

Iris volume decreases during pupillary dilation

Hiroshi Ishikawa, MD,^{1,2} Robert Ritch, MD,^{1,2} Sek-Tien Hoh, MD,¹ Jeffrey M. Liebmann, MD^{1,2}

¹The Department of Ophthalmology, The New York Eye and Ear Infirmary, New York, NY, USA.

²The New York Medical College, Valhalla, NY, USA.

Correspondence and reprint requests:

Robert Ritch, Professor and Chief, Glaucoma Service, Department of Ophthalmology, The New York Eye and Ear Infirmary, 310 East 14th Street, New York, NY 10003, USA.

Acknowledgment:

Supported in part by the Donald Engel Research Fund of the New York Glaucoma Research Institute and The New York Eye and Ear Infirmary Department of Ophthalmology Research Fund (Dr Hoh).

Dr Hoh has since moved to the Department of Ophthalmology, Singapore National Eye Center, 11 Third Hospital Avenue, Singapore 168751.

Presented in part at the annual meeting of the Association for Research in Vision and Ophthalmology, Fort Lauderdale, FL, May 2001.

Drs Ishikawa, Liebmann, and Ritch have a proprietary interest in the software discussed herein.

Abstract

Objective: To evaluate changes in iris cross-sectional area and volume under dark and lighted conditions using ultrasound biomicroscopy.

Patients and methods: Patients underwent ultrasound biomicroscopy imaging using standardized lighting conditions. Imaging was repeated after at least 2 minutes in standardized dark room conditions (physiological dilation) or 30 minutes after instillation of tropicamide 1% (pharmacological dilation). Images were exported to an IBM-compatible computer. Iris volume and cross-sectional area were then measured using an automated software program of our own design capable of calculating iris volume with axial alignment using keratometry and corneal diameter information.

Results: Twenty two eyes of 22 healthy people were enrolled. In the pharmacologically dilated eyes, mean iris volume was $41.21 \pm 2.64 \text{ mm}^3$ before and $35.88 \pm 3.92 \text{ mm}^3$ after dilation ($12.5 \pm 11.4\%$ reduction; $p = 0.009$, paired t-test). For eyes undergoing physiologic dilation, mean iris volume was $39.43 \pm 7.83 \text{ mm}^3$ using lighted conditions and decreased to $36.80 \pm 6.70 \text{ mm}^3$ in the dark ($6.3 \pm 4.8\%$ reduction; $p = 0.004$). The change in pupillary diameter correlated significantly with iris volume and iris cross-sectional area change after physiological dilation ($r^2 = 0.41$ and 0.35 , $p = 0.03$ and

0.04 , respectively, Pearson correlation), but not after pharmacological dilation ($p > 0.2$).

Conclusion: Cross-sectional iris area decreases with pupillary dilation. The iris volume decrease during physiological change was proportionately less than with pharmacological dilation.

Key words: Iris volume, Pupillary dilation, Ultrasound biomicroscopy, Uveoscleral outflow

Introduction

When the pupil dilates, the distance from the iris insertion at its root to the pupillary margin is reduced. When the pupil constricts, the distance increases. If the iris is analogous to an elastic solid object, its volume should remain constant. If so, its thickness should increase in the dilated position to maintain the same volume as imaged in the constricted position. Qualitative analysis of ultrasound biomicroscopic (UBM) images before and after dilation, however, gives the impression that the cross-sectional area of the iris becomes smaller with pupillary dilation, suggesting that iris volume decreases (**Figure 1**).

Quantitative UBM studies have been based primarily on linear measurement using calipers supplied with the software.¹⁻¹¹ Area and volume measurements have been limited by lack of appropriate software. To investigate the iris volume change, a software program has been developed for

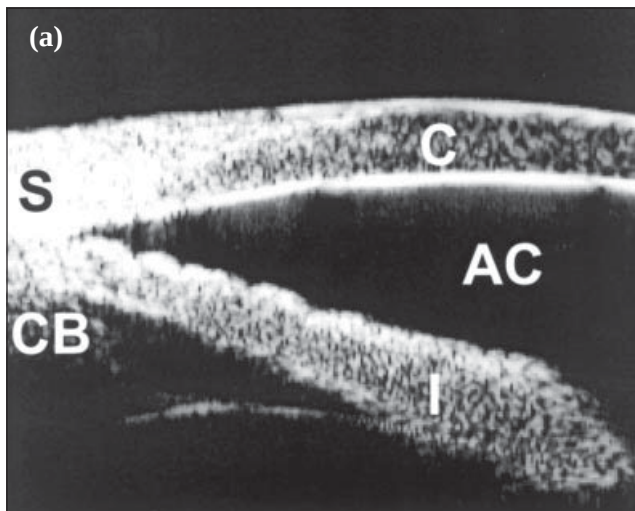


Figure 1. Ultrasound biomicroscopy of an iris under (a) lighted and (b) dark conditions. The cornea (C), sclera (S), anterior chamber (AC), iris (I), and ciliary body (CB) are visible.

measuring iris volume using UBM images. The goal of this study was to assess changes in iris volume in light and dark room conditions and following pupillary dilation.

Patients and methods

Healthy volunteers with no ocular pathology underwent a complete eye examination, autokeratometry, and measurement of corneal diameter using a hand-held caliper. UBM (P40, Paradigm Medical Industries, Salt Lake City, USA) was performed in the supine position in standardized light conditions using a 50 MHz transducer, providing tissue resolution of approximately 50 μm and penetration depth of 4 to 5 mm. After the initial UBM image was obtained, UBM imaging was performed after at least 2 minutes in standardized dark room conditions (physiological dilation) or 30 minutes after instillation of tropicamide 1% (pharmacological dilation). Captured image files were exported into an IBM computer and analyzed using a software program of our own design.

The measurement algorithm calculates the iris volume as follows:

1. Images are exported from the UBM unit.
2. Speckle noise in the image is reduced by 2-dimensional linear convolution with a kernel created by repeated self-convolution with the following 3 x 3 matrix:

$$\frac{1}{16} \cdot \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

3. Using a threshold technique, ocular structures are separated from the background noise.
4. The location of the scleral spur is identified. The position of the scleral spur is defined as the innermost point of a line separating ciliary muscle and scleral fibers (**Figure 2a**).
5. The keratometry and corneal diameter data are entered. A line is drawn separating iris root and ciliary body. The iris is identified (**Figure 2b**).

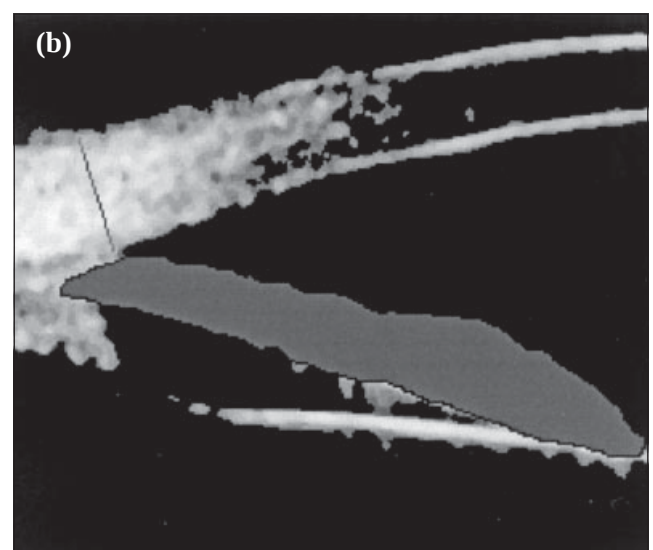
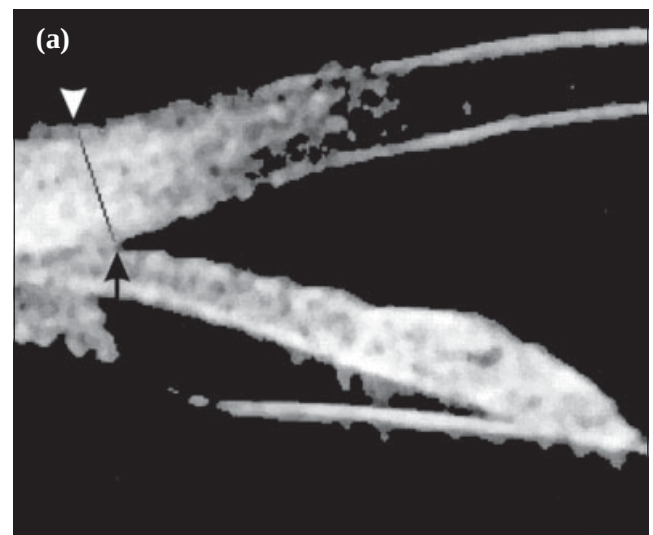


Figure 2. (a) The scleral spur is located by the operator (arrow). A perpendicular line is drawn to the corneal surface (arrowhead) to calculate the rotation of the optical axis. (b) Following the identification of the iris insertion by the observer, the program automatically selects the iris in red.

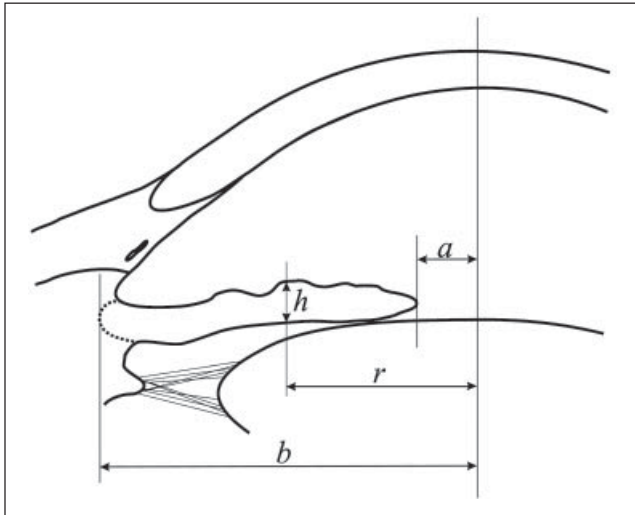


Figure 3. Diagram of iris volume calculation: *a* is the distance between the optical axis and the pupillary edge, *b* is the distance between the optical axis and the point on the iris furthest away from the axis, *h* is the thickness of the iris at distance *r* from the optical axis.

6. The optical axis is automatically determined by a mathematical formula based on the scleral spur location, keratometry, and corneal diameter. The software assumes that the image is scanned perpendicularly to the limbus so that the scanned plane includes the optical axis. To make sure that this assumption is true, we performed UBM on the plane in which the iris appears shortest (confirming that the scanning plane is passing across the optical axis assuming that the pupil is round and centered) and the cornea and the iris surface have high intensity (confirming that the scanning plane is perpendicular to the corneal and iris surface). All volunteers had round pupils.
7. The iris volume is calculated using the following formula:

$$\int_a^b 2\pi r \cdot h \cdot dr$$

where *a* = the distance between optical axis and pupillary edge; *b* = the distance between the optical axis and the point on the iris furthest from the axis; and *h* = iris thickness at distance *r* from the optical axis (**Figure 3**).

The software also calculates the pupil diameter automatically by measuring the distance from the optical axis to the pupillary edge and multiplying by 2.

Results

Twenty two eyes of 22 healthy volunteers were enrolled (mean age $\pm$ SD, 45.6 ± 14.8 years; mean refractive error, -1.3 ± 2.7 D). Ten volunteers were randomly assigned to pharmacological dilation, while the others were assigned to physiological dilation.

In the eyes receiving pharmacological dilation, the mean iris volume was 41.21 ± 2.64 mm³ before and 35.88 ± 3.92 mm³ after dilation ($12.5 \pm 11.4\%$ reduction; $p = 0.009$, paired t-test). The mean iris cross-sectional area was $2.31 \pm$

0.26 mm² before and 1.51 ± 0.22 mm² after dilation ($33.8 \pm 13.2\%$ reduction; $p < 0.0001$). The change in pupillary diameter did not correlate with the change in iris volume or area change ($r^2 = 0.16$ and 0.01 , $p = 0.24$ and 0.81 , respectively, Pearson correlation). For eyes undergoing physiological dilation, the mean iris volume was 39.43 ± 7.83 mm³ in light conditions and decreased to 36.80 ± 6.70 mm³ in the dark ($6.3 \pm 4.8\%$ reduction; $p = 0.004$). The cross-sectional iris area was 2.44 ± 0.35 mm² in lighted conditions and decreased to 1.90 ± 0.21 mm² in the dark ($21.8 \pm 7.4\%$ reduction; $p < 0.0001$). The change in pupillary diameter correlated significantly with iris volume and area change ($r^2 = 0.41$ and 0.35 , $p = 0.03$ and 0.04 , respectively).

Discussion

An understanding of iris physiology is important for assessing the effects of drugs on the iris, for elucidating the mechanisms of pupillary and reverse pupillary block, and for evaluating the physiology of iris motion. Information regarding the dynamic changes in iris position and the relationship of the iris to adjacent structures would be helpful in this regard.

Although cross-sectional anterior chamber geometry may be quantified by slit-lamp photography using the Scheimpflug principle and computer correction for the optical effects of the cornea,^{12,13} this method lacks sufficient resolution to create area and volume analysis of anterior segment structures. We developed a software program to measure cross-sectional iris area and iris volume using UBM images to analyze dynamic iris changes during pupillary movement. This measurement of iris volume extrapolates the information of a single cross-sectional image into 3-dimensional structural information. This mathematical representation is a useful model to demonstrate changes in iris morphology under different conditions.

The decrease in iris volume and cross-sectional area was greater in pharmacologically dilated eyes than in eyes that were physiologically dilated. As the former results in maximal dilation of the pupil, a greater reduction in iris volume than with physiologic dilation is consistent. Nevertheless, the significant decrease in iris volume with physiological dilation suggests that this might play a functional role in aqueous humor dynamics. These findings suggest that aqueous is being drawn into the iris with pupillary constriction and released with dilation, the iris functioning in the manner of a sponge. The iris stroma must therefore be more compact in the dilated state compared with the constricted one. Aqueous could enter the iris stroma through the anterior border layer of the iris. This raises the question as to whether, when aqueous is released from the iris, it is all released back into the anterior chamber or whether some aqueous could be mechanically pumped through the iris root into the ciliary body as part of the uveoscleral outflow pathway. This pathway has been assumed to consist of aqueous flow from the anterior chamber through the ciliary body face and into

the ciliary muscle.¹⁴⁻¹⁶ An additional component of flow through the iris root would introduce a potentially dynamic aspect to this pathway.

The pupil has been reported to constrict 4 times as fast as it dilates.¹⁷ One possible reason for this, in addition to differences in the intrinsic strengths of the iris sphincter and dilator muscles and their mutually antagonistic effects, might

be the effect of movement of aqueous into and out of the iris stroma. One could speculate that, during dilation, elimination of aqueous from the iris stroma requires more time than does entry of aqueous into the iris. The iris might continue to take up aqueous from the anterior chamber after the pupil has constricted. If this is the case, iris volume and cross sectional iris area may increase for a short time following maximal constriction. This has yet to be investigated.

References

1. Caronia RM, Liebmann JM, Stegman Z, et al. Increase in iris-lens contact after laser iridotomy for pupillary block angle closure. *Am J Ophthalmol* 1996;122:53-57.
2. Liebmann JM, Tello C, Chew SJ, et al. Prevention of blinking alters iris configuration in pigment dispersion syndrome and in normal eyes. *Ophthalmology* 1995;102:446-455.
3. Pavlin CJ, Sherar MD, Foster FS. Subsurface ultrasound microscopic imaging of the intact eye. *Ophthalmology* 1990;97:244-250.
4. Pavlin CJ, Harasiewicz K, Sherar MD, et al. Clinical use of ultrasound biomicroscopy. *Ophthalmology* 1991;98:287-395.
5. Pavlin CJ, Foster FS. Ultrasound biomicroscopy in glaucoma. *Acta Ophthalmol* 1992;204 (Suppl):7-9.
6. Pavlin CJ, Ritch R, Foster FS. Ultrasound biomicroscopy in plateau iris syndrome. *Am J Ophthalmol* 1992;113:390-395.
7. Potash SD, Tello C, Liebmann J, et al. Ultrasound biomicroscopy in pigment dispersion syndrome. *Ophthalmology* 1994;101:332-339.
8. Sakuma T, Sawada A, Yamamoto T, et al. Appositional angle closure in eyes with narrow angles: an ultrasound biomicroscopic study. *J Glaucoma* 1997;6:165-169.
9. Sawada A, Sakuma T, Yamamoto T, et al. Appositional angle closure in eyes with narrow angles: comparison between the fellow eyes of acute angle-closure glaucoma and normotensive cases. *J Glaucoma* 1997;6:288-292.
10. Sokol J, Stegman Z, Liebmann JM, et al. Location of the iris insertion in pigment dispersion syndrome. *Ophthalmology* 1996;103:289-293.
11. Stegman Z, Sokol J, Liebmann JM, et al. Reduced trabecular meshwork height in juvenile primary open-angle glaucoma. *Arch Ophthalmol* 1996;114:660-663.
12. Richards DW, Russell SR, Anderson DR. A method for improved biometry of the anterior chamber with a Scheimpflug technique. *Invest Ophthalmol Vis Sci* 1988;29:1826-1835.
13. Sasaki K, Sakamoto Y, Shibata T, et al. The multi-purpose camera: a new anterior eye segment analysis system. *Ophthalmic Res* 1990;22 (Suppl 1):3-8.
14. Toris CB, Pederson JE. Effect of intraocular pressure on uveoscleral outflow following cyclodialysis in the monkey eye. *Invest Ophthalmol Vis Sci* 1985;26:1745-1749.
15. Pederson JE, Toris CB. Uveoscleral outflow: diffusion or flow? *Invest Ophthalmol Vis Sci* 1987;28:1022-104.
16. Kelly DE, Hageman GS, McGregor JA. Uveal compartmentalization in the hamster eye revealed by fine structural and tracer studies: implications for uveoscleral outflow. *Invest Ophthalmol Vis Sci* 1983;24:1288-1304.
17. Tsujisawa I, Ishikawa S. Pupillographic examination. In: *Ophthalmology Mook*. Vol. 41. Kanehara Co: Tokyo; 1989.