Long-Term Refractive Outcomes After Combined Phacoemulsification and Trabeculectomy in Glaucoma Patients

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Research article

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Abstract

Background: To investigate long-term refractive outcomes after phacotrabeculectomy and to determine risk factors that may cause unstable refractive outcomes after phacotrabeculectomy in glaucoma patients.

Methods: A total 120 eyes of 120 patients who had underwent uncomplicated phacotrabeculectomy (combined group) or phacoemulsification (phaco-only group) were included. Best-corrected visual acuity (BCVA), intraocular pressure (IOP) were measured before and after surgery, and anterior segment parameters including anterior chamber depth (ACD), lens vault (LV), and anterior vault (AV) measured using anterior-segment optical coherence tomography were compared between the two groups. The mean absolute error (MAE) at 3, 6, 12, and 24 months postoperatively were compared. Risk factors associated with unstable refractive outcomes (MAE ≥ 0.5) were investigated in the combined group.

Results: In both groups, BCVA was improved and IOP was decreased significantly. MAE at 3, 6, 12, 24 months postoperatively were not significantly different between two groups. The risk factors for unstable refractive outcomes after 12 months of phacotrabeculectomy were old age and LV. Whereas, the only factor predicting unstable refractive outcome after 24 months of phacotrabeculectomy was LV. The cut-off value of LV for predicting unstable refractive outcome analyzed by the ROC curve was 0.855 mm.

Conclusions: Phacotrabeculectomy may be an effective treatment with predictable long-term refractive outcomes similar to phacoemulsification in patients with glaucoma. However, elderly patients or patients with large LV may be predisposed to unpredictable postoperative refractive outcomes after phacotrabeculectomy.

Background

When planning the surgery of a patient with cataract and medically uncontrolled glaucoma, it becomes difficult to decide whether to perform trabeculectomy and phacoemulsification at the same time or to perform phacoemulsification after trabeculectomy. It has already been reported that axial length (AL) and anterior chamber depth (ACD) decrease [1–3] and keratometry changes [4–6] after trabeculectomy. Because these parameters play an important role in determining the intraocular lens (IOL) power[7–10], there is a possibility that postoperative refractive errors may increase if the IOL power calculation formula used for phacoemulsification is used when performing phacotrabeculectomy [11, 12].

If phacoemulsification is performed with uncontrolled intraocular pressure (IOP), surgery becomes difficult due to high posterior pressure [13]. Complications such as hypotony, hyphema, shallow anterior chamber may occur after phacotrabeculectomy [14, 15], and the frequency of complications is higher than that of phacoemulsification alone [16, 17]. Nevertheless, there are several advantages of phacotrabeculectomy such as improving visual acuity after surgery, minimizing postoperative IOP spikes, and reducing morbidity that can occur in two stage operations [18–20]. Since the success rate has been
increased by the use of mitomycin C [21, 22], phacotrabeculectomy is widely performed in recent clinical trials.

As the calculations for IOL power improve due to the development of preoperative evaluations and surgical techniques, refractive outcomes are becoming more predictable [22, 23]. There is increasing interest in reducing refractive errors after phacotrabeculectomy because trabeculectomy can affect refractive outcomes after phacoemulsification. Recently, several studies focusing on refractive outcomes after phacotrabeculectomy have been published [11, 18, 22–25].

However, most of the previous studies examined short-term refractive outcomes of less than 6 months, and no studies have investigated risk factors that can cause unstable refractive outcomes after phacotrabeculectomy. Therefore, the present study aims to compare the long-term refractive outcomes of phacotrabeculectomy and phacoemulsification, and to determine the factors that predict unpredictable refractive outcome after phacotrabeculectomy.

**Methods**

**Subjects**

We retrospectively reviewed medical records of patients who had undergone uncomplicated phacotrabeculectomy (combined group) or uncomplicated phacoemulsification (phaco-only group) between September 2015 and December 2018. Patients underwent phacotrabeculectomy when IOP was not controlled even with the maximal tolerated medical treatment. Patients who were able to follow-up for more than one year were included, and exclusion criteria included prior keratorefractive surgery, ocular disease that may affect refractive errors except glaucoma and cataract, IOL in the ciliary sulcus or sclera fixation of IOL, and bleb needling after phacotrabeculectomy. If both eyes of a patient satisfied these criteria, one eye was chosen randomly. Ethical approval was obtained from the Chonnam National University Hospital Institutional Review Board, and the study protocol followed the guidelines of the Declaration of Helsinki.

**Data Collection**

All patients underwent preoperative evaluations including best-corrected visual acuity (BCVA), manifest refraction using autorefractor keratometer (ARK; Topcon KR-8900®, Topcon, Tokyo, Japan), IOP using Goldmann applanation tonometry, and slit-lamp examination. For comparison, BCVA was converted to logarithm of the minimum angle of resolution (LogMAR) and the refraction value was converted to spherical equivalent (SE) by adding spherical power to 1/2 of cylinder power. And 12 months after the surgery, BCVA and IOP were measured to investigate the effect of the two operations on visual acuity and IOP.

K-value using ARK and axial length (AL) using partial coherence interferometry (Lenstar®, Haag-Streit, Bern, Switzerland) were measured, and SRK-T formula was used to calculate IOL power and predicted
refractive errors. Additionally, anterior segment parameters were measured by using anterior-segment optical coherence tomography (AS-OCT) device (Visante®, Carl Zeiss Meditec, Dublin, CA). A single examiner (S.W.P) selected the best images with no motion artifacts, good visibility of the scleral spur, and no image artifacts from the eyelids. And then, two independent examiners (Y.S.K and M.S.S) who were blinded to other clinical information analyzed images using custom software (Iridocorneal module, Carl Zeiss Meditec). Anterior chamber depth (ACD) was defined as the distance between the center of posterior corneal surface and anterior lens surface, lens vault (LV) was defined as the maximum perpendicular distance between the anterior lens surface and horizontal line connecting the two sclera spurs, and anterior vault (AV) was defined as the sum of ACD and LV.\textsuperscript{26}

### Surgical Technique

Surgical procedures were performed by a single surgeon (S.W.P) under topical or retrobulbar anesthesia. Standard phacoemulsification was used to remove the cataract through a temporal 2.8 mm clear corneal incision. In all cases, Acrysof SN60WF (Alcon, Fort Worth, TX) IOL was implanted in the capsular bag.

For a phacotrabeculectomy, a fornix-based conjunctival flap and rectangular shaped half-thickness scleral flap were created. Phacoemulsification and IOL implantation were performed through clear corneal incision at a different site with trabeculectomy. A sponge soaked in 0.04% mitomycin C was placed under the conjunctiva and Tenon’s capsule on the sclera for 3–5 minutes according to the discretion of the surgeon and based on the patient characteristics. Sclerotomy and peripheral iridectomy were performed. Finally, the scleral flap was sutured with 2 interrupted sutures using 10–0 nylon and the conjunctival was closed.

### Outcome Measures

Mean absolute error (MAE) was defined as the absolute value of the difference between predicted refractive errors and postoperative refractive errors. MAE at 3, 6, 12, and 24 months postoperatively were compared between two groups. The combined group was further divided into two subgroups based on the refractive outcomes; stable refractive outcomes (MAE < 0.5 diopters [D]) and unstable refractive outcomes (MAE ≥ 0.5 D). Risk factors associated with unstable refractive outcomes were investigated at 12 and 24 months postoperatively. The number of glaucoma medications used preoperatively and 12 and 24 months postoperatively were also compared to determine the IOP lowering effect of phacotrabeculectomy.

### Statistical Analysis

SPSS version 26.0 (SPSS Inc, Chicago, IL) was used for all statistical analyses. Independent \( t \)-test or Mann-Whitney U test was used to compare the continuous data of the two groups, and paired \( t \)-test was used to compare the values before and after surgery in the same group. Chi-square test was used to compare categorical data, and logistic regression analysis was used to investigate risk factors that may cause unstable refractive outcomes. Variables with a significance level at \( P < 0.1 \) in the univariable analysis were included in the multivariable analysis. The receiver operating characteristic (ROC) curve
analysis was used to determine the optimal cut-off value of risk factor predicting unstable refractive outcomes. The ability of the cut-off value to predict accurately is represented by the area under the curve (AUC). \( P \) values less than 0.05 were considered statistically significant.

**Results**

A total 120 eyes of 120 patients were enrolled in this study, and 60 eyes were included in each group. The subject's demographics and baseline characteristics of the included eyes are summarized in Table 1. Since patients in the combined group had medically uncontrolled glaucoma, the mean preoperative IOP was 29.60 ± 10.04 mmHg, which was significantly higher than those in phaco-only group (\( P < 0.001 \)). ACD was significant smaller in the combined group than that of the phaco-only group (\( P = 0.018 \)). There were no significant differences in age, sex, preoperative BCVA, AL, LV, and AV.

| Variables          | Combined group (n = 60) | Phaco-only group (n = 60) | \( P \) value |
|--------------------|-------------------------|---------------------------|--------------|
| Age (years)        | 65.65 ± 11.02           | 67.83 ± 8.88              | 0.234 \(^{a}\) |
| Sex (male/female)  | 34 / 26                 | 30 / 30                   | 0.464 \(^{b}\) |
| Baseline BCVA (LogMAR) | 0.67 ± 0.82          | 0.47 ± 0.58               | 0.124 \(^{a}\) |
| Baseline IOP (mmHg) | 29.60 ± 10.04          | 14.52 ± 2.50              | <0.001 \(^{a}\) |
| AL (mm)            | 23.16 ± 1.04           | 23.26 ± 1.17              | 0.337 \(^{a}\) |
| ACD (mm)           | 2.25 ± 0.48            | 2.48 ± 0.56               | 0.018 \(^{a}\) |
| LV (mm)            | 0.82 ± 0.36            | 0.71 ± 0.38               | 0.090 \(^{a}\) |
| AV (mm)            | 3.06 ± 0.40            | 3.19 ± 0.38               | 0.089 \(^{a}\) |

*BCVA* best-corrected visual acuity, *LogMAR* logarithm of the minimum angle of resolution, *IOP* intraocular pressure

*AL* axial length, *ACD* anterior chamber depth, *LV* lens vault, *AV* anterior vault

\(^{a}\) Independent t-test

\(^{b}\) Chi-square test

In both groups, BCVA was significantly improved (\( P = 0.001 \) and \( P < 0.001 \), respectively) and IOP was significantly decreased (\( P < 0.001 \) and \( P < 0.001 \), respectively) at 12 months postoperatively (Table 2). The phaco-only group tended to show better postoperative BCVA than the combined group, but there was no statistical significance (\( P = 0.065 \)). Mean postoperative IOP of the combined group was 13.35 ±
3.12 mmHg, which remained stable until 12 months after phacotrabeculectomy. MAE at 3, 6, 12, and 24 months postoperatively were not significantly different between the two groups (\(P = 0.072, P = 0.117, P = 0.226,\) and \(P = 0.083,\) respectively) (Table 3). That is, refractive outcomes after phacotrabeculectomy were similar with that of the phacoemulsification alone until 24 months postoperatively.

Table 2

Visual outcomes and IOP reduction at 12 months postoperatively.

| Variables                  | Combined group | Phaco-only group | \(P\) value<sup>a</sup> |
|---------------------------|----------------|------------------|-------------------------|
| Baseline                  |                |                  |                         |
| BCVA (LogMAR)             | 0.68 ± 0.82    | 0.47 ± 0.58      | 0.124                   |
| IOP (mmHg)                | 29.60 ± 10.04  | 14.52 ± 2.50     | <0.001                  |
| Postoperative             |                |                  |                         |
| BCVA (LogMAR)             | 0.48 ± 0.86    | 0.24 ± 0.56      | 0.065                   |
| IOP (mmHg)                | 13.35 ± 3.12   | 13.23 ± 2.20     | 0.814                   |

\(<P\) value<sup>b</sup><br>

| Variables |
|-----------|
| BCVA      | 0.001      | <0.001           |
| IOP       | <0.001     | <0.001           |

\(IOP\) indicates intraocular pressure, \(BCVA\) best-corrected visual acuity, \(LogMAR\) logarithm of the minimum angle of resolution

<sup>a</sup> Independent \(t\)-test for combined group and phaco-only group

<sup>b</sup> Paired \(t\)-test for baseline and postoperative value

Table 3

Refractive outcomes of the combined group and phaco-only groups.

| Variables                                              | Combined group | Phaco-only group | \(P\) value<sup>a</sup> |
|--------------------------------------------------------|----------------|------------------|-------------------------|
| MAE at 3 months postoperatively (D)                    | 0.69 ± 0.47    | 0.54 ± 0.47      | 0.072                   |
| MAE at 6 months postoperatively (D)                    | 0.66 ± 0.60    | 0.52 ± 0.32      | 0.117                   |
| MAE at 12 months postoperatively (D)                   | 0.59 ± 0.44    | 0.49 ± 0.43      | 0.226                   |
| MAE at 24 months postoperatively (D)<sup>b</sup>       | 0.63 ± 0.44    | 0.47 ± 0.36      | 0.083                   |

\(MAE\) mean absolute error, \(D\) diopters

<sup>a</sup> Independent \(t\)-test.

<sup>b</sup> Only forty-seven patients were included in each of groups at 24 months postoperatively.
Table 4 showed characteristics of the stable and unstable refractive outcome subgroups in the combined group at 12 and 24 months postoperatively. Patients in the unstable subgroup were significantly older ($P = 0.024$), and had a larger LV ($P = 0.038$) and larger AV ($P = 0.041$) than those in the stable subgroup at 12 months postoperatively. And patients in the unstable subgroup had significantly shallower ACD ($P = 0.040$) and larger LV ($P = 0.010$) than those in the stable subgroup at 24 months postoperatively.
Table 4
Characteristics of the stable and unstable subgroups in combined group at 12 and 24 months postoperatively.

| Variables                  | 12 months postoperatively | 24 months postoperatively | P value | 12 months postoperatively | 24 months postoperatively | P value |
|----------------------------|---------------------------|---------------------------|---------|---------------------------|---------------------------|---------|
|                            | Stable subgroup (n = 30)  | Stable subgroup (n = 20)  |         | Unstable subgroup (n = 30) | Unstable subgroup (n = 27) |         |
| Age (years)                | 62.47 ± 10.68             | 68.83 ± 10.58             | 0.024   | 62.40 ± 11.77             | 66.40 ± 10.55             | 0.222   |
| Sex (male/female)          | 17 / 13                   | 17 / 13                   | 1.000   | 12 / 8                    | 16 / 11                   | 0.599   |
| Type of glaucoma (ACG/OAG) | 17 / 13                   | 17 / 13                   | 1.000   | 9 / 11                    | 17 / 10                   | 0.177   |
| Baseline BCVA (LogMAR)     | 0.61 ± 0.82               | 0.74 ± 0.82               | 0.530   | 0.87 ± 1.05               | 0.44 ± 0.39               | 0.197   |
| Postoperative BCVA (LogMAR)| 0.40 ± 0.76               | 0.57 ± 0.95               | 0.449   | 0.59 ± 10.7               | 0.36 ± 0.60               | 0.334   |
| Baseline IOP (mmHg)        | 31.87 ± 10.50             | 27.33 ± 9.18              | 0.080   | 30.15 ± 9.23              | 29.37 ± 10.01             | 0.384   |
| Postoperative IOP (mmHg)   | 13.50 ± 2.67              | 13.20 ± 3.57              | 0.714   | 13.75 ± 2.86              | 13.48 ± 3.41              | 0.312   |
| AL (mm)                    | 23.11 ± 0.89              | 23.20 ± 1.19              | 0.735   | 23.20 ± 0.94              | 23.22 ± 1.16              | 0.249   |
| ACD (mm)                   | 2.23 ± 0.47               | 2.27 ± 0.50               | 0.492   | 2.28 ± 0.46               | 2.08 ± 0.41               | 0.040   |
| LV (mm)                    | 0.74 ± 0.31               | 0.89 ± 0.27               | 0.038   | 0.70 ± 0.35               | 0.94 ± 0.21               | 0.010   |
| AV (mm)                    | 2.96 ± 0.27               | 3.17 ± 0.47               | 0.041   | 2.99 ± 0.26               | 3.02 ± 0.45               | 0.418   |

ACG angle closure glaucoma, OAG open angle glaucoma, BCVA best-corrected visual acuity, LogMAR logarithm of the minimum angle of resolution, IOP intraocular pressure, AL axial length, ACD anterior chamber depth, LV lens vault, AV anterior vault

a Independent t-test
b Chi-square test
c Mann-Whitney U test
The univariable analysis showed that old age (OR = 1.060, \( P = 0.031 \)), large LV (OR = 6.838, \( P = 0.045 \)), and large AV (OR = 4.873, \( P = 0.047 \)) were associated with unstable refractive outcomes at postoperative 12 months after combined surgery. The multivariable analysis showed that old age (OR = 1.069, \( P = 0.030 \)) and large LV (OR = 5.687, \( P = 0.029 \)) were predictive factors of unstable refractive outcomes at 12 months postoperatively (Table 5). At postoperative 24 months, univariable and multivariable analysis determined that only large LV (OR = 19.647, \( P = 0.024 \)) was associated with unstable refractive outcomes after combined surgery (Table 6). ROC curve analysis was performed to determine the optimal cut-off value of the LV that can predict unstable refractive outcomes (Fig. 1). The AUC of LV at 12 months postoperatively was 0.619 and the AUC of LV at 24 months postoperatively was 0.689. In both ROC curves, the cut-off value of LV was 0.855 mm.
Table 5
Factors associated with unstable refractive outcomes in combined group at 12 months postoperatively.

| Variables                  | Univariable analysis | Multivariable analysis * |
|----------------------------|----------------------|--------------------------|
|                            | OR       | 95% CI   | P value | OR       | 95% CI   | P value |
| Age, per 1 year older      | 1.060    | 1.005–1.118 | 0.031   | 1.069    | 1.007–1.135 | 0.030   |
| Male gender                | 1.000    | 0.360–2.777 |         | 1.000    |           |         |
| ACG                        | 1.000    | 0.360–2.777 |         | 1.000    |           |         |
| Baseline BCVA, per 1 increase | 1.229 | 0.651–2.321 | 0.524   |          |           |         |
| Baseline IOP, per 1 mmHg increase | 0.953 | 0.903–1.006 | 0.084   | 0.963    | 0.905–1.024 | 0.229   |
| AL, per 1 mm increase      | 1.090    | 0.667–1.782 | 0.730   |          |           |         |
| ACD, per 1 mm increase     | 1.449    | 0.511–4.103 | 0.485   |          |           |         |
| LV, per 1 mm increase      | 6.838    | 1.043–44.809 | 0.045  | 5.687    | 1.195–27.064 | 0.029   |
| AV, per 1 mm increase      | 4.873    | 1.210–19.625 | 0.047  | 6.231    | 0.755–51.425 | 0.089   |

*Logistic regression analysis

**OR** odds ratio, **CI** confidence interval, **ACG** angle closure glaucoma, **BCVA** best-corrected visual acuity, **IOP** intraocular pressure, **AL** axial length,

**ACD** anterior chamber depth, **LV** lens vault, **AV** anterior vault.

*Only variables with a **P** value of less than .10 in the univariable analysis were included in the multivariable model.*
Table 6
Factors associated with unstable refractive outcomes in combined group at 24 months postoperatively.

| Variables                  | Univariable analysis | Multivariable analysis * |
|----------------------------|----------------------|--------------------------|
|                            | OR       | 95% CI  | P value a | OR       | 95% CI  | P value a |
| Age, per 1 year older      | 1.034   | 0.980–1.092 | 0.226   |          |         |           |
| Male gender                | 1.031   | 0.317–3.352 | 0.959   |          |         |           |
| ACG                        | 2.078   | 0.640–6.744 | 0.223   |          |         |           |
| Baseline BCVA, per 1 increase | 0.442 | 0.176–1.110 | 0.082   | 0.460   | 0.157–1.349 | 0.157   |
| Baseline IOP, per 1 mmHg increase | 0.991 | 0.933–1.054 | 0.781   |          |         |           |
| AL, per 1 mm increase      | 1.022   | 0.589–1.771 | 0.939   |          |         |           |
| ACD, per 1 mm increase     | 0.346   | 0.088–1.362 | 0.129   |          |         |           |
| LV, per 1 mm increase      | 21.309  | 1.813–250.393 | 0.015   | 19.647  | 1.469–262.802 | 0.024   |
| AV, per 1 mm increase      | 1.260   | 0.270–5.878 | 0.769   |          |         |           |

OR odds ratio, CI confidence interval, ACG angle closure glaucoma, BCVA best-corrected visual acuity, IOP intraocular pressure, AL axial length, ACD anterior chamber depth, LV lens vault, AV anterior vault.

* Logistic regression analysis

* Only variables with a P value of less than .10 in the univariable analysis were included in the multivariable model.

The patients in the combined group used an average of 2.8 medications preoperatively. The needs for glaucoma medication were significantly reduced to average of 1.12 medications at 12 months (P<0.001) and average of 1.27 medications at 24 months (P<0.001) postoperatively.

Discussion

Cataract surgery has the advantage of quick visual recovery and relatively low complications [27–29]. Since cataract surgery alone has an effect of reducing IOP in patients with angle closure glaucoma (ACG)
[16, 17, 30] and open angle glaucoma (OAG) [31–33], phacoemulsification plays an important role in the treatment of glaucoma. In patients with ACG, phacoemulsification significantly deepens the ACD and resolves angle crowding. Because these changes are small in patients with OAG, the exact mechanism why IOP decreases after cataract surgery in patients with OAG remains controversial [29]. Some studies reported that both changes of angle configuration and trabecular meshwork or extracellular matrix remodeling are involved [27, 28]. In the current study, the fact that IOP significantly decreased postoperatively in the phaco-only group also supports previous studies.

Preoperatively, the ACD of the combined group was significantly shallower than that of the phaco-only group. This finding can be explained by the prevalence of ACG (34 eyes) in the combined group, whereas the phaco-only group had twelve patients with ACG. Previous studies reported that the refractive outcome of patients with ACG was difficult to predict [34, 35], but our result showed relatively stable refractive outcome despite the large number of patients with ACG in the combined group.

Recently, the indications of phacotrabeculectomy are as follows: i) medically uncontrolled glaucoma, ii) tolerance of glaucoma medications, iii) postoperative IOP spikes may worsen visual field damage, iv) suspected compliance of glaucoma medications [15–17, 36]. Several studies reported that the IOP lowering effect of phacotrabeculectomy was superior than that of phacoemulsification alone in patients with glaucoma [36–38]. In the present study, the mean preoperative IOP of combined group was 29.60 ± 10.04 mmHg. It was significantly reduced to average of 13.35 ± 3.12 mmHg at 12 months postoperatively, and the postoperative need of glaucoma medications was significantly decreased. As in the previous studies, phacotrabeculectomy was found to be an effective treatment for lowering IOP.

In this study, we aimed to investigate the long-term refractive outcomes after phacotrabeculectomy, and we found that there was no significant difference in refractive outcomes compared to phacoemulsification alone until 24 months after surgery. It means that phacotrabeculectomy was effective not only for IOP control but also for stable refractive outcomes. Previous studies reported that myopic shift occurs after phacotrabeculectomy compared to phacoemulsification alone [11, 23–25]. A decreased ACD after trabeculectomy causes a myopic shift, and a decreased AL after trabeculectomy causes a hyperopic shift, conversely. Some authors of these studies estimated that a decrease in ACD had a greater effect on refractive errors than a decrease in AL, leading to myopic shift. In the current study, since the refractive errors were compared using the absolute value of the difference of refractive errors, we could not analyze whether myopic shift or hyperopic shift occurred after phacotrabeculectomy.

Law et al. [24] reported that K-value was increased after phacotrabeculectomy. Changes of not only ACD and AL but also K-value affect refractive errors, and if K-value increases, hyperopic shift may occur. Since this study did not measure postoperative K-value, ACD, and AL, it was not possible to analyze which factors had more significant effect on refractive outcomes. However, we hypothesized that there was no significant difference in refractive outcomes between combined group and phaco-only group because the changes of ACD, AL, and K-value after phacotrabeculectomy had a global effect.
Most of the studies that focused on the refractive outcomes of phacotrabeculectomy analyzed only short-term refractive outcomes less than 6 months [11, 18, 22–25], and one study reported by Chung et al. [12] had a limitation that the follow-up period of the control group was average of 4.81 months. Therefore, the present study is clinically significant because we analyzed long-term refractive outcomes of phacotrabeculectomy up to 24 months postoperatively.

Tzu et al. [39] reported that the risk factor for refractive errors in combined cataract and glaucoma surgery included old age. Though the follow-up time was less than 6 months and glaucoma drainage device surgery was included in the combined group, it remains a meaningful result. Old age has been associated with structural changes of scleral collagen fiber and changes of ACD [40, 41], therefore, some studies reported that age of patients may affect the refractive outcomes after cataract surgery [42, 43]. Our study also supports this result, as old age appeared to be a risk factor up to 12 months after phacotrabeculectomy. However, old age did not appear as a risk factor after 24 months of phacotrabeculectomy, which may be because of the relatively small number of patients.

Our group previously reported that one risk factor causing unpredictable refractive errors after cataract surgery in patients with glaucoma was large LV [44]. We speculated that large LV predispose to larger displacement of IOL position, resulting in unstable refractive outcomes. In agreement with the previous report, in the current study, large LV was a risk factor that could cause refractive errors up to 12 and 24 months after phacotrabeculectomy. Therefore, we suggest that LV plays an important role in predicting refractive errors after combined phacotrabeculectomy surgery in glaucoma patients as well as cataract surgery.

Ozaki et al. [45] reported that the LV of primary angle closure (PAC) patients was 1.034 mm on average, and that of normal people was 0.419 mm, and Hsia YC et al. [46] reported that LV of OAG patients was 0.55 mm on average. It has already been found that the increased LV is a risk factor of PAC and a predictive factor for refractive outcomes after cataract surgery in patients with glaucoma [44, 45], but there have been no studies analyzing the cut-off value of LV that can cause unpredictable refractive errors. We analyzed the long-term data after phacotrabeculectomy and found that a LV thickness of 0.855 or more was a risk factor for unstable refractive outcomes. Therefore, the surgeon should be very careful when operating patients with LV greater than 0.855 mm because unpredictable refractive errors can be obtained.

The current study has several limitations. First, we could not analyze which ocular parameters had a significant effect on refractive outcomes because some ocular parameters were not measured after surgery. Second, both patients with ACG and patients with OAG were included in the combined group, so the effect of angle status was not considered. Third, we did not consider digital massage or releasable suture removal that could affect refractive errors after phacotrabeculectomy. Finally, we did not analyze the complications that could occur after phacotrabeculectomy because only patients without complication were included. In the future, larger and more long-term studies that consider these factors will be needed.
Conclusions

In conclusion, phacotrabeculectomy is an effective treatment that significantly reduces IOP and decreases the use of glaucoma medications in patients with cataract and medically uncontrolled glaucoma. There was no significant difference in refractive errors compared to phacoemulsification alone, and patients who underwent phacotrabeculectomy could also get a stable refractive outcomes. However, the operator should be careful phacotrabeculectomy may increase in elderly patients or patients with large LV.

Abbreviations

AL: Axial length; ACD: Anterior chamber depth; IOL: Intraocular lens; IOP: Intraocular pressure; BCVA: best-corrected visual acuity; ARK: Automated keratoreflectometer; LogMAR: Logarithm of the minimum angle of resolution; SE: Spherical equivalent; AS-OCT: Anterior segment optical coherence tomography; LV: Lens vault; AV: Anterior vault; MAE: Mean absolute error; ROC: Receiver operating characteristic; AUC: Area under the curve; ACG: Angle closure glaucoma; OAG: Open angle glaucoma

Declarations

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Availability of data and materials

Data will not be shared in order to protect patient identify and confidentiality.

Authors’ contributions

YSK, MSS, and SWP designed the study. YSK, HH, and YSJ collected the data and involved in the analysis. YSK wrote the first draft of the manuscript. YSK, MSS, and SWP reviewed and revised the manuscript and produced the final version. All authors have read and approved the final manuscript.

Ethics approval and consent to participate
This study adhered to the Declaration of Helsinki and was approved by the Chonnam National University Hospital Institutional Review Board. Written informed consents were obtained after the subjects were fully informed of the purposes of this study.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare that they have no competing interests.

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Figures
Figure 1

Graphs showing the ROC curve of LV for unstable refractive outcomes at 12 months postoperatively (A) and at 24 months postoperatively (B). The AUC of (A) was 0.619 and the AUC of (B) was 0.689. The cut-off value of LV was 0.855mm in both (A) and (B). ROC = receiver operating characteristic; LV = lens vault; AUC = area under the curve.