Ophthalmic Research

Ophthalmic Imaging

Ophthalmic Res 2026;69:1–7
DOI: 10.1159/000550144

Received: July 24, 2025
Accepted: December 6, 2025
Published online: December 17, 2025

Changes of Schlemm's Canal and Trabecular Meshwork Dimensions from Digital Ocular Massage in High Myopia: A Pilot Study

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Keywords

Schlemm's canal · Trabecular meshwork · Intraocular pressure · High myopia · Ocular massage

Abstract

Introduction: This study evaluated changes of Schlemm's canal (SC) and trabecular meshwork (TM) dimensions from digital ocular massage in high myopia. ***Methods:*** Healthy participants with either high myopes (≤−6.00 D) or with refractive errors ≥ −3.00D were recruited. Right eyes underwent digital ocular massage. Intraocular pressure (IOP) was monitored using rebound tonometry. Anterior chamber angle was imaged using swept-source optical coherence tomography. IOP, SC, and TM were compared before and immediately after digital ocular massage. ***Results:*** Sixteen eyes from 16 high myopes (−6.00 D to −8.125 D) and 18 eyes from 18 control participants (+0.50 D to −2.875 D) were included. There was no difference in age and gender distribution between the two groups. The two groups shared similar IOP, SC area, SC length, TM length, and TM thickness at baseline. Both groups had significant IOP drop from a baseline of around 15 mm Hg to 9 mm Hg after ocular massage. High myopia demonstrated a mild enlargement of the SC area (from 10,655.60 ± 4,362.02 μm^2 to 12,632.40 ± 4,393.19 μm^2, p = 0.098), not reaching statistical significance. The TM thickness was reduced from 160.21 ± 26.29 μm to 151.77 ± 26.91 μm, p = 0.018). Control eyes showed significant enlargement of SC area (from 8,540.71 ± 3,905.98 μm^2 to 11,686.53 ± 4,586.37 μm^2, p = 0.001) and SC length (from 240.47 ± 69.96 μm to 280.40 ± 59.37 μm, p = 0.041). ***Conclusion:*** Control eyes showed significant enlargement of SC in responding to IOP drop while high myopia did not.

Introduction

Glaucoma is a leading course of irreversible blindness [1]. While elevated intraocular pressure (IOP) does not independently cause glaucoma, it remains the only modifiable risk factor for this condition. IOP regulation is determined by the production and outflow of the aqueous humor. The majority of the aqueous humor drains through the conventional pathway involving the trabecular meshwork (TM) and the Schlemm's canal (SC) [2]. A small amount of aqueous humor is drained through the unconventional pathway via the uveoscleral outflow [3]. Myopia is widely prevalent worldwide, especially in Asia. High myopia significantly increases the chance of glaucoma onset [4, 5]. Ocular massage could

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help control IOP such as after trabeculectomy [6, 7], or after Ahmed valve surgery [8]. Filtration bleb was found enlarged from ocular massage; hence, aqueous outflow could be improved to lower the IOP [9]. Ocular massage could also reduce IOP spikes after intravitreal injection of bevacizumab [10, 11]. Practitioners could perform ocular massage in patients with acute angle closure attacks to lower their IOP temporarily, before any medical treatment can be offered [12].

With good-resolution anterior segment optical coherence tomography (AS-OCT), the corneoscleral region can be imaged to identify the SC and TM. Chen et al. [13] applied AS-OCT and found that eyes with high myopia had larger SC area and length at all four quadrants compared with low myopia. Kagemann et al. [14] found that the SC area was significantly smaller in patients with glaucoma than in healthy subjects. Chung et al. [15] measured SC area and TM width of newly diagnosed open-angle glaucoma patients. Greater IOP reduction was found from IOP-lowering medications in patients with larger baseline SC area. The TM width had no effect on IOP reduction. Therefore, an increased SC area may enhance aqueous outflow, leading to a reduced IOP. Our group applied AS-OCT and found that dilatation of SC from digital ocular massage contributed to the IOP lowering effect [16]. It is noteworthy that eyes with a smaller baseline SC area exhibited a more significant SC expansion (Fig. 5 of Wu et al. [16]).

Despite eyes with high myopia exhibiting bigger SC dimensions compared to those with low myopia, may highly myopic eyes have a diminished IOP reduction from ocular massage when compared to a control group without high myopia? This represented a deficiency in the existing literature. The current study investigated effects of digital ocular massage on IOP variation in patients with high myopia. We hypothesized that eyes with high myopia may possess a larger SC dimension than the control group yet may demonstrate a lesser SC expansion from ocular massage compared to the control group.

Methods

This study was performed in accordance with the Declaration of Helsinki. This human study was approved by Institutional Review Board of The Hong Kong Polytechnic University – approval: HSEARS2022022001. All adult participants provided written informed consent to participate in this study.

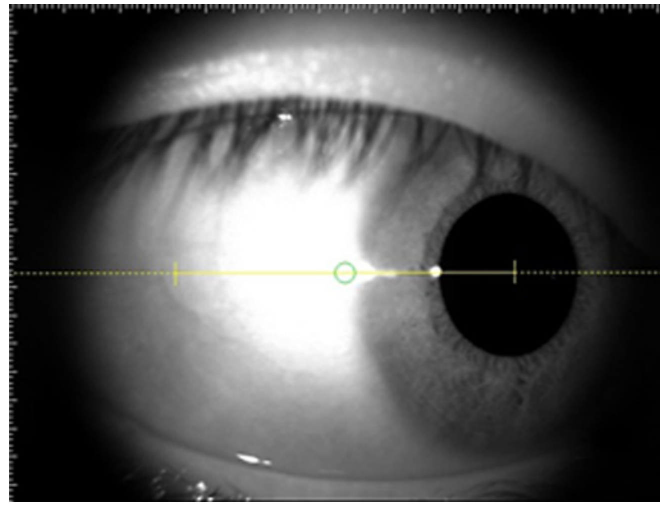

Fig. 1. Example showing a yellow reference line across the corneal reflex.

Healthy adult high myopia (sphere + ½ cylinder ≤ −6.00 D) and control group (sphere + ½ cylinder ≥ −3.00 D) were recruited and measured with auto-refraction (Nidek ARK-510A, Nidek Co., Ltd., Japan). Participants must be a minimum of 18 years old. Additional inclusion criteria included the absence of ocular disease or ocular surgery, as well as the absence of chronic illness. Participants with IOP of 21 mm Hg or above were excluded. Right eye was selected as the study eye. Baseline measurements included noncontact tonometry (Nidek NT-530P, Nidek Co., Ltd., Japan), rebound tonometry (Icare ic200, ICare Finland Oy, Helsinki, Finland), and swept-source AS-OCT (Casia SS-1000, Tomey Corporation, Nagoya, Japan). The Series mode of the Icare 2000 was used to automatically obtain six consecutive measurements. The device displayed an average value of the four best measurements. This averaged IOP reading was considered the first attempt. Each acquisition consisted of two attempts, and the average results were used for the analysis.

A customized 3D-angle high-definition protocol was used from swept-source AS-OCT (raster of 128 B scans each with 512 A scans over a 6 mm × 6 mm region). Participants were seated in a dark room and instructed to look at a nasal peripheral fixation light in order to acquire images of the temporal corneoscleral region of the right eye. To ensure consistency before and after the ocular massages, one examiner took the images and placed a reference line across the corneal reflex during each acquisition (Fig. 1).

All captured images were exported and manually analyzed by an independent examiner using the ImageJ software (National Institutes of Health, USA). For each

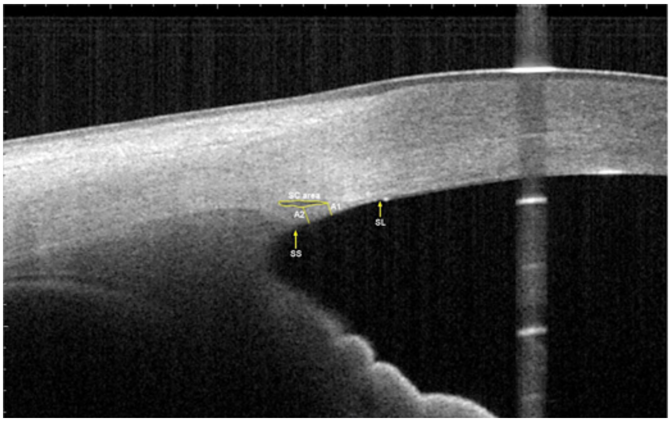

Fig. 2. Example showing delineation of the Schlemm's canal (SC) area and the marking of scleral spur (SS), Schwalbe line (SL). Trabecular meshwork thickness is an average of A1 and A2.

image, an outline of the SC was drawn freehand, and the area surrounded by the outline of the SC was depicted (Fig. 2). The diameter of the SC was measured from the posterior to the anterior end points of the outline. The TM length was defined as the distance between the scleral spur and Schwalbe's line. The TM thickness was calculated as the average of two measurements made at the anterior end point of the SC and halfway down the SC. Our prior study examined intra-examiner repeatability and inter-examiner reproducibility utilizing ten AS-OCT images. The intra-examiner intraclass correlation coefficient and coefficient of variation (CoV) were 0.995 and 2.69%, respectively, whereas the inter-examiner intraclass correlation coefficient and CoV were 0.973 and 6.91%, respectively [16].

Each subject was taught to perform ocular massage using their fingertips [17]. To standardize the procedure, a video clip regarding ocular massage was prepared and shown to each subject. The participants were instructed to close their eyes and place their index finger on the surface of the right upper eyelid. A light force was applied in circular motion for 2 s, followed by a 2-s release, and this 4-s cycle was repeated for 10 min. The participants were reminded not to open their eyes during the ocular massage. An examiner helped ensure that the participants performed the procedure correctly and for 10 min. Rebound tonometry and swept-source AS-OCT were performed immediately after the ocular massages.

Statistical Analysis

All statistical analyses were performed using SPSS Statistics (version 26, IBM SPSS Inc., USA). The normality of the data was checked using the Shapiro-Wilk test. Results were presented as mean ± standard deviation. Rebound tonometry and swept-source AS-OCT before and immediately after digital ocular massage were compared in the high myopia group and the control group. The corneoscleral parameters included SC area, SC length, TM length, and TM thickness. Chen et al. [13] found that Chinese high myopes had larger SC area (7,274.8 ± 3,247.4 μm^2) than low myopes (4,631.1 ± 2,431.9 μm^2) in the temporal quadrants. We need 16 participants in each group to demonstrate similar difference with 0.05 alpha and 80% power.

Results

The current study included 16 eyes from 16 high myopia and 18 eyes from 18 control participants. The two groups had similar age and gender distribution (Table 1). The temporal SC area of high myopia (10,655.60 ± 4,362.02 μm^2) was larger than the control group (8,540.71 ± 3,905.98 μm^2) but not reaching statistical significance ($p = 0.164$).

Both groups had significant IOP drop from baseline, from around 15 mm Hg to 9 mm Hg after ocular massage (Tables 2, 3). Baseline IOP of high myopia was 14.82 ± 1.98 mm Hg, which dropped to 9.29 ± 1.87 mm Hg after ocular massage ($p < 0.001$). High myopia had enlarged SC area, from 10,655.60 ± 4,362.02 μm^2 at baseline to 12,632.40 ± 4,393.19 μm^2 after ocular massage. This change did not reach statistical significance ($p = 0.098$). The TM thickness was reduced from 160.21 ± 26.29 μm to 151.77 ± 26.91 μm ($p = 0.018$).

Control eyes had similar IOP drop as high myopia after ocular massage, from 15.95 ± 3.19 mm Hg to 9.18 ± 2.40 mm Hg ($p < 0.001$). There was significant enlargement of the SC area (from 8,540.71 ± 3,905.98 μm^2 to 11,686.53 ± 4,586.37 μm^2, $p = 0.001$) and SC length (from 240.47 ± 69.96 μm to 280.40 ± 59.37 μm, $p = 0.041$). There was no significant change in TM. Figure 3a and b exemplify AS-OCT images from a control subject, illustrating the enlargement of the SC (increased SC area and extended SC length) following ocular massage.

Discussion

In the current study, we found a significant IOP drop from digital ocular massage. This is similar to our previous finding [16]. The mechanism of IOP drop is partly due to a dilatation of the SC.

Chen et al. [13] found that high myopia had larger SC area and length than low myopia. Significant difference was found in the superior, temporal, and nasal quadrants for SC area, whereas SC length was significantly larger in

Table 1. Results (mean ± standard deviation, range) of high myopes and control at baseline

	High myopes	Range	Control	Range	Significance
Age, years	22.12±4.95	18–40	21.39±1.72	18–26	*p = 0.621
SER, D	−6.88±0.64	−6.00 to −8.13	−1.11±1.17	0.50 to −2.88	p < 0.001
Gender	7 male and 9 female		9 male and 9 female		Chi^2 = 0.716
NCT, mm Hg	16.24±2.10	12.00–19.30	16.11±2.84	11.30–20.30	p = 0.874
IOP, mm Hg	14.82±1.98	11.45–17.50	15.95±3.19	11.35–20.70	*p = 0.251
SCA, μm^2	10,655.60±4,362.02	5,324.86–23,346.34	8,540.71±3,905.98	3,475.82–18,764.57	*p = 0.164
SCL, μm	289.33±90.99	123.28–498.71	240.47±69.96	116.59–380.57	p = 0.087
TML, μm	759.73±141.29	497.77–1,013.16	724.43±90.04	599.86–913.04	p = 0.386
TMT, μm	160.21±26.29	119.09–220.35	146.59±17.36	126.33–179.68	p = 0.081

SER, spherical equivalent refraction; NCT, noncontact tonometry; IOP, intraocular pressure from rebound tonometry; SCA, Schlemm's canal area; SCL, Schlemm's canal length; TML, trabecular meshwork length; TMT, trabecular meshwork thickness. *Nonparametric test.

Table 2. Results (mean ± standard deviation and range) of high myopes before and after ocular massage

	Before	Range	After	Range	Significance
IOP, mm Hg	14.82±1.98	11.45–17.50	9.29±1.87	7.25–13.50	p < 0.001
SCA, μm^2	10,655.60±4,362.02	5,324.86–23,346.34	12,632.40±4,393.19	6,540.58–24,897.47	*p = 0.098
SCL, μm	289.33±90.99	123.28–498.71	296.38±71.34	159.85–431.28	p = 0.758
TML, μm	759.73±141.29	497.77–1,013.16	760.43±123.59	552.97–990.35	p = 0.971
TMT, μm	160.21±26.29	119.09–220.35	151.77±26.91	111.30–219.25	p = 0.018

IOP, intraocular pressure from rebound tonometry; SCA, Schlemm's canal area; SCL, Schlemm's canal length; TML, trabecular meshwork length; TMT, trabecular meshwork thickness. *Nonparametric test.

the temporal and nasal quadrants in high myopia. They also found a significant and negative correlation between SC area and IOP. Thus, eyes with a larger SC tends to have a lower IOP probably because of enhanced aqueous outflow. Chen et al. [18] applied ophthalmodynamometry to compress eyeballs. Variation of the SC area and length was responsible for the IOP changes, in terms of an acute IOP rise from a collapsed SC and IOP drop from a dilatation of the SC.

Control eyes had a notable increase in both SC area and SC length, which was absent in high myopia. Consequently, the more significant reduction in IOP in control eyes (from 15.95 mm Hg to 9.18 mm Hg) compared to high myopia eyes (14.82 mm Hg to 9.29 mm Hg) might be ascribed to the enlargement of the SC. Aqueous outflow is not solely dependent on SC area. Outflow resistance of the SC inner wall played a more significant role in regulating IOP [19, 20]. Allingham et al. [21] proposed that a reduced SC inner wall area contributed significantly to the decreased outflow in glaucoma eyes since outflow resistance is inversely proportional to filtration area.

Apart from SC, TM dimensions also contributed to aqueous outflow and IOP regulation. Li et al. [22] applied a mouse model and used spectral-domain OCT to monitor SC and TM with a topical application of 1% pilocarpine. Pilocarpine induced opening of the SC area and widening the TM, which helped prevent collapse of SC. We found that high myopia had slightly greater SC area and SC length than control eyes (Table 1). However, they did not demonstrate significant enlargement of both SC area and length from ocular massage as control eyes did. On the contrary, a significantly reduced TM thickness was demonstrated (Table 2), which might

Table 3. Results (mean ± standard deviation and range) of control eyes before and after ocular massage

	Before	Range	After	Range	Significance
IOP, mm Hg	15.95±3.19	11.35–20.70	9.18±2.40	5.65–13.70	$p < 0.001$
SCA, μm^2	8,540.71±3,905.98	3,475.82–18,764.57	11,686.53±4,586.37	6,757.19–23,224.80	*$p = 0.001$
SCL, μm	240.47±69.96	116.59–380.57	280.40±59.37	197.58–430.47	$p = 0.041$
TML, μm	724.43±90.04	599.86–913.04	733.63±106.45	576.74–918.48	$p = 0.538$
TMT, μm	146.59±17.36	126.33–179.68	135.83±20.72	100.87–187.96	$p = 0.073$

IOP, intraocular pressure from rebound tonometry; SCA, Schlemm's canal area; SCL, Schlemm's canal length; TML, trabecular meshwork length; TMT, trabecular meshwork thickness. *Nonparametric test.

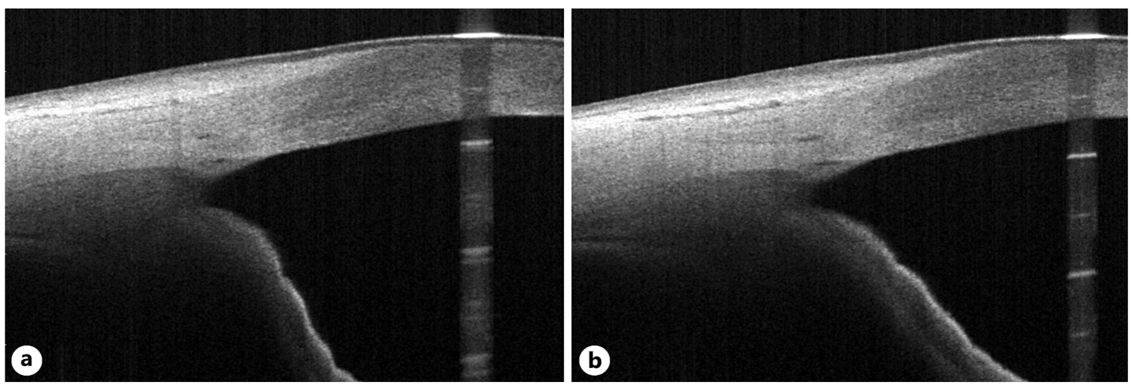

Fig. 3. Typical AS-OCT images of subject No. 22 before ocular massage (**a**) and after ocular massage (**b**). The Schlemm canal demonstrated significant enlargement after ocular massage.

hinder aqueous outflow from collapsed TM lamellae. It could also reduce dilatation of the SC lumen.

Chen et al. [13] indicated that eyes with high myopia exhibited an increased SC area and length. While a large SC dimension should promote aqueous outflow, a more significant expansion of the SC may be necessary for further improving aqueous outflow, which appears contradictory in our high myopic eyes. Different SC and TM changes from digital ocular massage between high myopia and control eyes could be related to different biomechanical properties of SC and TM. This feature is difficult to be measured clinically. A meta-analysis has revealed that corneal biomechanics, namely, corneal hysteresis, differ between high myopic and low myopic eyes [23]. Yii et al. [24] further proposed that impaired corneal biomechanics may manifest in myopia at around −3.00 D. A recent study indicated that reduced corneal hysteresis in highly myopic eyes adversely affects the incidence of glaucoma [25]. We question whether corneal hysteresis or other corneal biomechanics metrics could serve as biomarkers for aqueous outflow indication. Additional research in this area is warranted.

The current study is limited by a small sample size and the use of rebound tonometry instead of the gold-standard Goldmann tonometry. However, the Icare 200 model showed good agreement with Goldmann tonometry for an IOP <21 mm Hg [26]. We monitored only the temporal quadrant instead of measuring both the temporal and nasal quadrants. Further studies with larger sample sizes are needed to confirm the findings. A further restriction was the absence of long-term monitoring of the IOP changes. Wu et al. [16] applied ocular massage for a duration of 10 min. The IOP remained lower than baseline levels when it was assessed 5 min post-ocular massage. Lam et al. incorporated a 5-min ocular massage in their investigation [27]. A notable decrease in IOP occurred immediately following ocular massage, reverting to baseline levels 15 min thereafter. We expected that our participants would regain their IOP to baseline levels within a comparable timeframe. All participants watched the same video to learn how to perform ocular massage. Variations in the applied force may still occur among the same participants within the 5-min interval. The utilization of electronic eye massagers may provide a consistent massage experience [28].

In conclusion, digital ocular massage effectively reduces IOP. High myopia showed different changes in SC and TM. More studies on the biomechanical properties of these structures are warranted.

Acknowledgments

We would like to thank the Faculty of Health and Social Sciences in supporting Ruby WL Wong through a Summer Research Studentship and Antonia KW Wong through a research project ZEC7.

Statement of Ethics

This study protocol was reviewed and approved by Institutional Review Board of The Hong Kong Polytechnic University, Approval No. HSEARS2022022001. All participants provided informed written consent prior to their participation in the study.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Funding Sources

This study was funded by the InnoHK initiative of the Innovation and Technology Commission of the Hong Kong Special Administrative Region Government in the study design, planning, and execution.

Author Contributions

Conception and design: A.K.C.L., R.W.L.W., T.H.Y.W., H.K.C.L., C.H.T.L., and A.K.W.W. Analysis and interpretation: A.K.C.L. and R.W.L.W. Data collection: R.W.L.W., T.H.Y.W., H.K.C.L., C.H.T.L., and A.K.W.W. Obtained funding and overall responsibility: A.K.C.L.

Data Availability Statement

The data that support the findings of this study are not publicly available due to privacy reasons but are available from the corresponding author upon request.

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