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RESEARCH

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Changes in IOL power after laser peripheral iridotomy based on multivariate analysis

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Abstract

Background This study aimed to investigate the effect of laser peripheral iridotomy (LPI) on intraocular lens (IOL) power in patients with primary angle closure disease (PACD), and to construct mathematical models to assess changes in IOL power.

Methods This study included 58 eyes of PACD patients. IOL Master700 was used to analyze and compare the changes of IOL power and ocular related parameters in each formula before and after LPI. The number of cases with IOL power changes greater than 0.5 diopters (D) in each group were counted and significant differences were analyzed using Fisher's exact test. Pearson's linear correlation analysis was used to ascertain the relationship between IOL power changes and ocular parameter changes to establish mathematical models.

Results No significant difference was found in calculated IOL power changes before and after LPI in each group. There was significant difference in the number of cases with IOL change values greater than 0.5D between the primary angle closure glaucoma (PACG) and the other two groups for each formula. IOL power changes were mainly associated with △K and △AL. Mathematical models of IOL power changes after LPI were constructed based on linear regression analysis.(PAC group: $\triangle IOL_{Haigis}$=0.026–2.950×△AL-1.414×△K, $\triangle IOL_{Hoffer\ Q}$=-3.578×△AL-1.412×△K, $\triangle IOL_{SRK/T}$=-3.152×△AL-1.114×△K, $\triangle IOL_{Holladay\ 1}$=-3.405×△AL-1.291×△K, $\triangle IOL_{Holladay\ 2}$=-3.467×△AL-1.483×△K, $\triangle IOL_{BUII}$=-3.185×△AL-1.301×△K; PACG group:$\triangle IOL_{Haigis}$=-1.632×△K, $\triangle IOL_{Hoffer\ Q}$=-3.770×△AL-1.434×△K, $\triangle IOL_{SRK/T}$=-3.427×△AL-1.102×△K, $\triangle IOL_{Holladay\ 1}$=-3.625×△AL-1.278×△K, $\triangle IOL_{Holladay\ 2}$=-4.764×△AL-1.272×△K, $\triangle IOL_{BUII}$=-4.935×△AL-1.304×△K).

Conclusions LPI will cause changes in some ocular parameters in patients with PACD, with great effects on IOL power calculations was observed in patients with PACG. Mathematical models based on multivariate analysis hold promise for predicting IOL power changes subsequent to LPI.

Keywords Laser peripheral iridotomy, IOL power, Primary angle closure disease, Mathematical modeling

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Background

Primary angle closure disease (PACD) is the predominant form of glaucoma in China. According to the International Society for Geographic and Epidemiologic Ophthalmology (ISGEO) classification and the American Ophthalmology Clinical Guidelines, PACD is categorized into primary angle closure suspect (PACS), primary angle closure (PAC), and primary angle closure glaucoma (PACG). Laser peripheral iridotomy (LPI) is a crucial treatment method for PACS, PAC, and PACG [1, 2]. Previous studies demonstrated that LPI reduces the rate of progression of angle closure disease. Baskaran et al. indicated that LPI could attenuate the progression of PACS to PAC or PACG, thereby reducing the incidence of PACS advancing to PAC and PACG [3]. Fu et al. found that LPI could effectively control intraocular pressure (IOP) in patients with acute angle closure [4]. Despite the widespread utilization of LPI in angle closure disease, our clinical work has shown that LPI led to changes in IOL power in some patients. Do these changes influence the refractive status of subsequent cataract surgery? What factors are associated with these changes? Gerald Clarke promulgated The FullMonte IOL method, which introduced mathematical modeling methods to the calculation of IOL degree for the first time. John G. Ladas, Albert Jun, Aazim Siddiqui, and Uday Devgan have applied mathematical modeling methods to the calculation formula of IOL degree [5]. Can we predict the influence of LPI on the calculation of IOL degree through mathematical modeling based on changes in relevant parameters? In this study, by analyzing and comparing the changes in IOL power and relevant ocular parameters before and after LPI, we performed correlation analysis between the two types of changes to construct mathematical models, aiming to offer a basis for IOL power selection in LPI-treated patients undergoing cataract surgery.

Methods

Study participants

Adhering to the ethical principles outlined in the Declaration of Helsinki, prospective selection of 58 patients with PACD requiring LPI, who sought treatment at the Affiliated Hospital of Qingdao University from June 12, 2023, to January 31, 2024.

Inclusion criteria : (1) PACS is defined as a condition in which the posterior pigmented trabecular meshwork is not visible at ≥270° on static gonioscopy, without peripheral anterior synechiae (PAS) and with normal intraocular pressure (IOP) [6]; (2) PAC is defined as a condition in which iris–trabecular contact (ITC) is visible at >180° on static gonioscopy, accompanied by IOP>22 mm Hg and/or with PAS, without secondary causes of PAS, and glaucomatous optic nerve damage [6]; (3) PACG refers to GON damage occurring based on PAC [6]. In cases of PACG, patients who maintained stable IOP solely with miotic drugs after an acute attack and whose angle of the anterior chamber was mostly open, were considered for LPI. Additionally, those who required cataract surgery after stable IOP after an acute onset were also included in LPI. Exclusion criteria: presence of corneal edema that interfered with the examination; presence of ocular trauma or history of previous ocular surgery; severe fundus abnormalities; recent history of contact lens wear; or history of systemic or topical medication that could potentially affect ocular accommodation. If both eyes of a participant met the inclusion criteria for the same classification, the eye that better met the inclusion criteria was selected for inclusion in the study.

We collected relevant medical history, including name, age and past medical history. They were subjected to relevant ophthalmologic examinations, including visual acuity, IOP, slit lamp, gonioscopy (Bellevue, WE, USA.), ultrasound biomicroscopy (UBM), and examination of ocular fundus. Optical biometry was performed in patients before and after LPI using IOLMaster700® (Carl Zeiss Meditec, Jena, Germany), all patients have not used pilocarpine nitrate eye drops for 48 h prior to measurement.

Parameter measurement

Measurements were performed by a single experienced technician at two time points, before LPI and 1 week after LPI. The patients' IOP was measured using an icare tonometer (TAO11, Icare Finland Oy, Finland). The patients' axial length (AL), anterior chamber depth (ACD), central corneal thickness (CCT), lens thickness (LT), corneal diameter (white-to-white distance, WTW), mean corneal curvature (mean K), and relative lens position (RLP, RLP=LP/AL, LP=ACD + ½ LT) were recorded. Haigis, Hoffer Q, SRK/T, Holladay 1, Holladay 2, and Barrett Universal II formulas were used for IOL power calculation, and the choice of constants was based on TECNIS 1 ZCB00(The target of IOL power=0).

Statistical analysis

IBM® SPSS® Statistics 23.0 software was used for statistical analysis. Before analysis, the normality of all data was assessed using the Shapiro-Wilk test. Parameters that conformed to normal distribution were compared using the paired-samples t-test, and those that did not conform to normal distribution were compared using the Wilcoxon signed-rank test for related samples. The number of cases with IOL power changes greater than 0.5 diopters (D) in each group was recorded. Fisher's exact test was used to analyze significant differences in the number of cases with IOL power changes greater than 0.5D between the groups. Correlation analysis was performed between ocular parameter changes and △IOL in each

Table 1 Clinical characteristics of patients enrolled in each group

		PACS	PAC	PACG
Age (y)		64.2	66.19	66.55
Gender	Male	8(33.33%)	4(19.05%)	2(15.38%)
	Female	16(66.67%)	17(80.95%)	11(84.62%)

Continuous variables are expressed as means (SD), and categorical variables are expressed as numbers (percentages)

group, and those with correlation were first tested for normality and then analyzed using linear regression analysis to construct a linear regression model. Pearson's test was used for parameters that conformed to normal distribution, and Spearman's test was used for parameters that were not conformed to normal distribution. R^2 indicated the degree of model fit, with values ranging from 0 to 1. The closer the value of R^2 to 1, the better the degree of model fit. $P<0.05$ was deemed indicative of statistically significant differences.

Results

Patients' demographics (see Table 1).

This study cohort included 24 patients with PACS, 21 patients with PAC, and 13 patients with PACG. The mean age of the patients was 65.49±7.18 years, with 24.14% men and 75.8% women. The clinical characteristics of the patients are shown in Table 1. All parameters were subjected to the Shapiro-Wilk test for normality before analysis.

Effect of LPI on ocular biological parameters and IOP (see Table 2).

The effect of LPI on IOP was not statistically significant in the PACS and PAC groups (all $P>0.05$), and IOP was reduced in the PACG group ($P<0.05$, 23.47±15.03 mmHg before LPI and 15.68±6.31 mmHg after LPI). Compared with baseline, the effect of LPI on LT and mean K was not significant in any of the three groups (all $P>0.05$). WTW was decreased ($P<0.05$, 11.73±0.35 mm before LPI vs. 11.55±0.37 mm after LPI) and RLP was increased in the PACS group ($P<0.05$, 0.2108±0.03 before LPI vs. 0.2127±0.03 after LPI); AL was decreased ($P<0.05$, 22.50±0.65 mm before LPI vs. 22.49±0.66 mm after LPI) and RLP was increased in the PAC group ($P<0.05$, 0.20±0.03 before LPI vs. 0.21±0.02 after LPI); and ACD was increased ($P<0.05$, 1.69±0.28 mm before LPI vs. 1.73±0.26 mm after LPI) and CCT was decreased in the PACG group ($P<0.05$, 548.00±57.95 μm before LPI vs. 531.64±47.66 μm after LPI).

Effect of LPI on IOL power calculation (see Table 3).

Analysis revealed that the calculated IOL power changes in each group did not significantly differ before and after LPI (all $P>0.05$). | △ IOL |: The PACG group > PAC group > PACS group (see Table 4). Based on clinical considerations, we defined an IOL power change greater than 0.5D as clinically significant and recorded the number of cases with IOL power changes greater than 0.5D in each group (see Table 5). Fisher's exact test showed that the difference between the PACS and PAC groups in the number of cases with greater than 0.5D changes in calculated IOL power was not significant for each formula (all $P>0.5$). However, significant differences were noted between the PACG and PACS groups, as well as between the PACG and PAC groups, in such changes for each formula (all $P<0.05$).

Correlation and Linear Regression Analysis between Ocular Biological Parameter Changes and IOL Power Changes (see Tables 6, 7, 8 and 9; Figs. 1, 2 and 3).

Correlation analysis revealed that in the PACS group, △IOL calculated using the Holladay 2 formula was significantly correlated with △WTW ($P<0.05$), and △IOL calculated using the remaining five formulas was significantly correlated with △K (all $P<0.05$); in the PAC

Table 2 Ocular biological parameters and IOP in each group before and after LPI

Biological Parameters	Fore-LPI			Post-LPI			P1	P2	P3
	PACS	PAC	PACG	PACS	PAC	PACG	PACS	PAC	PACG
IOP(mmHg)	16.28±4.23	15.22±3.09	23.47±15.03	14.61±3.13	14.23±3.49	15.68±6.31	0.123	0.338	0.049*
AL(mm)	22.53±0.46	22.50±0.65	22.62±0.63	22.48±0.49	22.49±0.66	22.63±0.62	0.218	0.022*	0.828
ACD(mm)	2.41±0.28	2.22±0.20	1.69±0.28	2.42±0.27	2.23±0.17	1.73±0.26	0.08	0.145	0.03*
CCT(μm)	531.06±37.66	535.50±40.17	548.00±57.95	532.89±37.24	532.44±35.93	531.64±47.66	0.631	0.276	0.026*
LT(mm)	4.69±0.99	4.56±1.33	5.07±0.36	4.73±0.98	4.79±0.96	5.06±0.36	0.161	0.311	0.334
WTW(mm)	11.73±0.35	11.56±0.53	11.41±0.50	11.55±0.37	11.44±0.40	11.48±0.40	0.005*	0.139	0.719
RLP	0.2108±0.03	0.20±0.03	0.2111±0.01	0.2127±0.03	0.21±0.02	0.2120±0.01	0.000*	0.011*	0.215
Mean K (D)	44.29±1.30	44.44±1.45	44.2009±1.34	44.35±1.34	44.47±1.38	44.2027±1.30	0.257	0.459	0.989

Measurements are presented as mean±standard deviation [95% confidence interval]

P1: Significance of the differences between preoperative and postoperative values in the PACS group

P2: Significance of the difference between preoperative and postoperative values in the PAC group

P3: Significance of the difference between preoperative and postoperative values in the PACG group

* Indicated $p<0.05$, paired-sample t-test for those conforming to a normal distribution, and the Wilcoxon signed-rank test for related samples for comparisons of non-normal distributions

Table 3 IOL powers before and after LPI

Formulae	Fore-LPI			Post-LPI			P1	P2	P3
	PACS	PAC	PACG	PACS	PAC	PACG	PACS	PAC	PACG
Haigis	24.05 ± 1.21	23.71 ± 1.70	23.65 ± 1.81	24.04 ± 1.20	23.75 ± 1.80	23.60 ± 2.00	0.864	0.593	0.84
Hoffer Q	24.50 ± 1.27	24.30 ± 1.79	24.16 ± 1.94	24.49 ± 1.26	24.34 ± 1.90	24.11 ± 1.09	0.883	0.661	0.837
SRK/T	24.2183 ± 1.10	24.06 ± 1.58	23.90 ± 1.69	24.2105 ± 1.10	24.09 ± 1.67	23.87 ± 1.79	0.947	0.576	0.852
Holladay 1	24.35 ± 1.20	24.17 ± 1.68	24.03 ± 1.80	24.34 ± 1.20	24.20 ± 1.77	23.99 ± 1.92	0.775	0.634	0.873
Holladay 2	24.18 ± 1.13	23.79 ± 1.67	23.75 ± 1.77	24.16 ± 1.13	23.87 ± 1.80	23.71 ± 1.86	0.802	0.343	0.88
BU II	24.00 ± 1.27	23.73 ± 1.72	23.61 ± 1.82	24.03 ± 1.26	23.79 ± 1.83	23.59 ± 1.91	0.690	0.407	0.94

Measurements are presented as mean ± standard deviation [95% confidence interval]

P1: Significance of the differences between preoperative and postoperative values in the PACS group

P2: Significance of the difference between preoperative and postoperative values in the PAC group

P3: Significance of the difference between preoperative and postoperative values in the PACG group

* Indicated $p<0.05$, paired-sample t-test for those conforming to a normal distribution, and the Wilcoxon signed-rank test for related samples for comparisons of non-normal distributions

Table 4 Mean values of | △ IOL | before and after LPI in each group

	PACS	PAC	PACG
$\lvert\triangle IOL_{Haigis}\rvert$	0.215	0.231	0.642
$\lvert\triangle IOL_{Hoffer\ Q}\rvert$	0.212	0.241	0.632
$\lvert\triangle IOL_{SRK/T}\rvert$	0.171	0.199	0.505
$\lvert\triangle IOL_{Holladay\ 1}\rvert$	0.194	0.223	0.571
$\lvert\triangle IOL_{Holladay\ 2}\rvert$	0.242	0.255	0.595
$\lvert\triangle IOL_{BUII}\rvert$	0.230	0.242	0.605

group, △IOL calculated using the six formulas was significantly correlated with △AL and △K (all $P<0.05$), and the △IOL calculated using the Holladay 1 formula was also significantly correlated with △ACD ($P<0.05$); and in the PACG group, the △IOL calculated using the Haigis formula was significantly correlated with △K ($P<0.05$), and the △IOL calculated using the remaining five formulas was significantly correlated with △AL and △K (all $P<0.05$).

R^2 is a metric of the degree of model fit. The linear regressions for the PACS group had small R^2 (see Table 7) and could not explain most of the variation of IOL power changes, so IOL power changes were not modeled for this group.

Linear regression analysis of △IOL and related ocular parameter changes in the PAC group was performed (see Table 8). Independent variables with $P<0.05$ were included to construct the following models: $\triangle IOL_{Haigis}$ = 0.026–2.950 × △AL-1.414 × △K, $\triangle IOL_{Hoffer\ Q}$= -3.578 × △AL-1.412 × △K, $\triangle IOL_{SRK/T}$ = -3.152 x ΔAL-1.114 x ΔK, $\triangle IOL_{Holladay\ 1}$ = -3.405 x ΔAL-1.291 x ΔK, $\triangle IOL_{Holladay\ 2}$ = -3.467 x ΔAL-1.483 x ΔK, and ΔIOL_{BUII} = -3.185 x ΔAL-1.301 x ΔK.

Similarly (see Table 9), the following models for the PACG group were constructed: $\triangle IOL_{Haigis}$ = -1.632 × △K, $\triangle IOL_{Hoffer\ Q}$ = -3.770 × △AL-1.434 × △K, $\triangle IOL_{SRK/T}$ = -3.427 × △AL-1.102 × △K, $\triangle IOL_{Holladay\ 1}$ = -3.625 × △AL-1.278 × ΔK, $\triangle IOL_{Holladay\ 2}$ = -4.764 × ΔAL-1.272 × ΔK, and ΔIOL_{BUII} = -4.935 × ΔAL-1.304 × ΔK.

The constructed models can be used to predict the possible IOL power changes calculated using various formulas after LPI.

Discussion

LPI is a non-invasive, easy-to-perform, safe treatment technique that can balance the anterior and posterior chamber pressures, deepen the peripheral anterior chamber, widen the angle of the chamber, and detach the adherent iris from the trabecular meshwork. These actions restores the physiologic drainage pathway for the aqueous humor, consequently leading to a reduction in

Table 5 Percentage of IOL changes greater than 0.5D in each group after LPI

	PACS	PAC	PACG	P1	P2	P3
$\triangle IOL_{Haigis}$	1(4.17%)	1(4.76%)	7(53.85%)	0.721	0.001*	0.002*
$\triangle IOL_{Hoffer\ Q}$	1(4.17%)	1(4.76%)	7(53.85%)	0.721	0.001*	0.002*
$\triangle IOL_{SRK/T}$	0(0%)	0(0%)	6(46.15%)	/	0.001*	0.001*
$\triangle IOL_{Holladay\ 1}$	0(0%)	1(4.76%)	7(53.85%)	0.467	0.000*	0.002*
$\triangle IOL_{Holladay\ 2}$	1(4.17%)	1(4.76%)	7(53.85%)	0.721	0.001*	0.002*
$\triangle IOL_{BUII}$	1(4.17%)	0(0%)	6(46.15%)	0.533	0.004*	0.001*

P1: Significance of the difference between the PACS and PAC groups in the percentage of ΔIOL > 0.5D

P2: Significance of the difference between the PACS and PACG groups in the percentage of △IOL > 0.5D

P3: Significance of the difference between the PAC and PACG groups in the percentage of ΔIOL > 0.5D

* Indicated $p<0.05$, with a significant difference

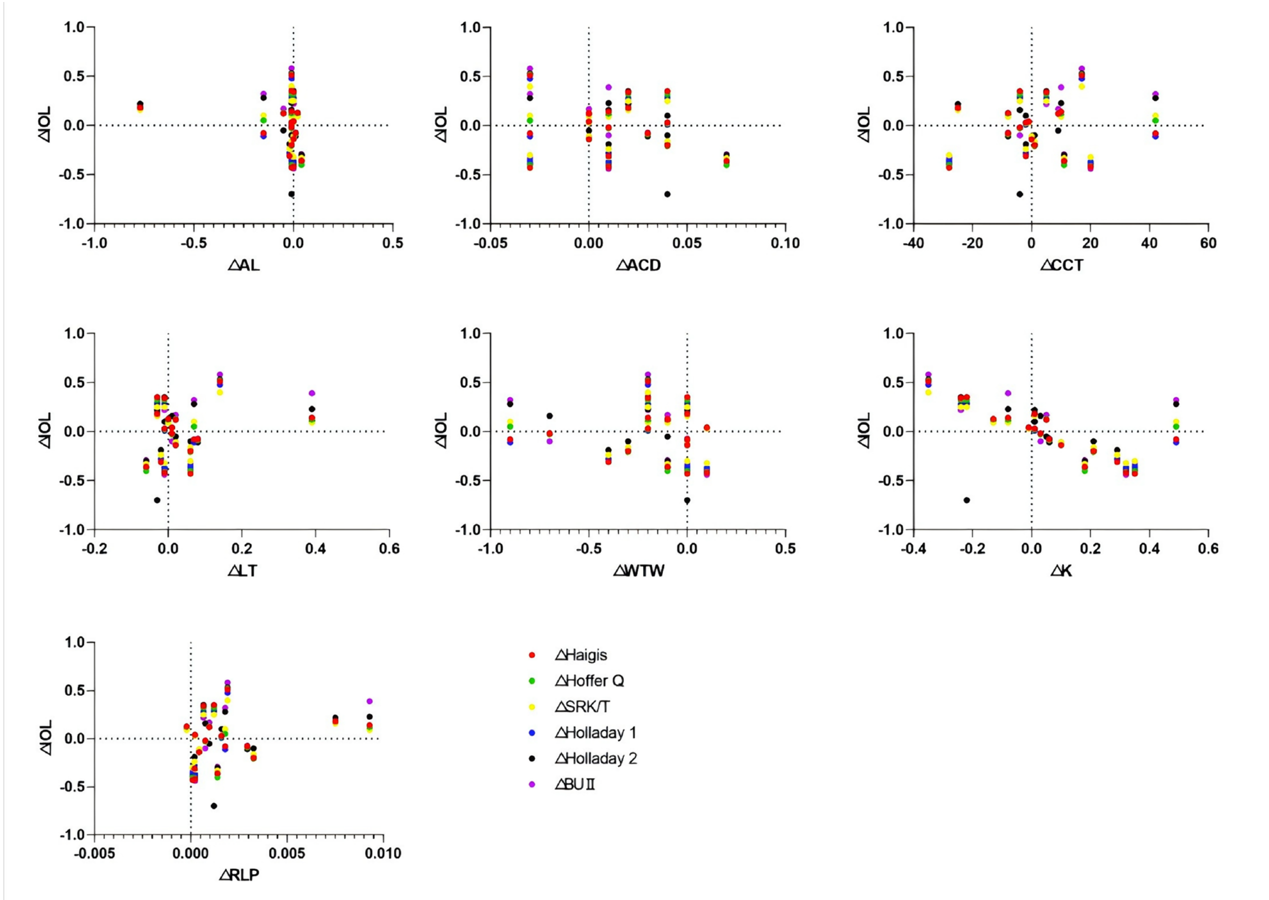

Fig. 1 Scatter plot of the correlation between ocular parameters changes and △IOL in PACS group

IOP [1, 7]. LPI is recognized as an important treatment for PACS, PAC, and PACG and has the following main indications [1, 8]: (1) PACS: Prophylactic laser iridotomy should be considered in patients who are not able to undergo regular follow-up, require frequent dilated pupil examination of the fundus, have a positive excitation test, have PACS in one eye, or have a family history of PAC/PACG and in those who have PAC or PACG in the ipsilateral eye. (2) PAC: LPI in such patients may reduce the risk of developing PACG. A previous study has reported that in PAC patients who have not yet developed angle synechiae, LPI performed by widening the angle and reducing pupillary block can control the progression of PAC to PACG [9]. (3) In cases of PACG, LPI can reduce the occurrence of subsequent subacute attacks and effectively reduce IOP in patients experiencing acute PACG attacks refractory to medical management [9]. (4) Additionally, LPI can mitigate pupillary block in other ocular conditions such as pigment dispersion syndrome, lens-derived glaucoma, aqueous misdirection, and nanophthalmos [10].

The primary clinical formulas utilized for intraocular lens (IOL) power measurement span several generations, including the third-generation formulas: Hoffer Q, SRK/T, and Holladay 1; the fourth-generation formulas: Haigis and Holladay 2; and the new generation of formula Barrett Universal II. These formulas predominantly rely on two key variables along with the IOL constant, with AL (axial length) and K (corneal curvature) being the most common parameters, although other factors may also be considered. Specifically, both Hoffer Q, Holladay 1, and SRK/T are grounded in these two variables, while the Haigis formula incorporates three variables: AL, K, and ACD (anterior chamber depth) [11]. Barrett Universal II is notably comprehensive, utilizing up to five variables: AL, K, ACD, LT (lens thickness), and WTW (white-to-white corneal diameter). Holladay 2 further expands this by considering up to seven variables, including additional factors such as the patient's age and preoperative refractive status [12, 13].

Significant milestones in the development of these formulas include the creation of the SRK/T formula in 1990 by Donald R. Sanders, John A. Retzlaff, and Manus C. Kraff. This formula innovatively combines linear regression methods with a theoretical eye model. Later, in 1993, Kenneth J. Hoffer introduced the Hoffer Q formula,

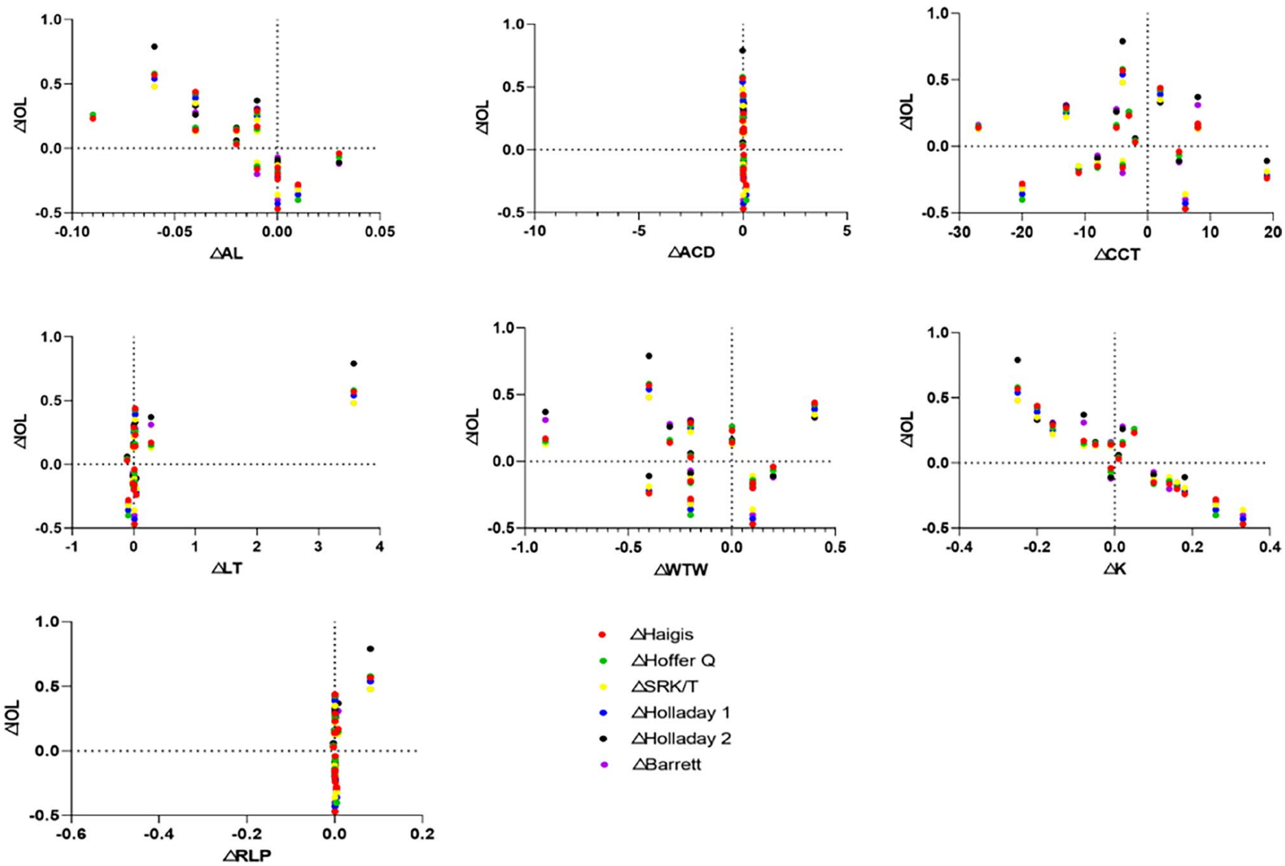

Fig. 2 Scatter plot of the correlation between ocular parameters changes and △IOL in PAC group

which is particularly tailored for eyes with short axial lengths and takes into account AL, K, and personalized anterior chamber depth (pACD). The Holladay 2 formula, introduced in 1996, uses seven parameters (in order of importance) to determine ELP: AL, mean K, horizontal WTW, preoperative refraction, ACD, LT, and age. In 1988, Jack T. Holladay introduced the Holladay 1 formula. In 2000, Wolfgang Haigis published the Haigis formula [13].

Across these formulas, AL, K, ACD, LT, and WTW are the main influencing factors. Some parameters may change slightly after LPI, but some change significantly. Our results showed that changes in LT and mean K in all groups after LPI were not statistically significant. Liu et al. and Yu et al. also demonstrated that the changes in LT after LPI were not statistically significant [14, 15], but Yang et al. showed a decrease in LT after LPI [16]. The effect of LPI on LT is still controversial and should be further investigated. The changes in mean K in our study were the same as that in a previous study [16]. Some studies suggest that although laser peripheral iridotomy (LPI) is a relatively safe procedure, it can still cause damage to the corneal endothelium, posing a risk of corneal decompensation. The change in keratometry (K) values after LPI may be due to the impact and damage caused by the laser energy to the cornea. Additionally, changes in axial length (AL) can also affect corneal curvature, thereby influencing K values [17]. The AL changes were insignificant in the PACS and PACG groups, with a small decrease in the PAC group. Liu et al. demonstrated no significant changes in AL after LPI [14]. Yang et al. reported a decrease in AL after LPI in the PAC/PACG group, but the reason for this needs to be further investigated [16]. Studies have reported that in glaucoma patients, after undergoing trabeculectomy, for every 1mmHg decrease in intraocular pressure (IOP), the axial length (AL) shortens by approximately 7 micrometers. Similarly, when IOP is non-invasively reduced, a 1mmHg decrease in IOP also results in a reduction in AL by about 7 micrometers. We consider that the reduction in AL may be related to the decrease in IOP. Although the primary angle-closure glaucoma (PACG) group experiences a larger change in IOP, the change in AL is not statistically significant. We speculate that this may be due to the similar proportions of AL increase and decrease within the group, but the specific reasons require further investigation [18]. ACD was increased in the PACG group, but the change was not statistically significant in the PACS and PAC groups. Previous studies showed that ACD was increased after LPI [15, 19–21]. Sahin et al. showed that

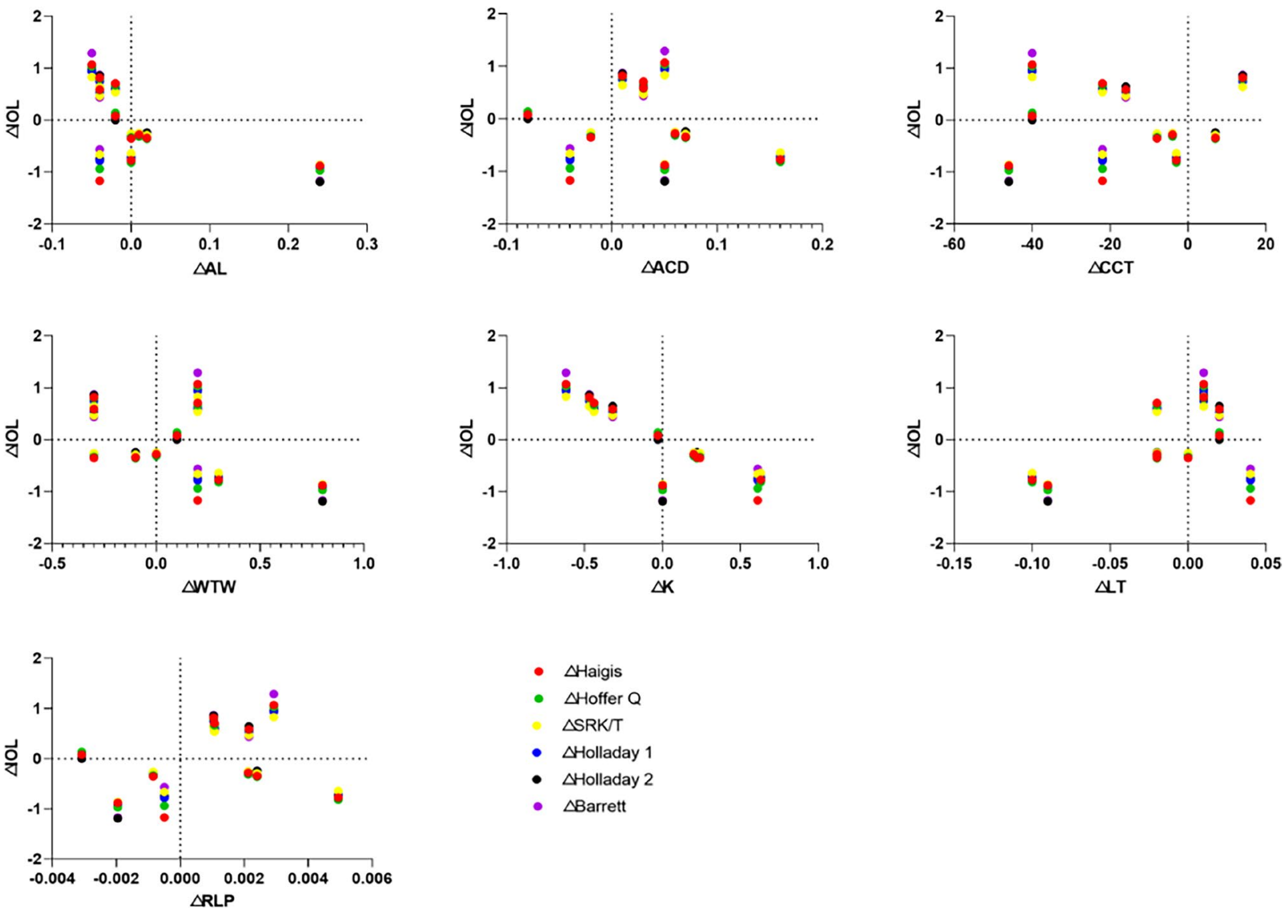

Fig. 3 Scatter plot of the correlation between ocular parameters changes and △IOL in PACG group

Table 6 Correlation analysis between LPI-induced ocular parameter changes and LPI-induced IOL power changes in each group

		△IOL_{Haigis}	△$IOL_{Hoffer Q}$	△$IOL_{SRK/T}$	△$IOL_{Holladay 1}$	△$IOL_{Holladay 2}$	△IOL_{BUII}
△AL	PACS	0.481	0.242	0.147	0.355	0.314	0.176
	PAC	0.004*	0.002*	0.001*	0.002*	0.005*	0.004*
	PACG	0.069	0.026*	0.026*	0.026*	0.025*	0.023*
△ACD	PACS	0.657	0.412	0.331	0.529	0.127	0.229
	PAC	0.086	0.063	0.052	0.045*	0.270	0.165
	PACG	0.785	0.616	0.583	0.592	0.662	0.571
△CCT	PACS	0.844	0.652	0.579	0.939	0.296	0.271
	PAC	0.758	0.854	0.863	0.844	0.998	0.778
	PACG	0.969	0.981	0.941	0.954	0.705	0.909
△LT	PACS	0.902	0.731	0.639	0.806	0.140	0.245
	PAC	0.129	0.129	0.111	0.135	0.057	0.111
	PACG	0.230	0.131	0.098	0.110	0.085	0.062
△WTW	PACS	0.794	0.612	0.583	0.898	0.030*	0.325
	PAC	0.669	0.719	0.714	0.711	0.182	0.395
	PACG	0.195	0.157	0.133	0.142	0.074	0.138
△K	PACS	0.000*	0.000*	0.000*	0.000*	0.161	0.004*
	PAC	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
	PACG	0.000*	0.000*	0.000*	0.000*	0.001*	0.001*
△RLP	PACS	0.191	0.204	0.216	0.270	0.123	0.054
	PAC	0.534	0.571	0.548	0.614	0.266	0.424
	PACG	0.545	0.615	0.587	0.608	0.449	0.518

* Indicated $p<0.05$, with a significant correlation between the two parameters

Table 7 Linear regression analysis of △IOL and related ocular parameters changes in the PACS group

Dependent variable	R^2	Independent variable	Coefficient	t	sig. (*P*)
1[a]	0.760	Constant	0.052	1.567	0.137
		△K	-1.066	-7.126	0.000*
2[b]	0.649	Constant	0.048	1.215	0.242
		△K	-0.974	-5.445	0.000*
3[c]	0.574	Constant	0.040	1.142	0.270
		△K	-0.723	-4.642	0.000*
4[d]	0.767	Constant	0.041	1.371	0.189
		△K	-0.963	-7.256	0.000*
5[e]	0.173	Constant	-0.104	-1.263	0.225
		△WTW	-0.479	-1.828	0.086
6[f]	0.417	Constant	0.075	1.400	0.181
		△K	-0.814	-3.386	0.004*

a: $\triangle IOL_{Haigis}$ b:$\triangle IOL_{Hoffer\ Q}$ c:$\triangle IOL_{SRK/T}$ d: $\triangle IOL_{Holladay\ 1}$ e:$\triangle IOL_{Holladay\ 2}$ f:$\triangle IOL_{BUII}$

* Indicated $p<0.05$, and the independent variables have a significant effect on the dependent variable

Table 8 Linear regression analysis of △IOL and related ocular parameter changes in the PAC group

Dependent variable	R^2	Independent variable	Coefficient	t	sig. (*P*)
1[a]	0.988	Constant	0.026	2.402	0.032
		△AL	-2.950	-9.116	0.000*
		△K	-1.414	-23.932	0.000*
2[b]	0.996	Constant	0.009	1.425	0.178
		△AL	-3.578	-19.742	0.000*
		△K	-1.412	-42.691	0.000*
3[c]	0.998	Constant	0.009	1.768	0.100
		△AL	-3.152	-21.337	0.000*
		△K	-1.114	-41.316	0.000*
4[d]	0.998	Constant	0.008	1.218	0.247
		△AL	-3.405	-19.346	0.000*
		△ACD	0.040	0.300	0.769
		△K	-1.291	-41.405	0.000*
5[e]	0.919	Constant	0.057	1.813	0.093
		△AL	-3.467	-3.726	0.003*
		△K	-1.483	-8.728	0.000*
6[f]	0.943	Constant	0.038	1.663	0.120
		△AL	-3.185	-4.651	0.000*
		△K	-1.301	-10.408	0.000*

a: $\triangle IOL_{Haigis}$ b:$\triangle IOL_{Hoffer\ Q}$ c:$\triangle IOL_{SRK/T}$ d: $\triangle IOL_{Holladay\ 1}$ e:$\triangle IOL_{Holladay\ 2}$ f:$\triangle IOL_{BUII}$

* Indicated $p<0.05$, and the independent variables have a significant effect on the dependent variable

Table 9 Linear regression analysis of △IOL and related ocular parameter changes in the PACG group

Dependent variable	R^2	Independent variable	Coefficient	t	sig. (*P*)
1[a]	0.848	Constant	-0.044	-0.474	0.647
		△K	-1.632	-7.091	0.000*
2[b]	0.989	Constant	-0.023	-0.894	0.397
		△AL	-3.770	-11.141	0.000*
		△K	-1.434	-22.254	0.000*
3[c]	0.994	Constant	-0.013	-0.855	0.417
		△AL	-3.427	-17.356	0.000*
		△K	-1.102	-29.322	0.000*
4[d]	0.993	Constant	-0.011	-0.581	0.577
		△AL	-3.625	-15.173	0.000*
		△K	-1.278	-28.096	0.000*
5[e]	0.983	Constant	-0.005	-0.170	0.869
		△AL	-4.764	-11.638	0.000*
		△K	-1.272	-16.319	0.000*
6[f]	0.978	Constant	0.012	0.323	0.755
		△AL	-4.935	-10.178	0.000*
		△K	-1.304	-14.121	0.000*

a: $\triangle IOL_{Haigis}$ b:$\triangle IOL_{Hoffer\ Q}$ c:$\triangle IOL_{SRK/T}$ d: $\triangle IOL_{Holladay\ 1}$ e:$\triangle IOL_{Holladay\ 2}$ f:$\triangle IOL_{BUII}$

* Indicated $p<0.05$, and the independent variables have a significant effect on the dependent variable

the volume of the anterior chamber was significantly increased after LPI in patients with PACS, which somewhat corroborates the increase in ACD after LPI [22]. The depth of the peripheral anterior chamber may have deepened, but the depth of the central anterior chamber may not have changed significantly in the PACS and PAC groups. Chen et al. and Pei et al. also showed no significant change in ACD after LPI in PACS patients [23, 24]. WTW was reduced in the PACS group, and the changes were not significant in the PAC and PACG groups, but Yang et al. showed no significant change in WTW after LPI [16]. The effect of LPI on WTW should be further investigated using a larger sample size.

Do changes in these biological parameters after LPI affect IOL power? Currently, literature on this topic is limited, with only one study available, which indicated changes in calculated IOL power after LPI in PACS, PAC, and PACG patients, but none of the changes were significant [16]. Our study also demonstrated that LPI resulted in varying degrees of IOL power changes in all three groups of patients, but the changes were not significant. Our data also indicates that patients in the PACG group had the most significant changes in IOL power. This group also had more pronounced changes in IOP, ACD, and relative lens position after LPI compared to the other two groups. Our research data also indicates that the change in IOL was most significant in the PACG group. The preoperative and postoperative intraocular pressure (IOP), anterior chamber depth, and relative position of the lens in this group showed greater changes compared to the other two groups. We believe that the larger fluctuations in ocular parameters such as IOP, axial length (AL), and anterior chamber depth in PACG patients may have caused the significant differences in IOL changes compared to the other groups. Some studies suggest that the reduction in AL may be related to the decrease in IOP, and the size of the axial length significantly affects IOL. Although the PACG group exhibited the greatest fluctuation in IOP, the change in AL was not statistically significant, which we speculate may be due to the similar proportions of AL increase and decrease within the group.

We recorded the number of cases with IOL power changes greater than 0.5D in each group and found that the PACG group had a larger proportion of patients with IOL power changes greater than 0.5D. Although the postoperative IOL power was generally not significantly different from the preoperative value in the PACG group, Fisher's exact test revealed that the number of cases with calculated IOL power changes greater than 0.5D was significantly different from that in both the PACS and PAC groups for each formula. This suggests that there is a more pronounced impact of LPI on IOL power measurement in the PACG group, and that its $P>0.05$ is possibly attributed to a comparable proportion of patients experiencing increased and decreased IOL power post-LPI. This group of patients is likely to undergo cataract surgery, raising concern about IOL power selection. When the △IOL is >0.5D, reassessment of IOL power is deemed necessary to optimize surgical outcomes. Therefore, our study underscores the importance of reassessing IOL power in PACG patients following LPI if they are to undergo subsequent cataract surgery.

What factors are associated with IOL power changes after LPI? Our correlation analysis showed that ΔK and ΔAL were negatively correlated with ΔIOL, in agreement with the IOL calculation formulas [25, 26]. In contrast, ACD, CCT, WTW, LT, and RLP did not correlate significantly with IOL power changes. We performed linear regression of the ocular parameters and IOL degree change values with significant correlation to construct linear regression models. However, the linear regression model for the PACS group had a small R^2 and could not account for most of the variation in the group. Thus, we only constructed linear regression models for the PAC and PACG groups, which could be used to predict possible IOL power changes of different formulas. The linear regression model for the PACS group was poorly fitted. The poor fit of the linear regression model in the PACS group might be due to the small values of ΔIOL and ocular parameter changes after LPI, which introduced larger errors in analysis results. This issue deserves further investigation using a larger sample size.

In addition, the trends in the changes of ocular biological parameters after LPI in each group, including WTW, AL, RLP, ACD, and CCT, were consistent. However, not all the changes in each group were statistically significant, necessitating further analysis with a larger sample size.

This study has some limitations. As mentioned earlier, the primary limitation is the small sample size of patients. Future research could benefit from a larger sample size for more robust findings. Additionally, in this study, we primarily observed changes within one week after laser surgery. The results of follow-up at three months post-surgery or even longer need further observation.

Conclusion

LPI performed for managing PACD can induce changes in some ocular parameters, and these changes have a small effect on IOL calculation in PAC and PACS patients but a large effect in PACG patients. Therefore, IOL re-measurement should be performed in LPI-treated PACG patients undergoing cataract surgery to obtain a better refractive status after surgery. Additionally, mathematical models based on multivariate analysis can predict the possible change values of different IOL formulas after LPI.

Abbreviations

LPI	Laser peripheral iridotomy
PACD	Primary angle closure disease
IOL	Intraocular lens
PACS	Primary angle closure suspect
PAC	Primary angle closure
PACG	Primary angle closure glaucoma
IOP	Intraocular pressure
ITC	Iris–trabecular contact
UBM	Ultrasound biomicroscopy
AL	Axial length
ACD	Anterior chamber depth
CCT	Central corneal thickness
LT	Lens thickness
WTW	White-to-white distance
Mean K	Mean corneal curvature
RLP	Relative lens position
LP	Lens position
D	Diopters

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Author contributions

Ling W carried out the design and conception of the research.Xinyu W, Shasha X, Yunxiao W, Zhiying Y, Fenglei W and Licun W participated in the acquisition of data.Xinyu W analyzed and interpreted the data.Xinyu W drafted the article. Ling W revised the article critically for important intellectual content.All authors gave final approval to the article.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Written informed consent was obtained from all individual participants' included in the study. Ethical approval by Ethics committee of the Affiliated Hospital of Qingdao University and was conducted in accordance with the Declaration of Helsinki. The committee's reference number is QDDXFSYY-2021-0124.

Consent for publication
Not applicable.

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The authors declare no competing interests.

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