

EXTENDED REPORT

Quantitative evaluation of changes in anterior segment biometry by peripheral laser iridotomy using newly developed scanning peripheral anterior chamber depth analyser

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Aim: Using the newly developed scanning peripheral anterior chamber depth analyser (SPAC), the effects of peripheral laser iridotomy (PLI) on peripheral anterior chamber depth (PACD) were determined quantitatively as was the association between PACD and chronic elevation of intraocular pressure (IOP) after PLI.

Methods: 16 eyes of 15 patients with acute primary angle closure glaucoma (PACG) attack, 14 eyes of 14 patients with narrow angle and PACG attack in their fellow eyes, and 13 eyes of seven patients with chronic angle closure glaucoma (CACG) were enrolled. The SPAC scanned the anterior ocular segment from the optical axis to the limbus and took 21 consecutive slit lamp images at 0.4 mm intervals. A computer installed program automatically evaluated the PACD and the averaged values of three measurements were employed for analysis.

Results: PLI significantly increased PACD and changed the iris contour from convex to flat or concave in all the enrolled eyes. The extent of the PLI induced PACD increase was enhanced with increasing distance from the optical axis. Comparing PACDs after PLI, eyes that received prophylactic PLI showed the greatest extent of PLI induced PACD increase, followed by eyes with CACG and eyes with PACG attack. The PACD of eyes with PACG attack was almost the same as that of the fellow eyes of PACG attack before prophylactic PLI. Eyes with PACG attack showed poorer IOP control after PLI than eyes with narrow angle and CACG with PLI.

Conclusions: PLI significantly increases PACD and the small PLI induced opening of PACD may contribute to chronic IOP elevation after PLI.

Primary angle closure glaucoma (PACG) is one of the major types of glaucoma in Asian countries^{1–6} and one of the leading causes of blindness in the world.⁷ Peripheral laser iridotomy (PLI) is considered to be a useful tool for the treatment of both acute PACG attack and chronic angle closure glaucoma (CACG).⁸ Today, PLI is the first line of intervention for both acute and chronic types of angle closure glaucoma (ACG).⁹ It is well known that prophylactic PLI reduces the possibility of intraocular pressure (IOP) elevation in patients with PACG and CACG. PLI increases the width of the angle^{8–10} but does not change the central anterior chamber depth (ACD).¹¹ During the follow up period, an increase in IOP was detected in some PACG patients who were relieved of the acute elevation of IOP.^{12–14} It is hypothesised that the narrowness of the PACD after PLI may be involved in the recurrence of IOP elevation. Therefore, it is critical to observe the anterior chamber configuration in PACG patients even after the resolution of the acute IOP elevation. The methods used for evaluating anterior chamber configuration include ultrasound biomicroscopy (UBM), A-mode ultrasonography, pachymetry, and Scheimpflug principle imaging.^{11–23} Although those methods provide very important information for treating patients and understanding the mechanism of PACG, each one has its own disadvantages that interfere with their widespread use in routine clinical practice or glaucoma screening by non-ophthalmologists.

We have developed a new slit lamp type system, called a scanning peripheral anterior chamber depth analyser (SPAC), that is easy to handle and can be used to evaluate peripheral

anterior chamber depth (PACD) non-invasively even by non-ophthalmologists.

In this study, we determined the effects of PLI on PACD quantitatively and the association between PACD and chronic IOP elevation after PLI using the SPAC.

PATIENTS AND METHODS

This study was conducted in accordance with the Helsinki Declaration and informed consent was obtained from all patients.

Patient profile

Enrolled eyes were categorised into three groups: eyes with PACG attack, eyes with narrow angle and PACG attack in their fellow eyes, and eyes with CACG. The criteria for the diagnosis of PACG attack were as follows: an increase in IOP of more than 30 mm Hg; at least one of the following subjective signs: rapid onset of ocular pain or discomfort, nausea and/or vomiting, or blurring of vision of recent onset or an antecedent episode of intermittent blurring with halos; and at least two of the following objective signs: corneal epithelial oedema, a mid-dilated unreactive pupil, iris bombe, or marked conjunctival injection.

Abbreviations: ACD, anterior chamber depth; AOD, angle opening distance; CACG, chronic angle closure glaucoma; PACD, peripheral anterior chamber depth; PACG, primary angle closure glaucoma; PAS, peripheral anterior synechia; PLI, peripheral laser iridotomy; SPAC, scanning peripheral anterior chamber depth analyser

Eyes that were subjected to intraocular surgery including any laser treatments, or those with uveitis, dense cataract, or ocular trauma were excluded from the study. Patients who presented with other symptoms for the acute elevation of IOP were also excluded (for example, uveitic, neovascular, phacomorphic, or phaco-anaphylactic).

PLI was performed to relieve the patient of the PACG attack or to eliminate the possibility of acute IOP elevation. The openness of the angle was evaluated using the Shaffer's classification—the most commonly used grading system—from 0 (closed) to 4 (wide open).²⁴⁻²⁵ The indications for prophylactic PLI were the following: eyes with angle openness of Shaffer's classification grade 1 or 2 and having fellow eyes with PACG attack; eyes with CACG having angle openness of Shaffer's classification grade 1 or 2 and having peripheral anterior synechia (PAS) or appositional angle closure; and at least one of the following: IOP elevation of more than 21 mm Hg or glaucomatous optic disc cupping with corresponding visual field defect confirming the results of multiple reliable static visual field tests. More than two glaucoma specialists calculated the PAS index by gonioscopic observation independently and the mean value was employed.

Scanning peripheral anterior chamber depth analysis system

The major components of the SPAC system are a slit lamp system (Takagi, Nagano, Japan), 1/3 inch black and white charge coupled device (CCD) camera, and a computer system (LaVie MA20V/B, NEC Tokyo, Japan) (fig 1). The detailed explanation of the system is available in the companion paper. The mean values were calculated from three satisfactory trials.

Preparation for examination

Patients instilling antiglaucoma ophthalmic solutions and taking oral medication were examined without changing any medications. Patients planning to have prophylactic PLI were examined before PLI without any pretreatment. The PLI was performed according to previous reports using an argon laser and a YAG laser after instilling 2% pilocarpine and 0.5%

apraclonidine ophthalmic solutions. After the PLI, 0.5% apraclonidine ophthalmic solution was instilled and 0.1% betamethasone ophthalmic solution was instilled four times a day for 2 days. Patients were instructed to visit the outpatient clinic 1 week later and the PACD measurement was repeated after ophthalmic examination including slit lamp examination, IOP measurement, and fundus examination.

UBM

The changes in angle contour by PLI were investigated by UBM (Paradigm Medical Industries, Inc, Salt Lake City, UT, USA). The angle contour was evaluated according to Pavlin's reports.²⁶⁻²⁹ The angle opening distance (AOD) is defined as the distance from the corneal endothelium to the anterior iris perpendicular to a line drawn along the trabecular meshwork at a given distance from the scleral spur. The computations were carried out at depths of 250 μm (AOD 250) and 500 μm (AOD 500) from the scleral spur.

Axial length and central anterior chamber depth

Other biometric parameters—namely, axial length and central anterior chamber depth, were measured by ultrasonography (UD 7000, Tomei, Aichi, Japan) and UBM. The changes in axial length and central chamber depth were investigated using 15 eyes that the SPAC system measured PACD before and after PLI.

Changes in iris contour by PLI

Changes in the iris contour were investigated in eyes with prophylactic PLI. One expert ophthalmologist (KK) categorised the iris contour into three groups: convex iris, flat iris, and concave iris in a masked fashion.

Statistical analysis

Paired *t* test, the Mann-Whitney U test, or the repeated ANOVA, were employed for statistical analysis. *p* Values less than 0.05 were considered statistically significant. All values were expressed as means (SD).

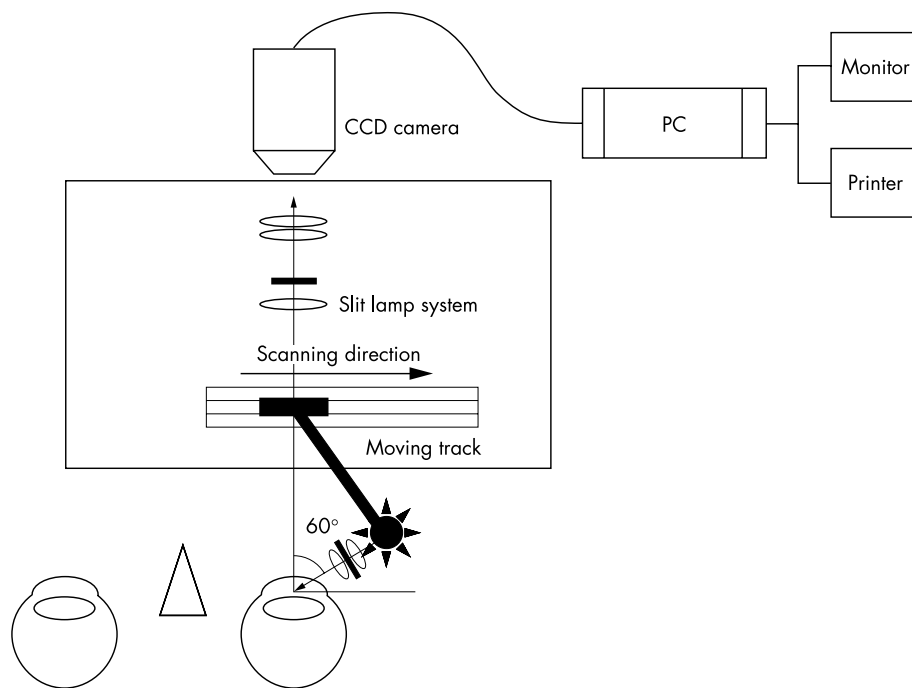


Figure 1 Schematic illustration of SPAC system. The major components of this system are one slit lamp system, 1/3 inch black and white charge coupled device (CCD) camera, and one computer system including a monitor and a printer. A slit ray is illuminated from the temporal side at an angle of 60 degrees and a slit lamp is moved laterally (as indicated by an arrow) on the track by a distance of 8 mm in 0.5 second, thereby taking 21 consecutive images at 0.4 mm intervals. The slit lamp images are transferred to the computer system. Biometric analysis is instantly performed and calculated values and images are displayed on the monitor. PC = personal computer.

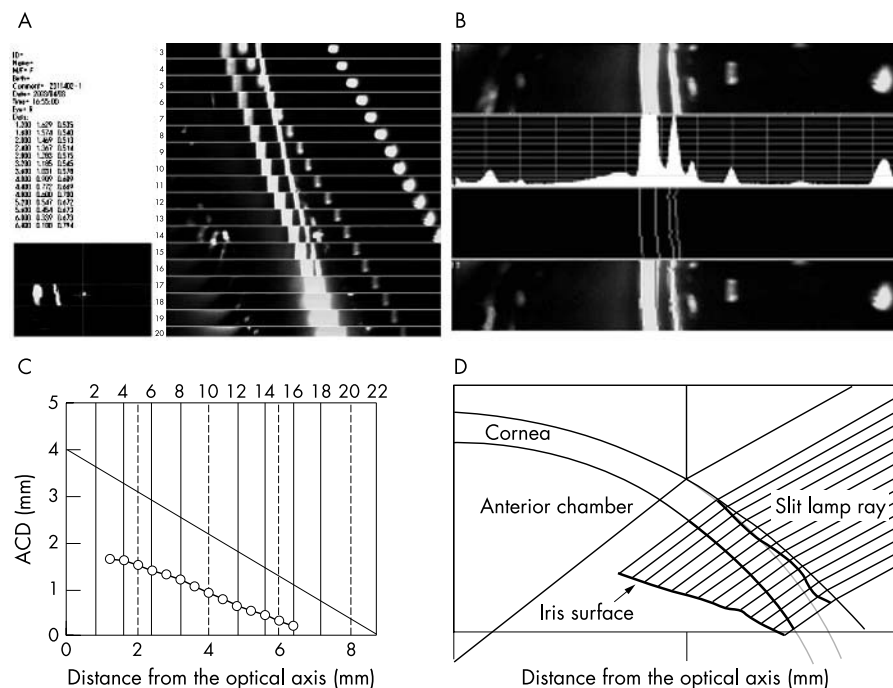


Figure 2 Representative SPAC images. Representative SPAC images of a female having narrow angle. (A) Twenty one consecutive images (right panel), eye monitoring window (lower left panel), and values (upper left panel) are displayed. (B) Sample image for determining PACD and corneal thickness. A slit lamp image (first row) and a histogram of the number of white pixels calculated from the slit lamp image (second row). Two major peaks indicate cornea (left) and iris (right). Determined margins of the cornea and the iris (third row). Margins are superimposed on the slit lamp image (fourth row). (C) An installed program creates a plot of PACD profile. The X axis is the distance from the optical axis and the Y axis is PACD in mm. (D) Drawing of the anterior ocular segment. Bold lines indicate boundaries of corneal epithelium, corneal endothelium, and iris surface.

RESULTS

Patient profile (table 1)

Fifteen patients with acute ACG attack were enrolled. Of these, one showed PACG attack in both eyes. Therefore, 16 eyes from the 15 patients were enrolled. Fourteen fellow eyes of these patients had prophylactic PLI and were defined as eyes with prophylactic PLI. Thirteen eyes from seven patients with CACG were also enrolled in this study. Fifteen eyes including 13 eyes with CACG and two eyes with narrow angle and PACG attack in their fellow eyes were measured for PACD before and after PLI. Fourteen eyes with narrow angle and PACG attack in their fellow eyes and 15 eyes with PACG attack were measured for PACD after PLI only.

The mean follow up period of eyes with PACG attack was 7.03 (5.18) years. Of the 16 PACG eyes, eight (50%) showed persistent IOP elevation that required antiglaucoma treatment and three (18.8%) showed failure of IOP control by medication and resultant trabeculectomy. Of the 14 fellow eyes, two required one antiglaucoma ophthalmic solution to maintain IOP within the normal range. Of the eyes with CACG, six (46.2%) required antiglaucoma ophthalmic solutions; the antiglaucoma ophthalmic solutions were able to control IOP elevation in all the six eyes. The follow up period for eyes with PACG attack was significantly longer ($p < 0.01$, the Mann-Whitney U test) than that for eyes with CACG. Eyes with PACG attack showed the highest PAS index, followed by eyes with CACG and fellow eyes. No significant difference was observed among the three groups in terms of

equivalent refractive error, age, axial length, and sex distribution.

PLI induced changes in PACD

The representative images of PLI induced changes in PACD are shown in figure 3. As shown in figure 4, the PACD values before and after PLI treatment were significantly different. PLI increased PACD at all investigated points. The p value of PLI induced PACD change at a distance of 6 mm from the optical axis is 0.03, whereas those at other investigated points are less than 0.01. Figure 5 shows that the amount of PACD change was greater in the mid-peripheral region than in the central region and the most peripheral region, although there were no significant differences among the investigated points. Figure 6 shows the percentage change of PACD induced by PLI. The extent of change increased with increasing distance from the optical axis. Near the optical axis, the percentage change was approximately 20%, whereas in the most peripheral region, it was more than 80%.

Comparison of PACDs after PLI (fig 7)

The PACDs after PLI were compared among the three groups. Eyes with prophylactic PLI showed the highest values of PACD, followed by eyes with CACG and eyes with PACG attack. The PACD values of eyes with prophylactic PLI were significantly higher than those of PACG attacked eyes at all the measured points ($p < 0.01$, paired t test). There was no

Table 1 Patient profile

Group	Age (year)	Sex (M:F)	Equivalent refractive error (D)	Axial length (mm)	PAS index* (%)	Follow up period† (year)
Attacked eye	71.54 (7.03)	2:13	0.52 (2.0)	22.26 (0.63)	52.73 (25.33)	7.03 (5.18)
Fellow eye	70.83 (6.85)	2:12	0.92 (1.6)	22.3 (0.63)	12.73 (17.37)	6.85 (5.07)
CACG	71.86 (6.28)	2:5	1.88 (2.05)	21.75 (0.51)	16.70 (7.78)	0.72 (0.49)

CACG = chronic angle closure glaucoma, D = dioptre, PAS = peripheral anterior synechia, * $p < 0.01$: attacked eye v fellow eye and attacked eye v CACG, † $p < 0.01$ attacked eye v CACG, fellow eye v CACG. The Mann-Whitney U test was employed.

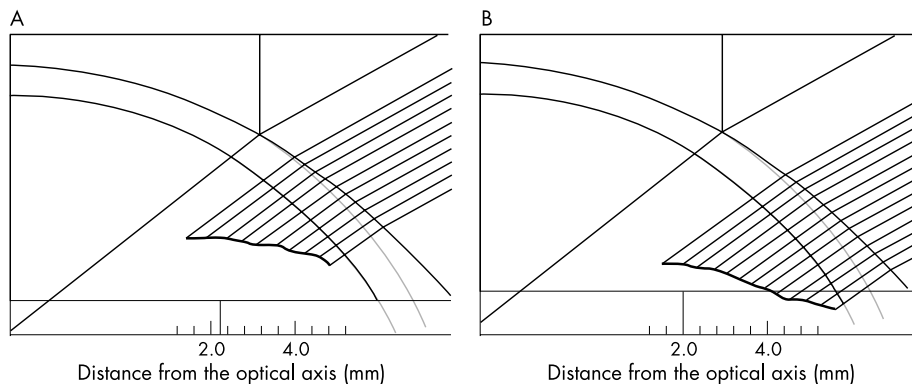


Figure 3 Representative images of PLI induced PACD changes. A 67 year old female patient whose left eye had a PACG attack and right eye showed narrow angle. Prophylactic PLI was performed on her right eye. The anterior chamber was narrow and iris contour was convex before the prophylactic PLI (A). The anterior chamber was widened and iris contour became flat after PLI (B).

difference in PACD between eyes with PACG attack after PLI and fellow eyes before PLI.

Changes in axial length and central chamber depth

Axial length and central chamber depth before PLI were 21.80 (0.63) mm and 1.84 (0.20) mm and those after PLI were 21.85 (0.57) mm and 1.88 (0.20) mm. PLI did not change axial length and central chamber depth significantly.

Changes in iris contour by PLI

Although all eyes showed convex iris contour before PLI, three eyes showed flat iris contour and 14 eyes showed concave iris contour after PLI. None of the eyes showed convex iris contour after PLI.

UBM analysis

Changes in angle biometry before and after prophylactic PLI were investigated by UBM in 15 eyes from eight patients. Before PLI, AOD 500 and AOD 250 were 23.7 (8.2) μ m and 15.9 (5.48) μ m, respectively, whereas after PLI, they were 36.6 (7.3) μ m and 23.5 (4.2) μ m, respectively. These changes in AOD 500 and AOD 250 were statistically significant ($p = 0.002$ for AOD 500 and $p = 0.003$ for AOD 250, paired t test).

DISCUSSION

The newly developed SPAC was able to reveal a significant change in PACD by PLI quantitatively, and the present results

were consistent with those of previous reports^{1 11} and were confirmed by UBM examination and slit lamp observation. Although the change in PACD was similar among the measured points, the percentage change was increased with increasing distance from the optical axis. In addition to the quantitative analysis of PACD, this study revealed a PLI induced change in iris contour. The iris contours of all the examined eyes were convex before PLI; however, none showed convex contours after PLI. This change was consistent with those reported in studies that employed UBM^{1 8 10 11} or an optical method using the Scheimpflug principle.¹⁸ Lee *et al* took anterior ocular segment images, measured the changes in ACD from the optical axis to the periphery at 1 mm intervals, and found increases in PACD at some measured points by PLI, although the changes were not significant.¹⁷ Taken together, our system was able to measure PACD quantitatively. In conclusion, PLI shifted the iris towards the posterior chamber but had no effect on the lens position, thereby increasing irido-lens contact. The PACD opening effect of PLI is the greatest at the most peripheral point of the anterior chamber.

Several reports have indicated that some eyes with PACG attack that were successfully treated with immediate PLI showed chronic IOP elevation during long term follow up and sometimes required filtering surgery.^{12 14 30} In this study, more than half of the enrolled eyes with PACG attack required antiglaucoma medication and trabeculectomy was performed on 21.4% of the eyes. On the other hand, most eyes with prophylactic PLI showed good IOP control. It is clear that the prognosis is much better in eyes with prophylactic PLI than in those with PLI after a PACG attack. The ACDs after PLI in eyes with PACG attack were similar to those before PLI in eyes with CACG and in eyes with prophylactic PLI. The PAS index in eyes with PACG attack

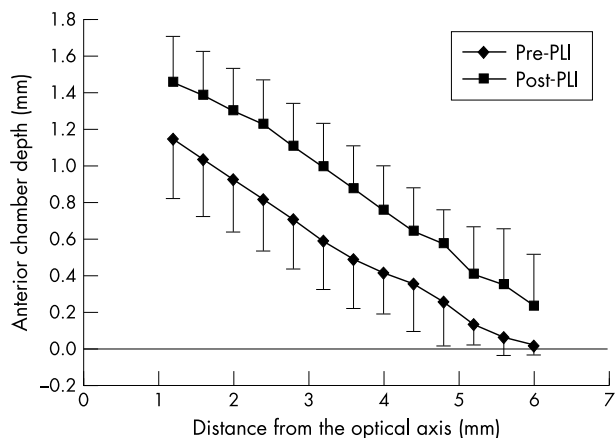


Figure 4 Prophylactic PLI induced PACD changes. Prophylactic PLI significantly increased PACD at all measured points. The p value of PLI induced PACD change at a distance of 6 mm from the optical axis is 0.03, whereas those at other investigated points are less than 0.01. Paired t test was employed. PLI = peripheral laser iridotomy, $n = 15$ eyes, bar = SD.

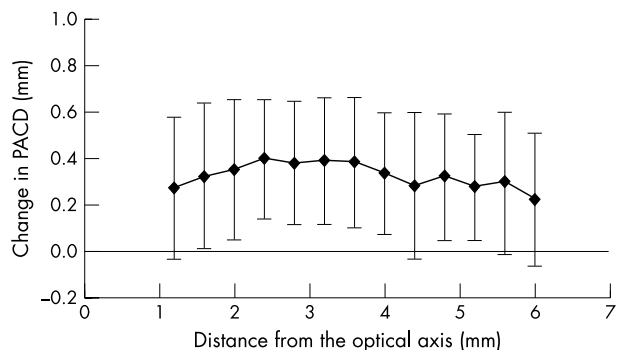


Figure 5 Amount of PLI (peripheral laser iridotomy) induced PACD change. There were no significant differences among the investigated points (the repeated ANOVA). $n = 15$ eyes, bar = SD.

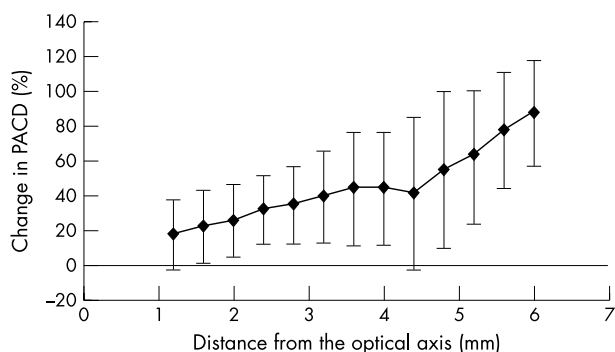


Figure 6 Percentage change of PACD induced by PLI (peripheral laser iridotomy), n = 15 eyes, bar = SD.

was significantly higher than that in eyes with prophylactic PLI. These results indicate that the small PACD opening is one of the risk factors for the development of PAS, namely, the creeping phenomenon. The present data confirm the importance of performing prophylactic PLI on eyes that are at a high risk of a PACG attack and indicate that PACD is one of the key parameters that influence the prognosis of eyes with PACG attack.

In the past, there were several studies that measured ACD quantitatively.^{15-17 19 20 31} However, the instruments or methods employed are not widely used today because of expensiveness, handling difficulty, complicated quantitative analysis, and low reproducibility. As described in another paper, those methods are not suitable for screening eyes that are at a high risk of developing PACG or CACG. Some optical methods have been introduced for evaluating PACD. However, these methods also have many disadvantages. The present system can evaluate PACD non-invasively and easily and all parameters of the anterior ocular segment automatically by means of a computer system. Therefore, the results are free from any operator associated bias and have high reliability. As the components of this system are one slit lamp system, one personal computer, and 1/3 inch black and white CCD camera, the production cost is low.

We installed several calibration programs to overcome disadvantages of instrument using optical methods for measuring the anterior ocular segment³² and investigated the consistency between values obtained by the present

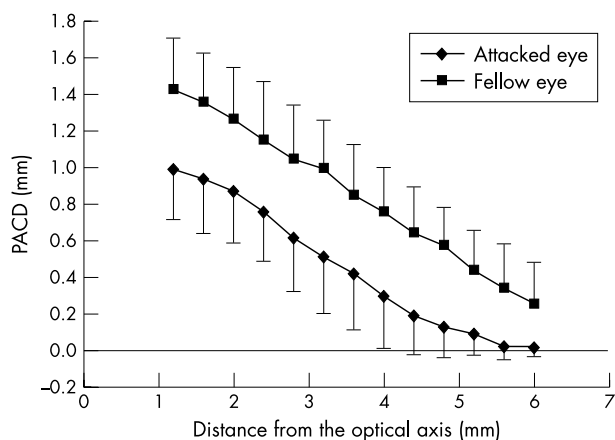


Figure 7 Comparison of PACD between attacked eyes and fellow eyes. PLI significantly increased PACD at all measured points. The p value of PLI (peripheral laser iridotomy) induced PACD change at all investigated points is less than 0.01 (paired t test). The paired t test was employed. Fifteen attacked eyes and 14 PLI eyes were enrolled. Bar = SD.

system and the true values obtained using dummy eyes and mathematical calculation as reported in the companion paper. We found that the values measured by this system are reliable and consistent with true values, and although there are some theoretical differences between measured values and true values in some situations, the differences are sufficiently small to be neglected for measuring the biometry of eyes.

The advantages of this system are mechanical simplicity, inexpensiveness, ease of handling, objectivity, and good quantitative measurement. This system may be useful for detecting high risk eyes in regular health check ups. Moreover, this system may help clinicians to judge whether eyes are at high risk for ACG attack.

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The lighter side



Although afflicted with superior oblique palsy, Architect Giovanni Cappolini created many great buildings. © Michael Balis.



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