which will slightly stretch its body.
   1. Use the other hand to grasp the loose skin immediately behind the ears. Secure the lower body of the animal by holding the tail between the ring finger and middle finger (or between the little finger and your palm).
      NOTE: Try not to grasp the skin too tight, to avoid suffocation and applying pressure on the eyes.
3. With the now free hand (initially holding the tail), bring the rebound tonometer near the mouse's eye, so that the tip of the IOP probe is approximately 2 - 3 mm from and perpendicular to the corneal apex. To measure the other eye, rotate the mouse so that the other eye is now in front of the tonometer.
4. Wait for the mouse to calm and press the measurement button once. Observe the tip of the IOP probe gently hit the corneal apex; with a single beep confirming successful measurement.
   NOTE: A double beep indicates a measurement error. It may help to have a second experimenter read and document the IOP readings whilst the first experimenter takes the measurements.
5. Repeat step 2.4 to obtain ten successful readings to derive an IOP. Reset the tonometer after the 5th reading. Allow an interval of 1 - 2 seconds between readings.
6. As per serial measurement in rats, measure mouse IOP at the same time of the day and under consistent lighting conditions.

3. Induction of Intraocular Pressure Elevation in Anesthetized Rats and Mice

1. Clean the surgical bench with 0.5% chlorhexidine in 70% ethanol. Cover the bench with sterile drapes. Autoclave all surgical equipment beforehand. Ensure all experimenters wear appropriate personal protective equipment (surgical masks, gowns and sterilized gloves).
2. To induce general anesthesia, place the animal in an induction chamber. Deliver 3 - 3.5% isoflurane with O_2 at a flow rate of 3 L/min.
   1. Maintain anesthesia with 1.5% isoflurane at 2 L/min delivered *via* a rodent face mask throughout the surgery. Ensure sufficient depth of anesthesia by the absence of a paw pinch reflex.
   2. Avoid respiratory depression by adjusting the flow rate when necessary to maintain the respiratory rate at approximately 60 breaths/min.
3. Randomly select one eye to induce ocular hypertension, with the contralateral eye to serve as an untreated control. Instill one drop of 0.5% proxymetacaine ophthalmic solution for topical anesthesia. To clean the ocular surface, rinse the eye with 3 mL of sterile normal saline.
4. Cover the animal with a sterile, fenestrated surgical drape, exposing the eye to be sutured.
5. Perform a purse-string suture on the bulbar conjunctiva around the globe. In rats, weave the 7/0 nylon suture parallel and 2 mm posterior to the limbus (**Figure 1**). In mice, place the 10/0 nylon suture at 1 mm posterior to the limbus.
   1. Take care not to penetrate the sclera. A sudden pupillary dilation during the surgical procedure indicates the sclera has likely been penetrated.
   2. Anchor the suture on the conjunctiva using 5-6 anchor points in rats, and 4-5 anchor points in mice.
   3. Avoid direct compression on the major episcleral veins by threading the suture underneath the conjunctiva at the crossing of these veins.
      NOTE: While we recommend avoiding compression of the major episcleral vein in rats, this is not routinely done in mice due to low visibility of these veins in mouse eyes. Even though the major veins are not directly compressed, it is likely that the smaller vessels in the episcleral vein plexus are under pressure, which may be a contributing factor to the sustained IOP elevation (please see Discussion for mechanism of IOP elevation).
6. Fasten the purse-string suture by tying a slipknot then followed by a second simple knot (**Figure 1**). To avoid an excessively high post-surgical IOP spike, have an assistant measure the IOP immediately before fastening the second knot.
   1. If the IOP is found to be too high, adjust the slip knot by partially releasing the tension on one end of the suture (arrow in **Figure 1A**).
   2. After the desired IOP is achieved (ideally 30 - 60 mmHg in rats or 30 - 40 mmHg in mice), tie off the second knot while maintaining a continuous pulling force on that end of the suture (arrow in **Figure 1A**).
   3. After the second knot has been tightened, trim the ends of the suture to minimize any foreign body sensation. Monitor the animal during recover from general anesthesia.

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NOTE: It is important to use the slipknot when tying the first knot to ensure adequate inward compression on the eye. After several weeks it is usually noted that the ends become embedded in the conjunctiva.

4. Monitoring IOP

1. Take the first IOP measurement at 2 minutes post-operatively under isoflurane anesthesia. Subsequently, monitor IOP when the rodent has regained consciousness as per the aforementioned steps 1 and 2.
   NOTE: Monitor the IOP twice during the first day (2 minutes and 1 hour), daily in the first week and once or twice per week thereafter.

5. Assaying Retinal Structure and Function

1. At the desired experimental end point (in this case after 8 weeks in rats and 12 weeks in mice), under general anesthesia using intraperitoneal injection with ketamine/xylazine, measure retinal function with the dark-adapted electroretinogram (ERG) as described in greater detail elsewhere[15,16,17].
   NOTE: We have found robust ganglion cell dysfunction, retinal nerve fibre layer thinning and ganglion cell loss for durations between 8-12 weeks. Others have successfully employed longer periods of IOP elevation[14,15].
2. Immediately after ERG measurement, measure the thickness of retinal nerve fiber layer (RNFL) and total retinal thickness using spectral domain optic coherence tomography (SD-OCT) [16,18].
3. At the end of the longitudinal study, euthanize the animals under deep anesthesia.
   1. Dissect the retina for histology[18], for example immunostaining of whole-mount retina using a retinal ganglion cell (RGC) specific antibody such as RNA-binding protein with multiple splicing antibody (RBPMS) or brain-specific homeobox/POU domain protein 3A (Brn3a)[16,19,22].

Representative Results

The following results in rats[18] and mice[16] have been previously reported and are summarized here. The circumlimbal suture produced a similar pattern of IOP elevation in rats and mice (**Figure 2**). A brief IOP spike, up to 58.1 ± 2.7 mmHg in rats and 38.7 ± 2.2 mmHg in mice, was found immediately after the suture procedure. In rats, IOP magnitude gradually reduced over time to be 44 ± 6 mmHg and 32 ± 2 mm Hg, at 3 and 24 hours, respectively[15]. After this initial IOP spike IOP remained relatively stable for several weeks. Over the experimental period, IOP in the ocular hypertensive (OHT) eyes remained elevated by ~ 9 mmHg for 8 weeks in rats, and by ~ 5 mmHg for 12 weeks in mice.

To assess RGC function, scotopic ERG at very dim stimulus energies elicits the positive Scotopic Threshold Response (pSTR), which was found to be reduced in the OHT eyes, relative to control eyes in both rats and mice (**Figure 3**). There was also a small reduction of the ERG a- and b-wave, which is likely to reflect a mild dysfunction of the photoreceptors and bipolar cells, respectively. The largest deficit however was found in the pSTR, confirming preferential inner retinal dysfunction subsequent to mild chronic IOP elevation.

Consistent with inner retinal dysfunction, a selective loss of cell density in the RGC layer was also evident in the cross-sections of OHT retina (**Figure 4A - 4C**). In contrast, cell numbers in the outer and inner nuclear layers remained unaltered[18], suggesting that off-target ischemic effects were minimal. Such findings in rats were corroborated by cell counts on whole-mount mouse retinae stained using an RGC specific antibody and confocal microscopy (**Figure 4E - 4G**). Similarly, OCT scans around the optic nerve head showed that chronic IOP elevation results in reduced RNFL thickness, whilst total retinal thickness remained unaltered in both species (**Figure 4D** and **4H**).

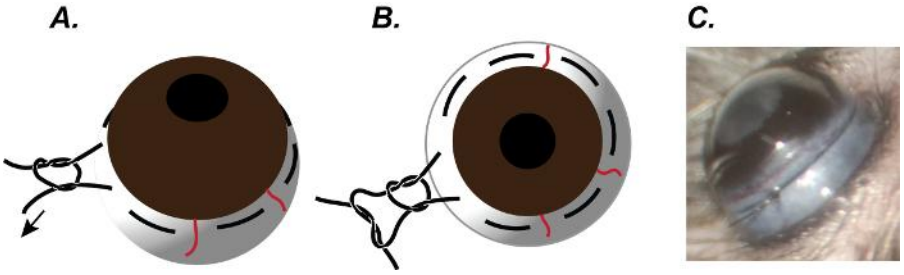


Figure 1. Circumlimbal suture application around the equator of the eye. A: Firstly, use a slipknot to tighten the purse-string suture by pulling only one string (arrow), which will ensure adequate inward compression. An assistant can measure the IOP immediately before fastening the second knot. **B**: Subsequently tie a second simple knot to lock the first knot. **C**: Photograph of circumlimbal suture on a mouse eye. Please click here to view a larger version of this figure.

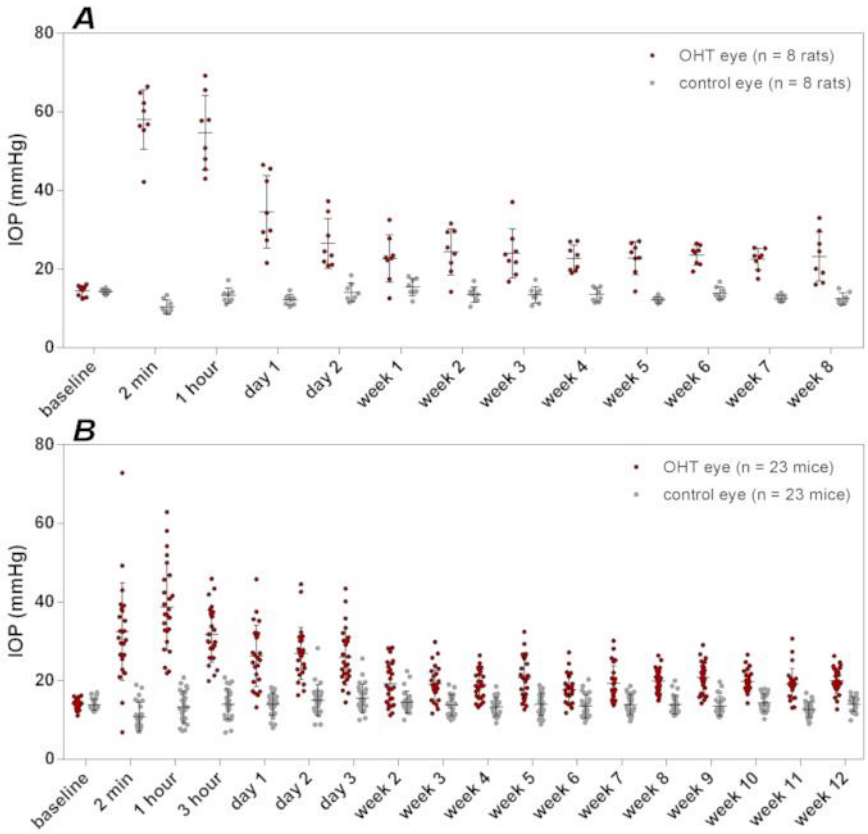


Figure 2. The circumlimbal suture raised intraocular pressure in this case for 8 weeks in rats (A, n = 8) and 12 weeks in mice (B, n = 23). IOP remained unchanged in contralateral control eyes. (individual OHT eyes represented by red symbols and control eyes by grey symbols). Average and standard deviations are overlaid in black. Data are replotted with permission from previous work [16,18]). Please click here to view a larger version of this figure.

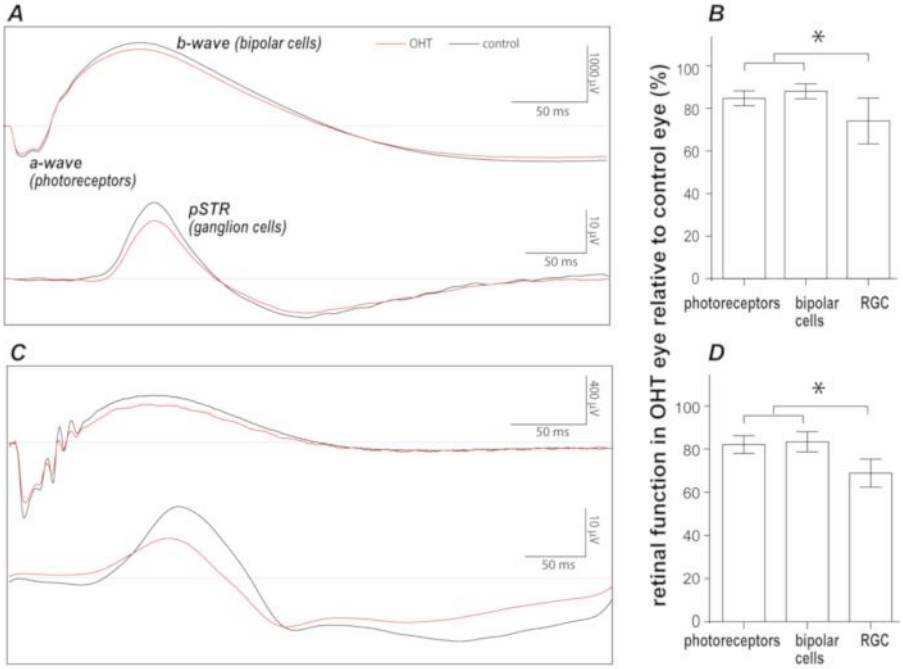


Figure 3. Chronic IOP elevation induced functional deficits particularly in the inner retina in both rats (A & B) and mice (C & D). A: Average ERG waveforms (n = 8 rats) in response to a bright and dim stimulus (2.07 and -5.31 log cd.s.m^{-2} for top and bottom trace respectively) after 8 weeks of IOP elevation. **B**: The relative amplitude of the pSTR, indicative of RGC function, was more affected than the photoreceptoral a-wave and the bipolar cell driven b-wave. **C** and **D** are as per **A** and **B** but derived from the average of 23 mice after 12 weeks of IOP elevation. Again, RGC dysfunction was more severe than photoreceptoral and bipolar cell dysfunction. Please click here to view a larger version of this figure.

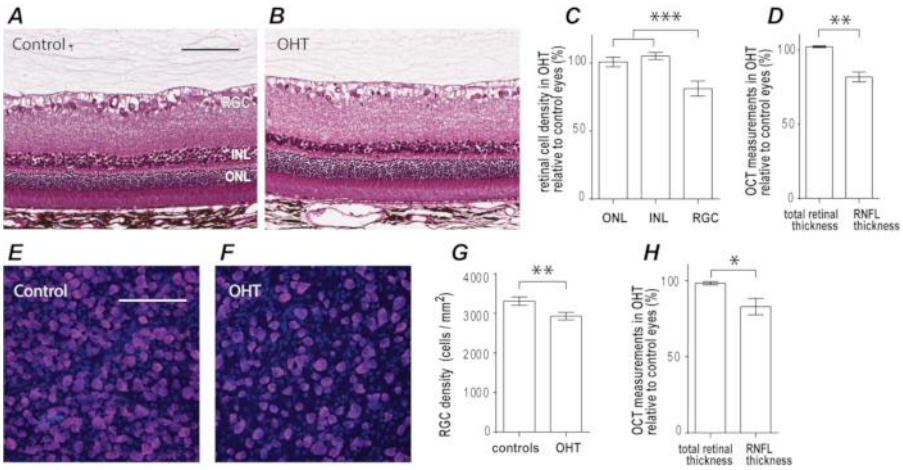


Figure 4. ERG: electroretinogram; OHT: ocular hypertension; IOP: intraocular pressure; pSTR: positive Scotopic Threshold Response; RGC: retinal ganglion cells; * P< 0.05. Error bars: standard error of mean. Data are reused with permission from previous work.[16,18] Please click here to view a larger version of this figure.

Discussion

The circumlimbal suture is a new model of chronic ocular hypertension. In addition to the studies from which the representative results are sourced[16,18], this animal model has been utilized in a number of recent studies[15,23,24,25,26]. Comparison across these previous reports shows that the method produces repeatable outcomes, including the magnitude of IOP elevation, as well as the brief IOP spike during model induction (see later discussion). Although the duration of IOP elevation needed to induce robust RGC changes is between 8 and 12 weeks, the model can be maintained for longer, with studies reporting outcomes for 15-16 weeks of IOP elevation[14,15]. In addition to repeatability, this method is relatively simple, cost effective, and can be used in both rats and mice. When compared with other approaches that involve penetrating the eye at model induction, this model is amenable to investigations that require clear optical media, such as electrophysiology or *in vivo* retinal imaging. One reason for this is that by avoiding paracentesis, the circumlimbal suture method aims to preserve the immune privilege of the eye and therefore minimize trauma-related inflammation and cataract. A previous study employing this technique, found that Iba-1 expression, a marker for inflammation, was not upregulated in the retina[15], however the presence of other inflammatory markers or anterior chamber inflammation have not yet been quantified in this model. Another advantage is that the IOP elevation can be reversed by suture removal, which

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is a simple procedure that can be done under light sedation and topical anesthesia[14,15]. This renders the circumlimbal suture a unique model for investigating the potential reversibility of ganglion cell injury in glaucoma[24].

Although the mechanism by which the suture procedure raises IOP is not completely understood, obstruction of aqueous outflow is the likely cause after ruling out several other factors. From previous studies, we have shown that the circumlimbal suture does not significantly alter anterior chamber depth or iridocorneal angle in both rats[15] and mice[16] and is therefore not a model of angle closure glaucoma. Additionally, as pupillary dilation and pupil size were not altered, the clarity of the optical media was preserved, and no frank inflammatory changes was observed with anterior chamber OCT or with retinal cross sections, we do not believe that intraocular pressure elevation arises through an inflammatory mechanism. Finally, our finding that IOP could be rapidly normalized after removal of the circumlimbal suture suggests that remodeling of the trabecular meshwork as a result of inflammation would be an unlikely cause of the IOP elevation[16,24]. Thus, it is likely that IOP elevation arises from aqueous outflow obstruction, either *via* compression of Schlemm's canal or the episcleral veins. Further investigation is underway to determine the precise cause of aqueous outflow obstruction induced by this model.

The circumlimbal suture has several limitations. One obvious concern is the initial IOP spike that occurs during the application of the suture, which gradually reduces over several hours. Indeed, an excessive IOP spike has the potential to induce ischemic-reperfusion injury, which is not typical of chronic open angle glaucoma. In this regard it is prudent to post surgically confirm normal retinal perfusion using ophthalmoscopy or OCT angiography.

The potential contribution of the IOP spike was recently addressed by comparing untreated control eyes with a sham control group where the suture was applied as per methods described above, and then removed after 2 days. In other words, these sham control eyes were subjected to the same acute IOP spike but not the chronic IOP elevation beyond 48 hours. We found that the long term outcomes, measured by ERG, OCT and RGC counts, remain unaltered in the sham controls when compared with untreated controls[16], showing that the initial IOP spike did not have an important role in the RGC deficit seen in this model. This is also supported by the fact that in the ocular hypertension (OHT) eyes, there was no correlation between the magnitude of the IOP spike and the RGC dysfunction in the long term, whereas there was a significant correlation with chronic IOP elevation[15]. Additionally, one study where the suture was removed after 8 weeks shows that ganglion cell fully recover, as measured by the pSTR[24], which supports the idea that the brief IOP spike resulting from the model induction makes little contribution to the retinal dysfunction found after chronic IOP elevation. Had the transient IOP spike been a contributing factor to the ganglion cell injury, one would not expect recovery after suture removal at week 8. Therefore, despite having the limitation of a transient IOP spike, the circumlimbal suture model of ocular hypertension is a useful addition to currently available small animal glaucoma models.

Although the aforementioned evidence supports the usefulness of this model, every effort should be made to minimize the transient IOP spike. The following may assist with model induction. First, the most common problem encountered is that IOP can return to normal a few days after suture application. The probable cause of this pressure normalization is that the suture knot gradually loosens over time. To troubleshoot, ensure the first (slip) knot is securely fastened before tying the second knot. This can be achieved by continuously maintaining tension on one end of the slip knot (arrow in **Figure 1A**) until the second knot is tied. The second most common issue is hyphema which can occur in the first few hours after suturing. In our experience, this was commonly associated with an excessively high IOP spike (usually ≥ 80 mmHg in rats and mice) or perforation of the eye when weaving the suture. Other complications of the procedure include cataract (usually reversible) in the short term, and loss of the suture in the long term due to suture slippage or tearing of the conjunctiva. We have not noted the development of any ocular surface infections in any cohort of rats or mice. For novices to microscopic surgery, some practice is required to master circumlimbal suture application. We have reported an initial success rate of 50% in our first cohort of mice (40 out of 81 mice)[16]. In our experience, this improves to 70 - 80% with practice. In a subsequent cohort of 60 mice, we found a total success rate of 70%, with hyphema (13%) and suture loss (17%) accounting for the 30% failure rate. In a cohort of 20 rats, we found a higher success rate (90%) than in mice, with only 2 rats being excluded due to hyphema (10%), and no animals were excluded due to suture loss. Perforation during surgery are rare occurrences in both rat and mouse models (~1%).

Disclosures

The authors have nothing to disclose.

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References

1. Morrison, J. C. *et al.* A rat model of chronic pressure-induced optic nerve damage. *Experimental Eye Research.* **64** (1), 85-96 (1997).
2. Feng, L., Chen, H., Suyeoka, G., & Liu, X. A laser-induced mouse model of chronic ocular hypertension to characterize visual defects. *Journal of Visualized Experiments.* (78) (2013).
3. Chiu, K., Chang, R., & So, K. F. Laser-induced chronic ocular hypertension model on SD rats. *Journal of Visualized Experiments.* (10), 549 (2007).
4. Quigley, H. A., & Addicks, E. M. Chronic experimental glaucoma in primates. I. Production of elevated intraocular pressure by anterior chamber injection of autologous ghost red blood cells. *Investigative Ophthalmology & Visual Science.* **19** (2), 126-136 (1980).
5. Bunker, S. *et al.* Experimental glaucoma induced by ocular injection of magnetic microspheres. *Journal of Visualized Experiments.* (96) (2015).
6. Weber, A. J., & Zelenak, D. Experimental glaucoma in the primate induced by latex microspheres. *Journal of Neuroscience Methods.* **111** (1), 39-48 (2001).
7. Moreno, M. C. *et al.* A new experimental model of glaucoma in rats through intracameral injections of hyaluronic acid. *Experimental Eye Research.* **81** (1), 71-80 (2005).

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8. Hoyng, P. F., Verbey, N., Thorig, L., & van Haeringen, N. J. Topical prostaglandins inhibit trauma-induced inflammation in the rabbit eye. *Investigative Ophthalmology & Visual Science.* **27** (8), 1217-1225 (1986).
9. Kezic, J. M., Chrysostomou, V., Trounce, I. A., McMenamin, P. G., & Crowston, J. G. Effect of anterior chamber cannulation and acute IOP elevation on retinal macrophages in the adult mouse. *Investigative Ophthalmology & Visual Science.* **54** (4), 3028-3036 (2013).
10. Waisbourd, M. *et al.* Reversible structural and functional changes after intraocular pressure reduction in patients with glaucoma. *Graefe's Archive for Clinical and Experimental Ophthalmology.* **254** (6), 1159-1166 (2016).
11. Foulsham, W. S., Fu, L., & Tatham, A. J. Visual improvement following glaucoma surgery: a case report. *BMC Ophthalmology.* **14** 162 (2014).
12. Anderson, A. J., & Stainer, M. J. A control experiment for studies that show improved visual sensitivity with intraocular pressure lowering in glaucoma. *Ophthalmology.* **121** (10), 2028-2032 (2014).
13. Ventura, L. M., Feuer, W. J., & Porciatti, V. Progressive loss of retinal ganglion cell function is hindered with IOP-lowering treatment in early glaucoma. *Investigative Ophthalmology & Visual Science.* **53** (2), 659-663 (2012).
14. Zhao, D. *et al.* in *ARVO abstract number 3696 - B0043.* annual meeting of Association for Research in Vision and Ophthalmology, Honolulu, Hawaii, USA, (2018).
15. Liu, H. H. *et al.* Chronic ocular hypertension induced by circumlimbal suture in rats. *Investigative Ophthalmology & Visual Science.* **56** (5), 2811-2820 (2015).
16. Zhao, D. *et al.* Characterization of the Circumlimbal Suture Model of Chronic IOP Elevation in Mice and Assessment of Changes in Gene Expression of Stretch Sensitive Channels. *Frontiers in Neuroscience.* **11** 41 (2017).
17. Nguyen, C. T. *et al.* Simultaneous Recording of Electroretinography and Visual Evoked Potentials in Anesthetized Rats. *Journal of Visualized Experiments.* 10.3791/54158 (113) (2016).
18. Van Koeverden, A. K., He, Z., Nguyen, C. T., Vingrys, A. J., & Bui, B. V. Systemic hypertension is not protective against chronic IOP elevation in a rodent model. *Scientific Reports.* **8** (1), 7107 (2018).
19. Rodriguez, A. R., de Sevilla Muller, L. P., & Brecha, N. C. The RNA binding protein RBPMS is a selective marker of ganglion cells in the mammalian retina. *Journal of Comparative Neurology.* **522** (6), 1411-1443 (2014).
20. Aihara, M., Lindsey, J. D., & Weinreb, R. N. Twenty-four-hour pattern of mouse intraocular pressure. *Exp Eye Research.* **77** (6), 681-686 (2003).
21. Jia, L., Cepurna, W. O., Johnson, E. C., & Morrison, J. C. Patterns of intraocular pressure elevation after aqueous humor outflow obstruction in rats. *Investigative Ophthalmology & Visual Science.* **41** (6), 1380-1385 (2000).
22. Nadal-Nicolas, F. M., Jimenez-Lopez, M., Sobrado-Calvo, P., Nieto-Lopez, L., Canovas-Martinez, I., Salinas-Navarro, M., Vidal-Sanz, M., & Agudo, M. Brn3a as a marker of retinal ganglion cells: qualitative and quantitative time course studies in naive and optic nerve-injured retinas. *Investigative Ophthalmology & Visual Science.* **50** (8), 3860-3868. (2009).
23. Liu, H. H., & Flanagan, J. G. A Mouse Model of Chronic Ocular Hypertension Induced by Circumlimbal Suture. *Investigative Ophthalmology & Visual Science.* **58** (1), 353-361 (2017).
24. Liu, H. H., He, Z., Nguyen, C. T., Vingrys, A. J., & Bui, B. V. Reversal of functional loss in a rat model of chronic intraocular pressure elevation. *Ophthalmic & Physiological Optics.* **37** (1), 71-81 (2017).
25. Liu, H. H., Zhang, L., Shi, M., Chen, L., & Flanagan, J. G. Comparison of laser and circumlimbal suture induced elevation of intraocular pressure in albino CD-1 mice. *PLoS One.* **12** (11), e0189094 (2017).
26. Shen, H. H. *et al.* Intraocular Pressure Induced Retinal Changes Identified Using Synchrotron Infrared Microscopy. *PLoS One.* **11** (10), e0164035 (2016).

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