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Original Article

# Verification of a formula developed to predict the postoperative intraocular pressure after cataract surgery in primary angle-closure glaucoma

Yu-Fan Chang [a,b], Yu-Chieh Ko [a,b], Ling-Ing Lau [a,b], Catherine Jui-Ling Liu [a,b,*]

[a] *Department of Ophthalmology, Taipei Veterans General Hospital, Taipei, Taiwan, ROC*
[b] *School of Medicine, National Yang-Ming University, Taipei, Taiwan, ROC*

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**Abstract**

*Background*: The aim of this study was to verify the accuracy of a formula predicting postoperative intraocular pressure (IOP) after phacoemulsification and intraocular lens implantation (PHCE-IOL) in primary angle-closure glaucoma (PACG). In a retrospective chart review of patients with PACG who underwent PHCE-IOL between 2011 and 2014, we collected preoperative IOP, axial length, anterior chamber depth (ACD), number of pre-PHCE glaucoma medications, and IOP and glaucoma medications at 1 month and 3 months post-PHCE.
*Methods*: Post-PHCE IOP values at 1 month and 3 months were compared with those predicted using the formula: postoperative IOP = 6.354 + 0.186 pre-PHCE IOP × pre-PHCE ACD. Agreements between measured and predicted IOP values were analyzed using correlation coefficients and Bland–Altman plots.
*Results*: Of the 62 eyes included, the average pre-PHCE IOP was 19.47 ± 5.84 mm Hg. Post-PHCE IOP values were 14.94 ± 4.03 mm Hg at 1 month and 14.21 ± 3.51 mm Hg at 3 months. Patients using more preoperative medications tended to show greater postoperative declines in medication usage. Predicted IOP significantly correlated with post-PHCE IOP measured at 1 month ($R = 0.314$, $p = 0.013$) and 3 months ($R = 0.325$, $p = 0.01$). Bland–Altman plots of difference against average of measured and estimated IOP revealed two cases falling outside ± 1.96 standard deviation at 1 month, and five cases at 3 months, indicating good consistency between measurement and prediction.
*Conclusion*: This formula was useful for predicting IOP at 1 month and 3 months after PHCE-IOL in PACG. It aids clinicians in preoperative assessment of whether PHCE-IOL alone is likely to achieve acceptable postoperative IOP control.


*Keywords:* anterior chamber depth; intraocular pressure; phacoemulsification; primary angle-closure glaucoma

## 1. Introduction

Primary angle-closure glaucoma (PACG) is estimated to be responsible for approximately half of the cases of binocular glaucoma blindness worldwide.[1,2] Accumulating evidence suggests that the lens plays an important role in anterior chamber narrowing. Aging is associated with a progressive increase in the number of lens fibers, with corresponding increases in lens thickness and anterior curvature. This leads to decreasing depth of the anterior chamber and narrowing of the chamber angle, especially in eyes with shorter axial length (AL).[3,4] Numerous studies have demonstrated that phacoemulsification with intraocular lens implantation (PHCE-IOL) substantially widens the anterior chamber angle and reduces intraocular pressure (IOP) in eyes with PACG.[5–9] Different studies have reported average IOP reductions ranging from 6% to 32%, possibly depending on the preoperative IOP level and the duration of postoperative follow-up.[7,10–17] Even higher

Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

* Corresponding author. Dr. Catherine Jui-Ling Liu, Department of Ophthalmology, Taipei Veterans General Hospital, 201, Section 2, Shih-Pai Road, Taipei 112, Taiwan, ROC.

*E-mail address:* jlliu@vghtpe.gov.tw (C.J.-L. Liu).

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IOP reductions have been reported in studies of eyes with acute PACG.[18−20]

Although cataract extraction is an effective IOP-lowering treatment, it is sometimes insufficient for long-term IOP control. In cases of chronic PACG where IOP is not medically controlled before PHCE-IOL, up to 12% might require invasive glaucoma intervention for IOP control within 2 years after cataract surgery.[12] Other studies have reported the need for further operations in 3−16% of cases.[11,13,14] Siriwardena et al[21] demonstrated greater and more prolonged anterior chamber flare at 3 months after cataract surgery compared with trabeculectomy, suggesting that glaucoma filtering surgery conducted a few months after cataract surgery carries a higher risk of surgical failure. To aid preoperative decision making, we have demonstrated in a prospective study that preoperative anterior chamber depth (ACD) and IOP are significant predicting factors for IOP at 3 months after PHCE-IOL in eyes with PACG.[10] These findings were confirmed in a subsequent study with a longer follow-up period, and a formula was then constructed to predict IOP at 12 months after cataract surgery in eyes with PACG.[11]

The present study aimed to test whether the formula previously derived from 12-month postoperative data was applicable for estimating short-term IOP at 1 month and 3 months after PHCE -IOL in another group of PACG eyes. This knowledge would assist with preoperative decision making to determine which eyes would benefit most from cataract surgery alone in terms of IOP control, thus avoiding complications of unnecessary combined cataract and glaucoma surgery.[22]

## 2. Methods

We retrospectively reviewed the charts of all PACG patients who underwent PHCE-IOL performed by one surgeon (C.J.L.) at Taipei Veterans General Hospital from January 2011 to June 2014. The included surgical procedures all comprised temporal clear-cornea phacoemulsification with in-the-bag implantation of some variety of one-piece AcrySof (Alcon, Fort Worth, TX, USA) IOL selected based on each patient's needs and preferences. The study was reviewed by the Institutional Review Board in Taipei Veterans General Hospital. Informed consent was not necessary because this was a retrospective chart review. All patients' information was de-identified prior to data analysis and was analyzed anonymously.

PACG was diagnosed based on findings of occludable anterior chamber angle and characteristic glaucomatous optic neuropathy. An anterior chamber angle was considered occludable when <90° of the posterior trabecular meshwork was visible on static gonioscopy in a dark room with the eye in the primary position. Glaucomatous optic neuropathy was defined as an optic disc showing vertical cup elongation, focal neuroretinal rim thinning or notching, or an asymmetric cup-to-disc ratio of >0.2 between the two eyes, as well as corresponding retinal nerve fiber bundle visual field defects. The study excluded eyes with angle closure secondary to uveitis, neovascularization, tumor, posterior segment disease, or surgery, as well as eyes that had undergone ocular laser surgery or surgery other than laser peripheral iridotomy (LPI). Also excluded were eyes with corneal diseases that might influence IOP measurement, patients with concurrent diseases that might cause visual field defects, and patients with a post-PHCE-IOL follow-up period of <3 months.

Within 1 month before PHCE-IOL, all patients underwent ophthalmic examinations, including best-corrected visual acuity (BCVA), ocular biometry, slit-lamp biomicroscopy, tonometry, gonioscopy, fundoscopy, and automated perimetry. AL and ACD were measured using IOLMaster V.5.02 (Carl Zeiss Meditec, Oberkochen, Germany). For each patient, we recorded the IOP by noncontact tonometry and number of glaucoma medications taken before PHCE-IOL, and at 1 month and 3 months after PHCE-IOL. Fixed combination glaucoma medication − such as Cosopt (Merck Sharp and Dohme, Whitehouse Station, NJ, USA), Combigan (Allergan Australia, Irvine, CA, USA), or Azarga (Alcon Canada, Alcon Pharma GmbH, Puurs, Belgium) − was counted as two medications.

The estimated numerical value of the postoperative IOP was calculated using the following formula: IOP after PHCE-IOL = 6.354 + (0.186 pre-PHCE IOP × pre-PHCE ACD).[11] Spearman correlation analysis was used to compare the estimated postoperative IOP with the measured IOP values obtained at 1 month and 3 months after cataract surgery. The agreement between the estimated and measured IOP values was also analyzed by Bland−Altman plot. All analyses were performed using SPSS version 20.0 (SPSS, Chicago, IL, USA).

## 3. Results

A total of 62 eyes (54 patients) were included in the data analysis. Table 1 shows the patients' characteristics. The

Table 1
Characteristics of the 62 PACG eyes and preoperative and postoperative data.

| Characteristics ($n$ = 62) | Mean ± SD |
|---|---|
| Age (y) | 74.1 ± 0.2 |
| Pre-PHCE BCVA (LogMAR) | 0.61 ± 0.39 |
| Pre-PHCE vertical C/D ratio | 0.76 ± 0.17 |
| Pre-PHCE visual field mean deviation (dB) | −12.81 ± 9.03 |
| Central corneal thickness (μm) | 554.9 ± 38.6 |
| Pre-PHCE anterior chamber depth (mm)[a] | 2.50 ± 0.31 |
| Pre-PHCE axial length (mm)[a] | 23.07 ± 1.10 |
| Intraocular pressure (IOP) | |
| Pre-PHCE IOP (mmHg)[a] | 19.5 ± 5.8 |
| Post-PHCE IOP at month 1 | 14.9 ± 4.0 |
| Post-PHCE IOP at month 3 | 14.2 ± 3.5 |
| Estimated IOP | 15.4 ± 2.8 |
| No. of glaucoma medications | |
| Pre-PHCE number of medications[b] | 2.0 ± 1.3 |
| Post-PHCE number of medications[c] | 0.9 ± 0.9 |

BCVA = best corrected visual acuity; C/D ratio = cup-to-disc ratio; IOP = intraocular pressure; PHCE = phacoemulsification; SD = standard deviation.

[a] Preoperative measurement within 1 month of surgery.

[b] Preoperative number of medications within 1 month before surgery.

[c] Postoperative number of medications at 3 months after surgery.

average age was 74.13 years; 19 were male and 35 female. All patients underwent uneventful clear cornea PHCE-IOL. No patients required surgical intervention within 3 months following cataract surgery.

Of the operated eyes, 63% had received LPI before undergoing cataract surgery. The average pre-PHCE IOP was 19.47 ± 5.84 mm Hg while being treated with an average of 2.0 ± 1.3 glaucoma medications. The post-PHCE IOP was 14.94 ± 4.03 mm Hg at 1 month and 14.21 ± 3.51 mmHg at 3 months. Compared with preoperative levels, postoperative IOP was decreased by 4.26 mm Hg (a 23% reduction) at 1 month and by 5.26 mm Hg (a 26% reduction) at 3 months. Preoperatively, 56 eyes (90%) were treated with glaucoma medication: seven with >3 medications, 16 with three medications, 15 with two medications, and 18 with one medication. At 3 months after surgery, 10 eyes (18%) required the same number of medications for IOP control, 29 eyes (52%) required one less medication, 12 eyes (21%) required two less medications, three eyes (5%) required three less medications, and one eye (1.7%) required four and five less medications after surgery. There was a trend toward a greater postoperative reduction of glaucoma medications with increasing number of preoperative glaucoma medications required (Fig. 1).

Correlation analysis revealed that the estimated post-PHCE IOP values derived using the previously developed formula were positively correlated with the measured IOP values at 1 month ($R = 0.314$, $p = 0.013$; Fig. 2A) and 3 months ($R = 0.325$, $p = 0.01$; Fig. 2B) after surgery. We found no significant difference between 1-month IOP and estimated IOP ($p = 0.396$). The 3-month IOP significantly differed from the estimated IOP ($p = 0.024$). However, this difference was no longer significant ($p = 0.081$) when we excluded the two outliers that were distant from other clustered points on the scattered plot (indicated by arrows in Fig. 2A and 2B). These points represented data from the same two eyes at 1 month and 3 months after surgery. Both of these cases showed elevated IOP lasting for several weeks following an episode of acute angle closure attack; after which, the patients were referred to us for further treatment. None of the other cases enrolled in this study had a history of acute angle closure attack.

The Bland−Altman plots also revealed good agreement between the estimated and the measured IOP values at 1 month and 3 months postoperatively (Figs. 3 and 4). The measurements for two eyes fell outside of ± 1.96 standard deviation (SD) from the mean difference between the estimated and measured IOP at 1 month, and the measurements for five eyes were outside of this range at 3 months. Each of these five eyes had a pre-PHCE IOP >27 mm Hg, and four of these eyes were treated with ≥3 glaucoma medications before PHCE-IOL. Of these five cases, only one eye had a measured IOP value that was higher than the estimated value at 3 months after surgery, while the other four eyes had measured IOP values lower than the estimated values.

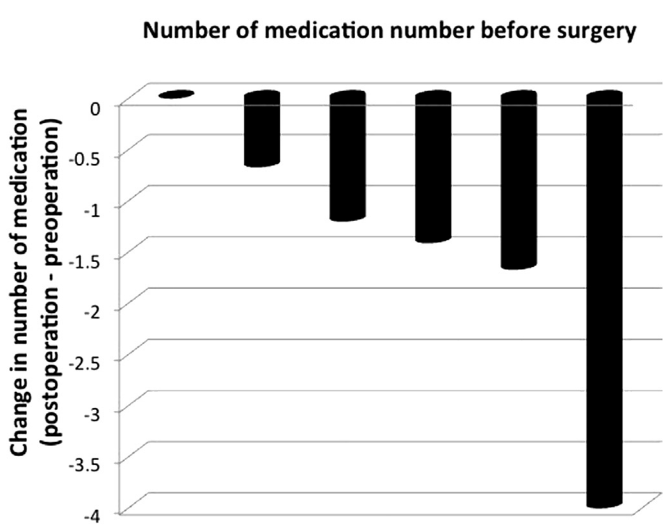


Fig. 1. The ordinate axis shows changes in the number of glaucoma medications at 3 months after cataract surgery. The abscissa axis shows the numbers of preoperative glaucoma medications.

## 4. Discussion

The present study investigated eyes with PACG that were treated with PHCE-IOL, and found mean IOP reductions of 23% at 1 month postoperatively and of 26% at 3 months postoperatively. Direct comparisons of our study with previous reports are difficult because of differing study designs, but our results were in agreement with previous reports that showed a reduction of 8−31% at 3 months after cataract surgery.[7,10−14] Moreover, none of the included 62 eyes required additional glaucoma medication or further glaucoma intervention to control IOP during the first 3 months postoperatively. In fact, we found that eyes that were preoperatively treated with more glaucoma medications tended to obtain a greater reduction in the number of medications 3 months postoperatively. To the best of our knowledge, this has not previously been reported, and its clinical implication warrants further investigation.

More importantly, 92% of the eyes in our study achieved a postoperative measured IOP that was in agreement, based on the Bland−Altman plot, with the estimated IOP calculated using our previously constructed formula (5 patients fell outside the ± 1.96 SD of the Bland−Altman plot, representing "not in agreement").[11] The differences between the estimated and measured IOP values were within ± 3.0 mm Hg in 32 eyes (52%) at 1 month postoperatively and in 42 eyes (68%) at 3 months postoperatively. The utilized formula had been constructed based on 12-month postoperative IOP data from another group of chronic PACG eyes, but it still provided reasonable estimations of postoperative IOP at 1 month and 3 months after PHCE and IOL implantation in our present study group. In clinical practice, estimation of IOP within 3 months of cataract surgery may be more important than long-term IOP estimation. After cataract surgery alone, postoperative IOP may become more difficult to control because of ocular inflammation and steroid use. Patients who are preoperatively using three or more glaucoma medications have only limited choices of additional glaucoma drugs to reduce pressure elevation, and additional glaucoma surgery performed

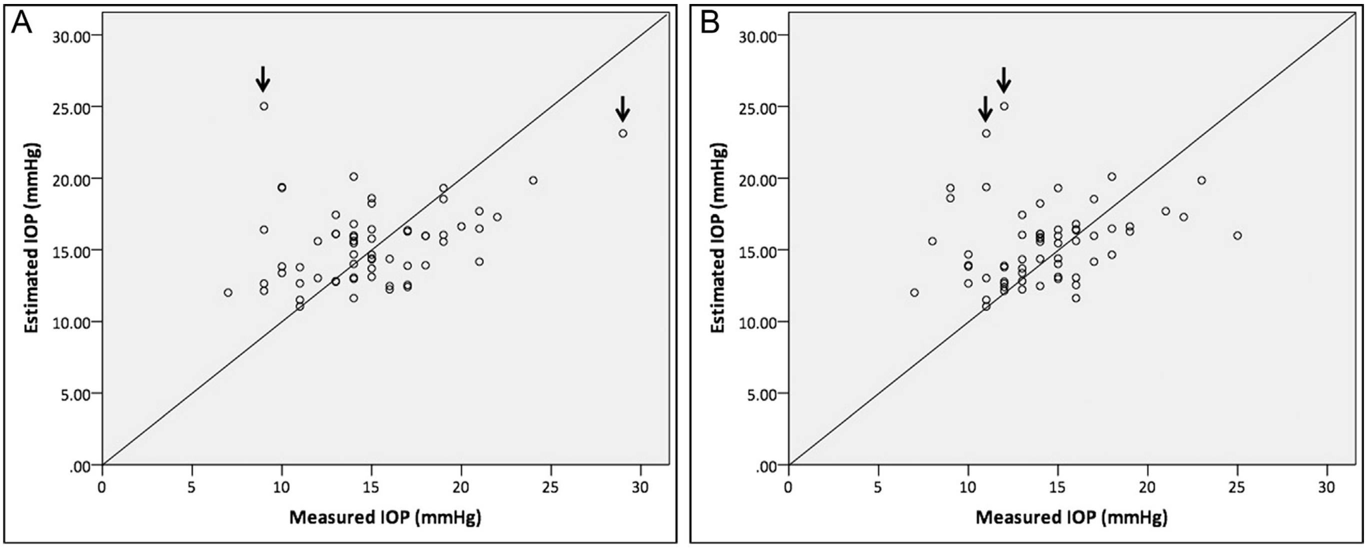


Fig. 2. The scatter plots illustrate the relationships between the estimated IOP and the measured IOP values obtained at 1 month postoperatively (A) and 3 months postoperatively (B). Circles falling on the oblique line represented cases for which the measured IOP was equal to the estimated IOP. The black arrows indicate the two outliers in each plot. IOP = intraocular pressure.

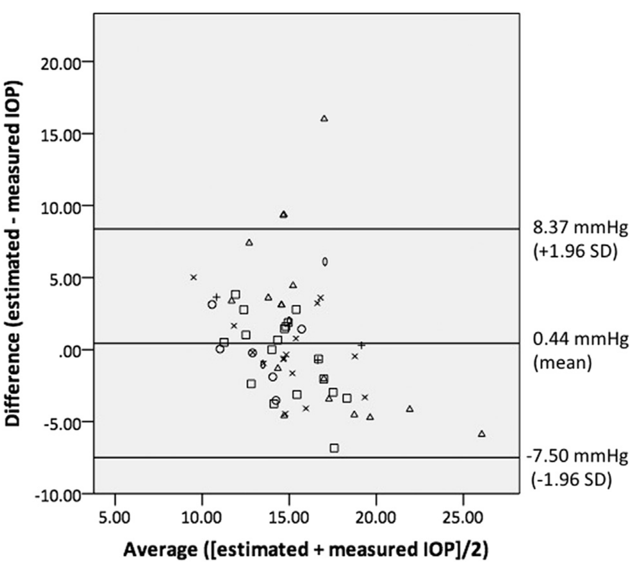


Fig. 3. This Bland−Altman plot shows the IOP average against the difference between the estimated IOP and measured IOP at 1 month after surgery. The three horizontal lines represent +1.96 SD (8.37 mm Hg), the mean (0.44 mmHg), and −1.96 SD (−7.50 mmHg) of the difference between the two values. The different shapes represent different numbers of preoperative medications: ○ = no medication; □ = 1 medication; × = 2 medications; △ = 3 medications; + = 4 medications; 0 = 5 medications). IOP = intraocular pressure; SD = standard deviation.

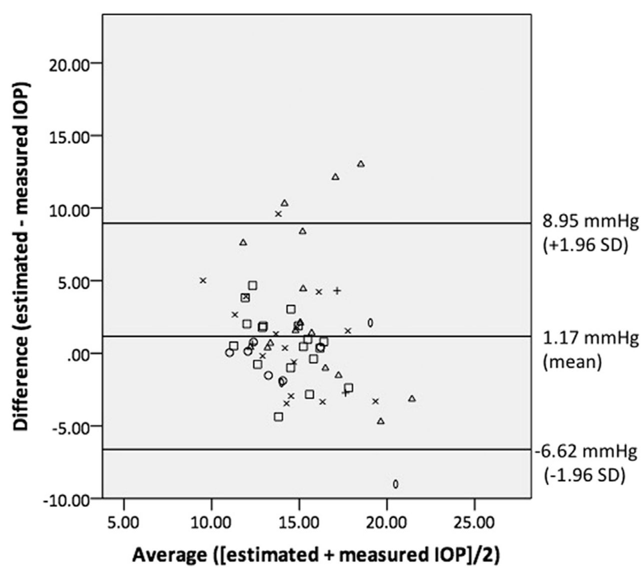


Fig. 4. This Bland−Altman plot shows the IOP average against the difference between the estimated IOP and measured IOP at 3 months after surgery. The three horizontal lines represent +1.96 SD (8.95 mm Hg), the mean (1.17 mm Hg), and −1.96 SD (−6.62 mm Hg) of the difference between the two values. The different shapes represent different numbers of preoperative medications: ○ = no medication; □ = 1 medication; × = 2 medications; △ = 3 medications; + = 4 medications; 0 = 5 medications). IOP = intraocular pressure; SD = standard deviation.

during the early postoperative period carries a risk of failure due to inflammation.[10]

Two eyes in our present study were found to be outliers in both the correlation analysis and the Bland−Altman plots at Postoperative Months 1 and 3. The pre-PHCE IOPs of these eyes were 34 mm Hg and 38 mm Hg, respectively, while on three glaucoma medications, including oral acetazolamide. Pre-PHCE gonioscopy revealed 360° peripheral anterior synechia with slit opening inferiorly on indentation. The IOP values measured at 3 months after surgery (11 mm Hg and 12 mm Hg, respectively) were lower than the estimated IOP values (23.11 mm Hg and 25.01 mm Hg, respectively) for these two cases. These were the only two eyes in this study that had been afflicted with an acute episode of angle closure within 1 month of cataract surgery. Medical intervention following the acute attack reduced the IOP, but medication did not lower the IOP to <30 mmHg before PHCE-IOL. In such cases, a large anterior-placed lens,[8,15] potentially compromised trabecular outflow,[23,24] inflammation, and ocular congestion with uveal effusion and anterior rotation of the ciliary body may all contribute to making it difficult to control the IOP with glaucoma medication.[3,25] However, the impact of inflammation and ocular congestion on aqueous drainage outflow may be reversible after lens removal and inflammation control, which may at least partly explain why the measured postoperative IOP was lower than the estimated value. In the study from which the IOP-estimation formula was developed,[11] all patients had PACG with IOP that was controlled before cataract extraction. A few cases had a history of acute attack, but these acute attacks had occurred years earlier.

Accumulating evidence, including our present findings, demonstrates that PHCE-IOL can lower IOP and reduce the need for glaucoma medication. Studies using ultrasound biomicroscopy, Scheimpflug videophotography, rotating camera scanner, and anterior segment optical coherence tomography reveal increases of the width and depth of the anterior chamber angle in PACG after cataract surgery, to the extent that they become similar to normal eyes.[18,26–29] By comparing preoperative and postoperative gonioscopy findings, Lai et al[16] demonstrated a decrease in the extent of peripheral anterior synechial closure after PHCE in eyes with PACG and coexisting cataract. This could be caused by resolution of synechia with weak adherence to the trabeculum through the positive flushing pressure and viscoelastic agent injection into the anterior chamber during PHCE, as well as to the removal of a bulky lens. Moreover, the increased trabecular outflow facility induced by the PHCE ultrasound may also contribute to IOP reduction after surgery. Previous studies have shown improved aqueous outflow facility after PHCE,[30] which may be related to interleukin-1α production from the trabecular meshwork cells in response to PHCE ultrasound.[31]

In conclusion, the present study demonstrated that our previously constructed IOP estimation formula, which utilizes preoperative IOP and ACD, is useful for estimating IOP at 1 month and 3 months after surgery. The proposed prediction formula provides another piece of information in preoperative patient consultation about whether PHCE-IOL alone is likely to achieve the target IOP each individual eye requires, so as to avoid life-long potential complications of combined glaucoma filtering surgery.

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