Original Article

Biomechanical testing of a modified knotless transscleral suture fixation technique: an *ex vivo* study

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Background: To investigate the safety and effectiveness of a modified transscleral suture through *ex vivo* tests.

Methods: *Ex vivo* tests were performed in full-thickness porcine scleral pieces using modified knotless transscleral zigzag-shaped suture (Z-suture) fixation technology. The minimum traction force required to loosen or rupture the suture was assessed. The effects of different polypropylene sutures (10-0, 8-0), different suture spans (2.0, 3.0, 4.0 mm), different passes (3, 4, 5 passes), and scleral grooves were investigated.

Results: The average minimum traction forces required to loosen 10-0 polypropylene sutured for 3.0 mm with a suture span of 3, 4, and 5 passes, were 0.18 (0.15–0.18), 0.22 (0.21–0.22), and 0.37 (0.37–0.37) N, respectively. The maximum traction force to prevent the suture from rupturing for the 10-0 polypropylene suture was 0.37–0.41 N in the sclera. The average of the minimum traction forces required to loosen the 8-0 polypropylene sutured with 5 passes and spanning 2.0, 3.0, and 4.0 mm were 0.37 (0.3 –0.39), 0.42 (0.42–0.45), and 0.50 (0.50–0.51) N, respectively, which were 14–28% higher than that of the 10-0 polypropylene suture under same conditions (all P values <0.01). In addition, there was no statistical difference (P=0.3258) for the 8-0 polypropylene suture used with a 3.0-mm suture span and 5 passes between conditions with or without scleral grooves.

Conclusions: The minimum traction force required to loosen or rupture the suture in the sclera was associated with suture specification, suture span, and the number of passes, but was uncorrelated with double scleral grooves. The 8-0 polypropylene suture with double scleral grooves may be a more favorable choice for knotless transscleral fixation.

Keywords: Biomechanical test; transscleral fixation; modified surgery; Z-suture

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Introduction

Congenital ectopia lentis (CEL) is a disease caused by the elongation or disjunction of the lens zonule due to abnormal congenital development, which causes the lens to deviate from the normal position (1). CEL often leads to severe ametropia, including irregular astigmatism, anisometropia, and monocular diplopia, which significantly affects the quality of vision of patients (2). Surgery is currently an effective treatment for CEL, however, there is still no consensus on the best surgical method for these patients (3). Transscleral suture fixation of the intraocular lens (IOL) is a commonly used surgical method for congenital lens dislocation (4-6). Although many modified techniques for IOL transscleral fixation have been introduced, few biomechanical evaluations have been conducted on this surgical approach (7).

Among the commonly used techniques, suture rupture and knot-related problems are the most reported complications (8-10). Traditional transscleral suture fixations are performed using a 10-0 polypropylene suture (11), which can provide enough tensile in the short-term. However, the IOL dislocation rate has increased over time, suggesting that suture rupture caused by degeneration of sutures is a factor that cannot be ignored (12,13). Recently, the 8-0 polypropylene suture has been used in traditional transscleral suture fixations due to its high tensile strength and comparatively lower susceptibility to degradation, but few studies have evaluated the biomechanical performance of 8-0 polypropylene suture in patients with IOL transscleral suture fixation (14,15). Additionally, knot-related problems, such as knot exposure, knot erosion, and suture erosion, are difficult problems caused by traditional transscleral suture fixations (8,16,17). To reduce knot-related complications, Szurman *et al.* first introduced a knotless IOL intrascleral fixation procedure using a 10-0 polypropylene suture and a zigzag-shaped suture (Z-suture) to fix the IOL (18). However, in their research, only the 10-0 polypropylene suture was evaluated, and the effect of suture span on friction force was not discussed. The sutureless intrascleral fixation technique, which fixes the haptics of the IOL in the scleral tunnels, was introduced to avoid suture-related complications. A good prognosis was achieved in adults (19-21). However, it has not been widely performed in children, and the long-term safety and efficacy of the sutureless technique need to be investigated (3).

The porcine sclera has been considered a good model for human sclera (22,23). In this study, we aimed to investigate the biomechanical characteristics of the porcine sclera under different stitch parameters with the intention of providing biomechanical data for IOL fixation in clinical practice, especially for IOL fixation in children. We present the following article in accordance with the ARRIVE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-3184/rc) (24).

Methods

This study was approved by the relevant regulations of the Animal Care and Ethics Committee of Zhongshan Ophthalmic Center, Sun Yat-sen University (ID: 2019KYPJ184). Experiments were performed in compliance with the relevant laws and the institutional guidelines for the care and use of animals. A protocol was prepared before the study without registration. Fifty-five fresh porcine eyes (Yorkshire swine; both genders; 6 months old; 110–125 kg) were obtained from the local abattoir within 2 hours postmortem. The experiments were performed in the simulated surgery demonstration classroom in the Zhongshan Ophthalmic Center, Sun Yat-sen University.

Specialized ophthalmic surgical instruments were used for porcine eye preparation, and the double-armed 8-0 and 10-0 polypropylene suture needle (Prolene; Ethicon, Inc., Bridgewater, NJ, USA) were used to suture the sclera of the porcine eyes. The minimum traction force required for mobilizing the suture was measured by a high-precision, push–pull dynamometer (ZQ-990LA; Zhiqu Test Machine Inc.; Dongguan, China), which was accurate to 0.01 N.

The porcine eye was fixed on an eye seat model. The conjunctiva was separated at the 4 and 10 o'clock directions to expose the sclera. A total of 110 traction trials were performed using this setup. Two 4.0-mm-long parallel marked lines were drawn by a dye pen 2.0 mm posterior to the limbus. The preset suture span (2.0, 3.0, or 4.0 mm) determined the distance between the above 2 marked lines (*Figure 1A*). The Z-suture technique used in this study was similar to that of a previous study (18). In brief, the suturing was started 2.0 mm posterior to the limbus from one marked line to another marked line. The next pass was repeated in the opposite direction, resulting in a zigzag pattern. The number of passes ranged from 3 to 5; the distance between the 2 adjacent passes was about 1.0 mm, and the suture depth was about half of the scleral thickness. Once the Z-suture was completed, the suture was cut without any knot (*Figure 1B*). Then, the sclera was cut into a 15 mm × 15 mm scleral piece with partial limbus and fixed

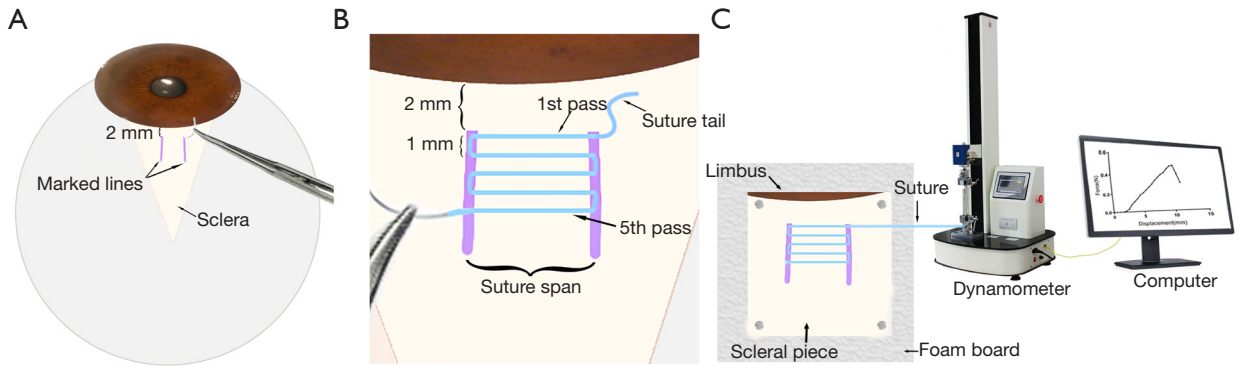

Figure 1 Schematic diagram of traction force test. (A) The conjunctiva was separated to expose the sclera. Two 4.0-mm-long, parallel-marked lines were drawn by a dye pen 2.0 mm posterior to the limbus. The preset suture span (2.0, 3.0, or 4.0 mm) determined the distance between these 2 marked lines. (B) Suturing was started at 2.0 mm posterior to the limbus from one marked line to another marked line. The next pass was repeated in the opposite direction, resulting in a zigzag pattern. The number of passes ranged from 3 to 5; the distance between the 2 adjacent passes was about 1.0 mm, and the suture depth was about half of the scleral thickness. Once the Z-suture was completed, the suture was cut without any knot. (C) The sclera was cut into a 15 mm × 15 mm scleral piece with partial limbus and was fixed on a foam board. The dynamometer dragged the suture tail parallel to the limbus at a speed of 0.08 mm/s. The traction force was continuously recorded and uploaded in real-time to a computer and displayed graphically. The minimum traction force required to loosen or rupture the suture was automatically determined for each trial based on the sudden drop in the force-displacement curve.

on a foam board. The dynamometer dragged the suture tail parallel to the limbus at a speed of 0.08 mm/s. The traction force was continuously recorded and uploaded in real time to a computer and displayed graphically. The minimum traction force required to loosen or rupture the suture was automatically determined for each trial based on the sudden drop in the force-displacement curve (25) (*Figure 1C*).

The experiments were performed with combinations of different polypropylene sutures (10-0 and 8-0 sutures), different suture spans (2.0, 3.0, 4.0 mm), and different suture passes (3, 4, 5 passes). In all, 90 scleral pieces from different porcine eyes were randomly divided into 18 subgroups. Each subgroup contained 5 scleral pieces. Experiments using the 10-0 polypropylene suture group were considered the control group. The minimum traction force required to loosen or rupture the suture was recorded.

Another 4 subgroups trials (both 10-0 polypropylene suture and 8-0 polypropylene suture with or without grooves) were conducted to investigate the effect of scleral grooves on traction force. Each subgroup also contained 5 scleral pieces from different porcine eyes. In brief, 2 4.0-mm-long, parallel, marked lines were drawn 2.0 mm posterior to the limbus at a distance of 3.0 mm. Next, double scleral grooves were carved precisely in the abovementioned marked lines. The depth of the scleral grooves was half of the scleral thickness. Then, the suture was shuttled from one groove to the other groove with 5 passes and eventually buried in the scleral grooves. The minimum traction force required to loosen or rupture the suture was recorded.

Statistical analysis

The minimum traction force under the same stitch parameters was repeated 5 times, and the results are presented as median (interquartile range). Data distribution was assessed using the quantile-quantile (Q-Q) plot. The Wilcoxon rank-sum test was used to compare the differences between groups, with a P value <0.05 regarded as statistically significant. The statistical analysis was performed using Stata software v. 15.0 (StataCorp., College Station, TX, USA) and graphed by GraphPad Prism v. 7.04 (GraphPad Software Inc., San Diego, CA, USA).

Results

Table 1 shows the minimum traction force required to loosen or rupture the suture in the Z-suture setting without double scleral grooves under different stitch parameters. The average minimum traction forces of the 8-0 polypropylene suture spanning 2.0, 3.0, and 4.0 mm with 5 passes were 0.37 (0.37–0.39), 0.42 (0.42–0.45), and

Table 1 Traction force needed to disrupt the Z-suture setting under different conditions

Stitch parameters	10-0 polypropylene suture (N)	8-0 polypropylene suture (N)	P value
2.0 mm			
5 passes	0.29 (0.28–0.29)	0.37 (0.37–0.39)	0.0071
4 passes	0.19 (0.17–0.19)	0.27 (0.23–0.27)	0.0071
3 passes	0.10 (0.10–0.11)	0.17 (0.17–0.18)	0.0071
3.0 mm			
5 passes	0.37 (0.37–0.37)*	0.42 (0.42–0.45)	0.0062
4 passes	0.22 (0.21–0.22)	0.30 (0.30–0.32)	0.0072
3 passes	0.18 (0.15–0.18)	0.22 (0.22–0.25)	0.0071
4.0 mm			
5 passes	0.41 (0.39–0.41)*	0.50 (0.50–0.51)	0.0071
4 passes	0.32 (0.32–0.33)	0.43 (0.43–0.43)	0.0062
3 passes	0.20 (0.20–0.23)	0.32 (0.32–0.33)	0.0071

Data are shown as median (interquartile range), and P<0.05 is considered statistically significant. *, the traction force exceeded the tensile strength of the 10-0 polypropylene suture and resulted in suture rupture.

0.50 (0.50–0.51) N, respectively, which are 14–28% higher than those of the 10-0 polypropylene suture under the same conditions (all P values <0.01). Additionally, we observed that when we performed the Z-suture with 5 passes and a suture span of 3.0 mm or larger, the 10-0 polypropylene suture would rupture rather than loosen, which suggests that the traction force exceeded the tensile strength of the 10-0 polypropylene suture under the above conditions. However, the 8-0 polypropylene suture did not rupture under the above conditions.

The changes in traction force with different sutures and different suture conditions are shown in *Figure 2*. As the zigzag passes increased from 3 to 5 passes and the suture span increased from 2.0 to 4.0 mm, a larger traction force was needed to disrupt the Z-suture. Additionally, the 8-0 polypropylene suture required more force to be disrupted compared to the 10-0 polypropylene suture under the same suture conditions (all P values <0.01).

Figure 3 compares the traction force needed to disrupt a Z-suture with or without scleral grooves. For both the 8-0 and 10-0 polypropylene sutures, using a 3.0-mm suture span and 5 passes, the traction force required to disrupt the suture in the sclera with scleral grooves was similar to that without scleral grooves.

Table 2 summarizes previous studies which have reported postoperative suture-related complications. For 10-0 polypropylene sutures, the incidence of suture erosion, suture knot exposure, and suture rupture were 0 to 73%, 0 to 3.8%, and 0 to 16.7%, respectively. However, none of the above suture-related complications were reported in studies using the 8-0 polypropylene suture.

Discussion

Although Szurman's Z-suture is not widely used at present, it is a viable solution for avoiding knot-related complications and is a promising knotless transscleral fixation technique. This study aimed to assess the biomechanical characteristics of the transscleral suture technique based on *ex vivo* tension tests. We found that the friction produced by the 8-0 polypropylene suture was greater than that of the 10-0 polypropylene suture when the suture spanned 3.0 mm for 5 passes. The 10-0 polypropylene suture spanning 3.0 mm for 5 passes was adequate for the transscleral suture technique, as the suture would rupture first rather than loosen under these parameters. However, the 8-0 polypropylene suture was able to provide greater friction than the 10-0 suture without rupture when it spanned 3.0 mm for 5 passes. Double scleral grooves with a thickness up to half of the sclera, which could potentially reduce the risk of suture exposure and the discomfort of patients, did not reduce the friction generated by Z-suture fixation. However, this was not applied and tested in Szurman's method (18).

Previous studies have reported that 10-0 polypropylene

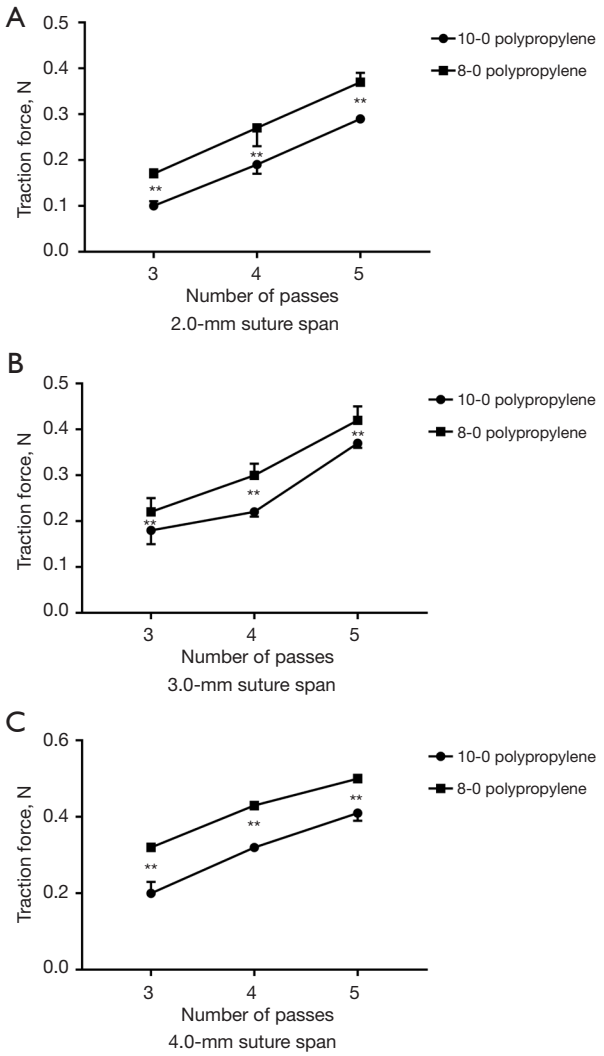

Figure 2 Traction force tests under different number of passes for 10-0 and 8-0 polypropylene sutures with a 2.0-mm suture span (A), 3.0-mm suture span (B), and 4.0-mm suture span (C). **, P<0.01.

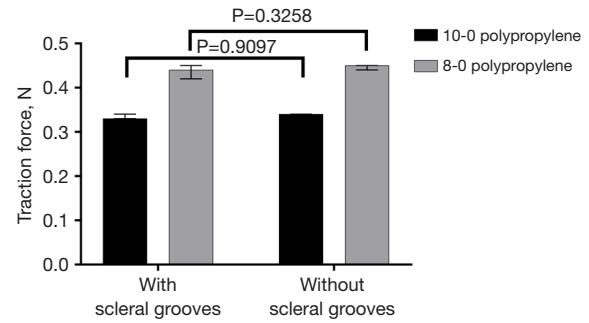

Figure 3 Traction force test under conditions with or without scleral grooves for the 10-0 and 8-0 polypropylene sutures using a 3.0-mm suture span and 5 passes.

sutures could produce a traction force adequate for maintaining the normal position of the IOL in most cases (26,27). However, another retrospective study found that rupture of the 10-0 polypropylene suture was observed in 16.7% of eyes after a mean 7.5 postoperative years (13). Additionally, with the traditional transscleral suture technique, suture-related complications, including suture erosion and scleral atrophy, have occurred even when knots have been hidden under a scleral flap or concealed in a scleral pocket or a scleral groove (8). Due to the unavoidable shortcomings of traditional suture fixation techniques, an increasing number of studies have reported modified IOL suture fixation techniques, mainly focusing on solving suture-related complications. For example, in a previous study in which thicker sutures were used to reduce the incidence of suture erosion, slightly reduced suture rupture rates (13.8%) were observed with the 9-0 polypropylene suture during a mean follow-up time of 63.9 months (28). Another study used an 8-0 polypropylene suture for IOL fixation, and no suture erosion complications were reported during the follow-up of 10 months (14). To reduce the exposure risk of knots and sutures, a sutureless scleral fixation technique was recently developed (19-21). However, these techniques are more challenging to execute and rarely supported by biomechanical evidence. Szurman *et al.* creatively applied the knotless Z-suture technique to avoid knot-induced complications (18). However, their study only evaluated the biomechanics of the 10-0 polypropylene suture with the downside of the sutures being exposed to the outside of the sclera, which is potentially risky and unsightly. Thus, it is essential to evaluate the biomechanical characteristics of different sutures under different stitch parameters in transscleral suture techniques.

In this study, we aimed to compare the traction force of the 8-0 polypropylene suture and the 10-0 polypropylene suture under different stitch parameters. The minimum traction force required to loosen or rupture the suture (0.37–0.41 N) was similar to that of Szurman's Z-suture (0.37–0.41 N) when the Z-suture spanned 3.0 to 4.0 mm for 5 passes using the 10-0 polypropylene suture, which further confirms the biomechanical characteristics of the 10-0 polypropylene suture in transscleral suture techniques. Notably, with the increase of the traction force, all 10-0 polypropylene sutures ruptured first rather than becoming loosened in the sclera when the Z-suture span was more than 3.0 mm for 5 passes. These results suggest that when the span of the 10-0 polypropylene suture is 3.0 mm, only 5 passes are needed. For the 8-0 polypropylene suture, there

Table 2 Previous reports on suture-related complications of 10-0 and 8-0 polypropylene sutures in the transscleral fixation technique

Author	Study year	Sample size	Suture type	Scleral treatment	Follow-up duration (months)	Suture-related complications		
						Suture erosion	Suture knot exposure	Suture breakage
Solomon K *et al.* (8)	1993	30 eyes	10-0 polypropylene	Scleral flaps	23	22 (73.3%)	–	0
Uthoff D *et al.* (16)	1998	624 eyes	10-0 polypropylene	Conjunctival flaps or scleral flaps	Not specified	112 (17.9%)	–	0
Luk AS *et al.* (12)	2013	104 eyes	10-0 polypropylene	Without	73.4±43	0	4 (3.8%)	2 (1.9%)
Cavallini GM *et al.* (9)	2015	13 eyes	10-0 polypropylene	Without	60–129	6 (46.2%)	–	0
Yang CS *et al.* (10)	2016	15 eyes	10-0 polypropylene	Sclera grooves	45	3 (20.0%)	–	0
Dimopoulos S *et al.* (13)	2018	66 eyes	10-0 polypropylene	Z-suture	64	0	0	11 (16.7%)
John T *et al.* (14)	2018	9 eyes	8-0 polypropylene	Scleral grooves	10	0	0	0
Mo B *et al.* (15)	2020	28 eyes	8–0 polypropylene	Scleral pockets	10.18±2.76	0	0	0

were no ruptures even when the traction force reached 0.50 N, suggesting that 8-0 polypropylene sutures can provide more tension for transscleral suture techniques.

Little is presently been known about the effect of suture span on the tension of knotless sutures in transscleral suture techniques. In the current study, we demonstrated that the minimum traction force required to loosen a suture increases with increased suture span, both for 10-0 and 8-0 polypropylene sutures. Similarly, the traction force also increased with an increase in the number of suture passes. We also found that the traction force of the 8-0 polypropylene suture spanning 3.0 mm for 5 passes was equal to or even higher than that of the 10-0 polypropylene suture spanning 4.0 mm for 5 passes. Considering that a wider suture span has been correlated with an increased risk of trauma and surgical complications, we recommend use of the 8-0 polypropylene suture spanning 3.0 mm for 5 passes in transscleral suture fixation.

A previous study reported that most patients with CEL undergoing surgery are children under 18 years old (29) and that these patients' frequent eye rubbing behavior may lead to the exposure of sutures. Burying knots in a scleral groove has been widely used to avoid suture exposure and reduce the discomfort of patients (30,31). In the current study, we demonstrated through an *ex vivo* traction force test that friction forces provided by the Z-suture are similar between sutures with and without double scleral grooves. Therefore, we recommend the Z-suture with double scleral grooves to reduce the incidence of suture-related complications.

There were some limitations of this study. First, the experimental results from porcine eyes cannot be directly applied to human conditions. Sclerae from large-sized pigs have a high thickness, lower permeability coefficient, and lower light transmission than do those from humans (23,32,33). However, human and porcine sclerae have similar water content, histology, and collagen bundle organization (23). Therefore, the porcine sclera was a relatively suitable material for this experiment. Secondly, only 10-0 and 8-0 polypropylene sutures using Z-suture fixation were tested in this study. However, this study discusses a modified knotless Z-suture fixation technique and provides an important biomechanical reference for clinical transscleral suture. Further clinical trials are needed to verify the superiority of this method. More biomechanical information on different sutures in different IOL fixations is required to evaluate the postoperative suture rupture rate and patient satisfaction.

Conclusions

In summary, this study proves that the 10-0 polypropylene suture will rupture rather than loosen in the sclera with a Z-suture spanning 3.0 mm for 5 passes. In addition, the 8-0 polypropylene suture may provide greater friction

with a Z-suture spanning 3.0 mm for 5 passes in the sclera, even when double scleral grooves are used. Our study suggests that the Z-suture with a 8-0 polypropylene suture and double scleral grooves may be a better choice for transscleral fixation of the IOL.

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Footnote

Reporting Checklist: The authors have completed the ARRIVE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-3184/rc

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-3184/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-3184/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was approved by the relevant regulations of the Animal Care and Ethics Committee of Zhongshan Ophthalmic Center, Sun Yat-sen University (ID: 2019KYPJ184). Experiments were performed in compliance with the relevant laws and the institutional guidelines for the care and use of animals.

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