Power prediction accuracy of intraocular lens after cataract surgery for patients with angle-closure or angle-closure glaucoma

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<TABLE OF CONTENTS>

LIST OF FIGURES

LIST OF TABLES

<ABSTRACT>

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Purpose: To assess the accuracy of intraocular lens (IOL) power predictions for cataract surgery in angle closure glaucoma (ACG) patients and to compare the accuracy of IOL power prediction for different types of artificial IOLs.

Methods: This prospective comparative case series included 35 eyes from 35 patients with primary ACG and 36 eyes from 36 subjects with normal open angles undergoing uneventful cataract surgery. In the ACG group, 17 eyes had three-piece IOL implantation and 18 eyes had one-piece IOL implantation. In the normal open angle group, 18 eyes had three-piece IOL implantation and 18 eyes had one-piece IOL implantation. Pre-operative anterior segment biometry including anterior chamber depth, lens thickness and axial length was compared between the angle closure group and the normal group for both one-piece and three-piece IOL implantations. Using the SRK/T formula, the absolute values of the differences between the predicted and actual spherical equivalent (SE) refractive errors were analyzed between the four groups.

The power of implanted IOL was calculated to predict postoperative SE by various formulas: SRK II, Haigis, and Hoffer Q by post-hoc analysis in each group. The predictive accuracy of the formula was analyzed by comparing the mean difference between the predicted and actual postoperative SE, that is, the mean absolute error (MAE).

Results: In the one-piece IOL implantation group, there was no difference in MAE between the ACG and normal open angle group (P=0.60). In the three-piece IOL implantation group, the MAE of the ACG group was larger than that of the normal open angle group (P=0.002). The MAEs calculated by SRK/T, SRK II, Haigis, and Hoffer Q were not significantly different between groups.

Conclusion: No difference in IOL power prediction was observed between SRK/T and other formulas. One-piece IOL was more accurate in ACG patients than the three-piece IOL, which may be associated with IOL haptic configuration or design.

Key words: angle-closure; cataract; glaucoma; intraocular lens; power prediction

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I. INTRODUCTION

Primary angle-closure glaucoma (PACG) is an impedance in the flow of aqueous humor from the posterior to the anterior chamber between the anterior surface of the lens and the posterior surface of the iris (Figure 1).[1] Chronic angle-closure glaucoma (CACG) refers to pathology in which portions of the anterior chamber angle are permanently closed by peripheral anterior synechiae.[2]

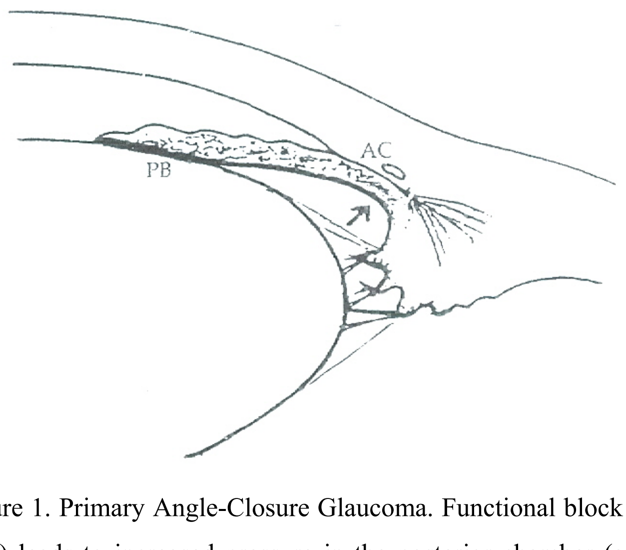

Figure 1. Primary Angle-Closure Glaucoma. Functional block between the lens and iris (*PB*) leads to increased pressure in the posterior chamber (arrow) with a forward shift of the peripheral iris and closure of the anterior chamber angle (*AC*).

PACG or CACG frequently coexist with cataracts. A thick and anteriorly positioned lens is an important cause of angle closure.[3-9] Lens extraction not only significantly deepens the anterior chamber and widens the drainage angle,[10-13] but also results in significant lowering of intraocular pressure (IOP) in CACG eyes.[10, 14-22] This may lead to inaccurate intraocular lens (IOL) power predictions for cataract surgery. Furthermore, ACG patients have larger lens capsules compared to normal controls,[6,23] which may lead to unstable artificial IOL positioning. Hyperopic shift in ocular power when an IOL is implanted in a more posterior plane due to posterior shifting of the capsular bag or a decrease in axial length due to IOP lowering after cataract extraction and myopic shift by instability of IOLs due to larger capsular volume and loosened lens zonules in ACG eyes have been thought to be the cause of inaccuracies in IOL power prediction after cataract surgery.[24] In a study of ACG patients, inaccuracy of IOL power prediction for cataract surgery has been reported, but the cause could not be determined from preoperative biometric data.[24]

In the present study, we focused on comparing the accuracies of IOL power predictions for different types of artificial IOLs and evaluating the predicted accuracies of SRK/T, SRK II, Haigis and Hoffer Q formula in ACG.

II. MATERIALS AND METHODS

Subjects

This study was composed of 35 consecutive eyes from 35 subjects with medically controlled CACG or PAC. 36 consecutive eyes of 36 subjects were recruited as a normal control group. Patients with cataract, no history of previous ocular surgeries except laser peripheral iridotomy or argon laser peripheral iridoplasty, and IOP controlled with or without anti-glaucoma medications were included in the study. Due to the possibility of additional glaucoma surgery, this study did not include eyes with uncontrolled CACG.

A total of 35 eyes were recruited for the angle-closure group. Of these 35 eyes, 17 were randomized into the three-piece IOL group (AC3) and 18 eyes were randomized into the one-piece IOL group (AC1). The normal control group consisted of 36 eyes, in which 18 were randomized into the three-piece IOL group (NC3) and 18 were randomized into the one-piece IOL group (NC1).

PAC was defined as a raised IOP higher than 21 mmHg or as pressure requiring IOP-lowering anti-glaucoma medications to maintain an IOP lower than 21 mmHg in the presence of more than 180 degrees of angle closure obstructing the pigmented part of the trabecular meshwork on gonioscopy. Medically controlled CACG was defined as PAC eyes with evidence of glaucomatous optic neuropathy.

Visually significant cataract was defined by the presence of nuclear sclerosis, cortical cataract, or subcapsular cataract such that the patient had difficulty in daily living activities due to reduced visual acuity.

We obtained prior approval for the study protocol by the Institutional Review Board of the Yonsei University Hospital System. Informed consent was obtained from all patients before recruitment.

Surgical procedures

All procedures were performed by two surgeons (CY Kim, TI Kim), under topical anesthesia from July 2006 through October 2008. Phacoemulsification was accomplished to remove the cataract through a corneal temporal incision and was followed by implantation of a foldable posterior chamber IOL. Cataract surgery was performed with no events or postoperative complications.

The IOLs used in the study were one-piece acrylic IOLs with manufacturer-recommended A-constants of 118.4 (SA60AT, SN60AT; Alcon, Fortworth, Texas, USA) and 118.7 (SN60WF; Alcon), three-piece acrylic IOLs with manufacturer-recommended A-constants of 118.4 (AR40e; AMO, Anasco, Puerto Rico, USA) and 118.7 (ZA9003; AMO). The SRK-T formula was used to select the IOL power.

The constants for each formula were not optimized. Preoperative biometric data in each group was used in the IOL power formula to calculate the power of the implanted IOL, which was then used to calculate the predicted refractive SE. The ultrasound A-scan (Ocusan, Alcon, Cleveland, USA) provided the SRK/T, SRK II, Haigis, Hoffer Q formulas.

Data Collection and Analysis

Sample size was calculated by means of the clinical outcome using: [25]

$$n = \frac{2(z_{\alpha/2} + z_{\beta})^2 \sigma^2}{\varepsilon^2}$$

Where ***n*** is the number of patients in the control group, $z_{\alpha/2}$=1.96, z_{β}=0.84, σ^2 is the pooled variance calculated by the standard deviation between the two groups in another study comparing ACG and normal patients.[26] ε is calculated by the mean difference between the two groups in another study comparing ACG and normal patients.[26]

We used α=0.05, β=0.2, and assumed two-sided testing and equal group sizes. The AC group and NC group each needed 18 subjects and, predicting the fall off rate to be 10%, a total of 20 subjects each was needed. As this study was done for both one-piece and three piece IOLs, an overall total of 80 subjects was calculated.

Preoperative IOPs were measured by the Goldmann applanation, best-corrected visual acuity (BCVA) by the Snellen chart, angle grading by indentation gonioscopy, spherical equivalent of refractive error (SE), axial length, lens thickness, anterior chamber depth (ACD) measured by A-scan ultrasonography, and keratometry (with automated keratometer, RK-3, Canon, Tochigiken, Japan) and were documented for each eye. Postoperatively, study visits were scheduled at three months, with a documentation of IOP as measured by the Goldmann applanation, BCVA, SE of residual refractive error, and the absolute value of the differences between the predicted and actual postoperative SE, that is, the mean absolute error (MAE).

All statistics were calculated using the Statistical Package for the Social Sciences 15.0 for Windows software package (SPSS Inc, Chicago, IL, USA). Continuous data were expressed in mean ± standard deviation, and preoperative and postoperative data of AC1 and NC1, AC3 and NC3 was compared using an independent *t* test as appropriate. Categorical data was expressed in ratios and compared using the chi-square test. The difference in MAEs among the formulas in each group was assessed using a mixed model. A P value of <0.05 was considered statistically significant.

III. RESULTS

Table 1 summarizes the patient demographics. There were more female than male patients in the angle-closure group. This is typical of CACG or PAC, as a female preponderance is known, though there is no published data to suggest that CACG is different, or responds to treatment differently, between the sexes.[27] The AC3 group was older than the NC3 group (P=0.01). The prevalence of angle closure is known to increase with age though there is no published data suggesting that IOL power prediction differs by age.[28]

Table 1. Patient Demographics for the Four Treatment Groups

	AC1	NC1	P-value	AC3	NC3	P-value
No. of eyes	18	18		17	18	
Mean age (y)	74.89 ± 6.34 (range, 62-86)	71.28 ± 6.68 (range, 61-84)	0.106	72.59 ± 7.03 (range, 57-85)	65.78 ± 7.57 (range, 50-79)	0.01
Male:female ratio	1:17	5:13	0.177	1:16	8:11	0.041

AC1 = one-piece intraocular lens (IOL) implanted angle-closure group; NC1 = one-piece IOL implanted normal control group; AC3 = three-piece IOL implanted angle-closure group; NC3 = three-piece IOL implanted normal control group; SD = standard deviation.

Table 2 summarizes the preoperative clinical statuses of the four groups. ACDs were significantly shallow in both the AC1 and AC3 group compared with the NC1 and NC3 groups (P<0.001). Lens thickness was thicker in the AC1 group compared with the NC1 group (P=0.002). Axial lengths were shorter in both the AC1 and AC3 groups compared with the NC1 (P<0.001) and the NC3 (P=0.002) groups. BCVA, IOP, SE did not show any differences between the AC1 and NC1 groups (P=0.105, P=0.405, P=0.210) or the AC3 and NC3 groups (P=0.113, P=0.483, P=0.946).

Table 2. Preoperative Clinical Statuses for the Four Treatment Groups

(mean ± SD)

	AC1	NC1	P-value	AC3	NC3	P-value
BCVA	0.47 ± 0.26 (range 0.0-0.9)	0.59 ± 0.20 (range 0.3-0.9)	0.105	0.50 ± 0.32 (range 0.05-1.0)	0.65 ± 0.21 (range 0.2-1.0)	0.113
IOP (mmHg)	15.33 ± 4.60 (range 8-26)	14.22 ± 3.17 (range 11-20)	0.405	13.53 ± 3.45 (range 8-21)	14.40 ± 3.71 (range 9-22)	0.483
SE (D)	-0.84 ± 2.33 (range -6.88-2.75)	0.21 ± 2.34 (range -7.25-3.62)	0.210	-0.70 ± 2.88 (range -8.50-2.25)	-0.63 ± 2.51 (range -7.63-2.25)	0.946
ACD (mm)	2.58 ± 0.44 (range 2.12-3.73)	3.28 ± 0.34 (range 2.89-3.93)	<0.001	2.48 ± 0.53 (range 1.91-3.65)	3.38 ± 0.31 (range 2.78-4.11)	<0.001
LT (mm)	4.80 ± 0.51 (range 3.30-5.37)	4.22 ± 0.56 (range 2.95-5.00)	0.002	4.53 ± 0.72 (range 3.22-5.55)	4.35 ± 0.57 (range 3.02-4.92)	0.420
AXL (mm)	22.44 ± 0.64 (range 21.34-23.63)	23.60 ± 0.79 (range 22.34-24.73)	<0.001	22.43 ± 0.80 (range 20.44-23.49)	23.50 ± 1.08 (range 21.28-25.42)	0.002

BCVA = best-corrected visual acuity; IOP = intraocular pressure; SE = spherical equivalent of refractive errors; ACD = anterior chamber depth; LT = lens thickness; AXL = axial length; D = diopter; SD = standard deviation

Differences in clinical statuses at three months after treatment are shown in Table 3. In the one-piece group, ACD deepened after the operation more in the AC group than in the NC group (P<0.001). The AC3 group also showed increased ACD deepening after the operation compared to the NC3 group but the difference was not significant (P=0.051). BCVA, IOP, AXL, and SE did not show any significant differences after surgery between the groups.

Table 3. Differences in Clinical Statuses at Three Months after Treatment

(mean ± SD)

	AC1	NC1	P-value	AC3	NC3	P-value
ΔBCVA	0.38 ± 0.25 (range -0.1-0.8)	0.32 ± 0.20 (range 0-0.7)	0.384	0.38 ± 0.28 (range -0.1-0.95)	0.31 ± 0.22 (range 0-0.7)	0.454
ΔIOP (mmHg)	-3.67 ± 4.27 (range -15-4)	-2.56 ± 3.60 (range -13-4)	0.405	-1.18 ± 3.05 (range -9-3)	-2.17 ± 3.62 (range -10-3)	0.389
ΔACD (mm)	1.34 ± 0.55 (range 0.18-2.37)	0.67 ± 0.45 (range -0.19-1.45)	<0.001	1.28 ± 0.70 (range -0.36-2.27)	0.88 ± 0.34 (range 0.35-1.49)	0.051
ΔAXL (mm)	0.21 ± 0.13 (range -0.06-0.38)	0.21 ± 0.29 (range -0.34-1.14)	0.971	0.15 ± 0.13 (range -0.08-0.36)	0.30 ± 0.40 (range -0.13-1.4)	0.138
ΔSE (D)	0.74 ± 2.39 (range -3.75-6.63)	-0.50 ± 2.51 (range -4.12-7.25)	0.156	0.47 ± 3.27 (range -3.16-8.75)	0.27 ± 2.47 (range -2.75-7.25)	0.854

Δ = Preoperative – postoperative value

Predictive IOL powers by the SRK/T formula are shown in Figure 2. The MAEs of the AC1 group was 0.55 ± 0.35 (range 0.08-1.29) and the NC1 group was 0.47 ± 0.48 (range 0.05-1.75). The one-piece IOL group showed no difference in MAE (P=0.60). The MAE of the AC3 group was 0.71 ± 0.47 (range 0.09-1.62) and that of the NC3 group was 0.26 ± 0.28 (range 0.0-1.09). In the three-piece IOL group, the NC3 group showed a lower MAE than the

AC3 group (P=0.002). Predictive IOL power by Hoffer Q (P=0.001), SRK II formula and Haigis formula (P=0.013) also showed a lower MAE in the NC3 group than in the AC3 group, but no difference was noted in the one-piece group.

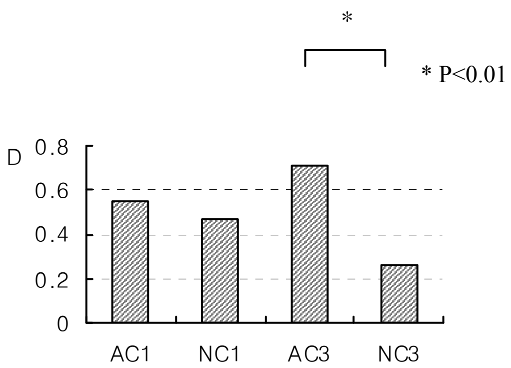

Figure 2. Predictive Intraocular Lens Powers for the Four Treatment Groups

MAE = mean absolute error = absolute value of the difference between the predicted and postoperative SE refractive errors; SE = spherical equivalent; D = diopter

Regression analysis results for the differences in ACD after operation and MAEs are shown in Figure 3. In the AC3 group, as the difference in ACD increased, the MAE decreased (R^2 = 0.2043) but not at a significant level (P=0.079). In the other groups, no significant correlation was noted.

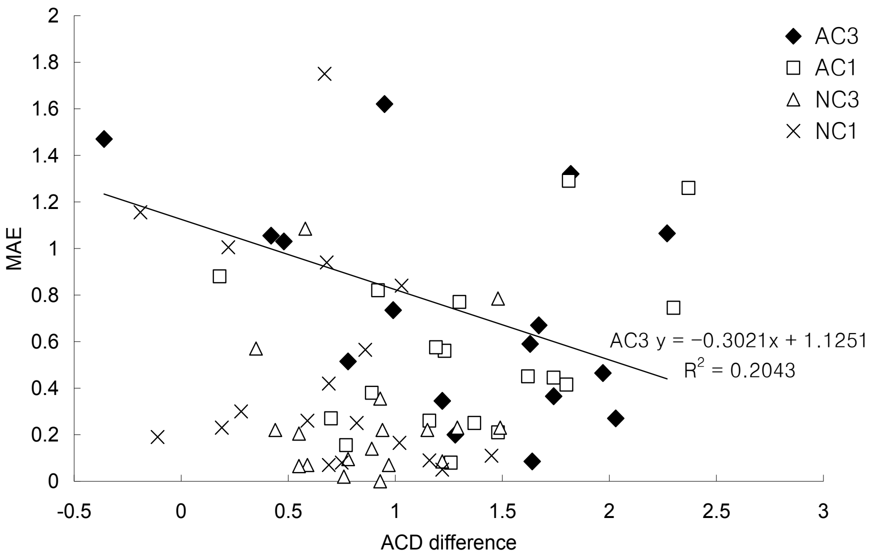

Figure 3. Regression analysis of Mean Absolute Error (MAE) and Anterior Chamber Depth (ACD) Difference

There were no significant differences in the power prediction accuracies of the four formulas for the prediction of postoperative SE refraction error as measured by the MAE (Table 4).

Table 4. Mean Absolute Error for all Eyes by Formula

Group	Eyes (No.)	Mean Absolute Error (D) ± SD			
		SRK/T	Hoffer Q	SRK II	Haigis
AC1	18	0.55 ± 0.35	0.54 ± 0.43	0.54 ± 0.42	0.52 ± 0.44
	P-Value		0.894	0.882	0.583
NC1	18	0.47 ± 0.48	0.44 ± 0.48	0.41 ± 0.43	0.49 ± 0.42
	P-Value		0.521	0.369	0.810
AC3	17	0.71 ± 0.47	0.73 ± 0.44	0.69 ± 0.53	0.66 ± 0.47
	P-Value		0.654	0.672	0.304
NC3	18	0.26 ± 0.28	0.30 ± 0.27	0.29 ± 0.31	0.26 ± 0.26
	P-Value		0.194	0.304	0.912

IV. DISCUSSION

There have been many studies comparing the stability of one-piece and three-piece IOLs.[29-34] In one study, 56 patients were examined who had implantation of a one-piece acrylic IOL in one eye and a three-piece acrylic IOL in the other eye.[29] The degree of IOL decentration and the tilt percentage of anterior capsule contraction in eyes with one-piece acrylic IOLs with soft acrylic loops were similar to those in eyes with three-piece acrylic IOLs. However, patients in that study had no pathologic conditions in their eyes. In another study, 52 eyes with glaucoma were examined and IOL tilt was more extensive in the eyes with glaucoma, especially in those with ACG, when compared to normal eyes.[31] Decentration was also greater in the glaucoma group than in the control group, although the differences were not significant. However, this study implanted only three-piece acrylic IOLs, so comparison with one-piece IOLs could not be done. The instability of IOLs in ACG patients has been thought to lead to inaccuracy of IOL power prediction for cataract surgery in ACG. In that study, IOL power prediction was inaccurate in ACG patients and the reason was thought to be associated with the unique anterior segment anatomy in ACG, but could not be definitively determined.[24] However, the type of IOL was not compared in that study.

To our knowledge, this study is the first to report a comparison between one-piece and three-piece acrylic IOLs in both normal and ACG patients. As ACG patients showed inaccuracies in IOL power predictions, the type of IOL was an important consideration. Our study demonstrated that three-piece acrylic IOLs showed larger MAEs in ACG patients than in normal patients. One-piece acrylic IOLs showed no difference in MAEs between ACG and normal patients.

Many biometric studies of primary ACG have shown that abnormal eye anatomy is associated with a shallower anterior chamber, a thicker lens, a steeper curvature of the anterior lens surface, and a more anterior lens position.[3-9, 35-37] These findings indicate that lens capsule configuration is also abnormal. It is therefore reasonable to predict that the implanted IOL may be more movable in eyes with ACG. The three-piece IOL used in this study had five degrees (AR40e) and six degrees (ZA9003) of anterior haptic angulation. The overall length was 13mm in all three-piece IOLs, which might not have been long enough to remain stabilized in the larger lens capsules of the ACG patients. Also, as reported, the three-piece IOL may have a loss of haptic memory with capsule contraction, and initial forward movement of the optic may occur. In contrast, a nonangulated one-piece IOL has better configuration memory such that the haptic is able to retain its figure even when capsule contracture occurs and thus the one-piece IOL results in less axial displacement.[38-39]

Regression analysis for ACD difference and MAE is shown in Figure 3. If the ACD did not get much deeper after cataract surgery, the MAE moved farther from the target goal diopter. This is another possible reason for power prediction inaccuracy in three-piece IOLs in ACG patients. Further studies are needed to determine the relationship between MAEs and anterior segment parameters.

Accurate prediction of postoperative refraction is essential for attaining the desired refractive outcomes after cataract surgery. The accuracy mainly depends on the accuracy of three factors: preoperative biometric data (axial length, anterior chamber depth, and keratometric index), IOL power calculation formulas, and IOL power quality control by the manufacturer.[40] In all methods of biometry, the postoperative position of the IOL (effective lens position) is one factor that must be predicted.[41] The commonly used SRK/T formula predicts postoperative ACDs as a function of corneal curvatures and axial lengths, together with an IOL A-constant.[42] This prediction is accurate for most eyes within the normal range, but errors may arise in extremely hyperopic eyes because there is a breakdown in the relationship between axial length and ACD.[41]

The SRK II formula is a second generation formula in which the ACD was replaced by an A-constant individual to each IOL style.[43] The Hoffer Q formula was developed with new constants for better effective lens position prediction and has been shown to be more accurate than the SRK/T in eyes with axial lengths of less than 22 mm.[44] The Haigis formula incorporates the preoperative ACD measurement to improve the accuracy of the predicted effective lens position.[45]

A retrospective analysis was performed for 76 eyes undergoing cataract surgery with IOLs ranging in power from 30 to 35 diopters. The analyses confirmed that the Haigis formula was overall the most accurate for optical IOLMaster biometry calculations in cataract surgery for extreme hyperopia, followed closely by the Hoffer Q formula.[41] It has also been reported in a study of 41 eyes with an axial length less than 22 mm that the Hoffer Q was more accurate than the SRK/T formula when customized ACD constants were not used.[46]

In ACG patients, ACD is the most important anatomical risk factor for angle-closure.[47] Subjects with angle closure have shorter axial lengths.[48-51] We thought that these anatomical differences might make a difference in MAE between IOL calculating formulas and tried to find a more accurate formula for ACG patients undergoing cataract surgery. However, all four formulas appeared to be comparable. This may be due to the error of anterior segment biometry acquired by an A-scan. Of the available routine diagnostic instruments, the IOLMaster measures axial length with the highest precision.[52] However, it cannot be used in cases of media opacity. As this study had patients with severe cataract, they could not be measured using the IOLMaster, so axial length was acquired by A-scan. Another reason could be that, although the axial length was significantly shorter in the AC group compared to that of the NC group, both the AC1 and AC3 groups had mean axial lengths over 22 mm such that the Hoffer Q formula was not thought to be the most accurate measure. Further studies are needed to evaluate the most accurate formula for ACG patients.

V. CONCLUSION

This study is the first to compare the IOL power prediction between one-piece and three-piece acrylic IOLs in both normal and ACG patients. One-piece IOLs were more accurate in ACG patients which is likely attributable to IOL haptic configuration or design. No difference in IOL power prediction was noted between the SRK/T and other formulas.

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<ABSTRACT>

폐쇄각 혹은 폐쇄각 녹내장 환자의 백내장 수술 시 인공 수정체 돗수 예측의 정확성

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목적: 폐쇄각 혹은 폐쇄각 녹내장 환자에서 백내장 수술 시 인공 수정체 돗수 예측의 정확성을 인공 수정체 종류에 따라 알아보고자 하였다.

방법: 폐쇄각 혹은 폐쇄각 녹내장 환자 35명, 총 35안, 정상 대조군 환자 36명, 총 36안을 대상으로 전향적 연구를 시행하였다. 백내장 수술 후 폐쇄각 녹내장 환자군에서는 17안이 삼체형 인공 수정체가 삽입되었고 18안에서는 일체형 인공 수정체가 삽입되었다. 정상 대조군에서는 18안이 삼체형 인공 수정체, 18안이 일체형 인공 수정체가 삽입되었다. 술 전에는 전방 계측치인 전방 깊이, 수정체 두께, 안축장 길이 등이 측정 되었다. SRK/T 공식을 이용하여 예측 잔여 굴절력과 실제 잔여 굴절력 차이의 절대값이 네 군 사이에서 비교되었다.

SRK ll, Haigis, Hoffer Q 공식을 이용하여 예측 잔여 굴절력을 계산하여 실제 잔여 굴절력과 비교하고 절대 오차값 (mean absolute error; MAE)이 구해져 SRK/T와 예측 정확도가 비교되었다.

결과: 일체형 인공 수정체 삽입군에서는 폐쇄각 환자군과 정상 대조군 사이에 MAE의 차이는 없었다 (P=0.60). 삼체형 인공 수정체 삽입군에서는 MAE가 폐쇄각 환자군에서 유의하게 높았다 (P=0.002). SRK/T, SRK ll, Haigis, Hoffer Q공식에 이해 계산된 MAE사이에서는 유의한 차이를 보이지 않았다.

결론: 폐쇄각 혹은 폐쇄각 녹내장 환자에서 SRK/T 공식을 이용하여 인공 수정체 돗수 예측의 정확성은 공식 별로 차이가 없었다. 폐쇄각 혹은 폐쇄각 녹내장 환자에서 일체형 인공 수정체가 돗수 예측의 정확성을 더 높일 수 있으며 이것은 구조적 차이에 의한 것으로 생각된다.

핵심되는 말 : 폐쇄각, 백내장, 녹내장, 인공 수정체