• Clinical Research •

Accuracy of optimized Sirius ray-tracing method in intraocular lens power calculation

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Abstract

● **AIM:** To evaluate the accuracy and predictability of ray tracing-assisted intraocular lens (IOL) calculation function in Sirius internal software and further improve the accuracy by optimizing the calculation of predicted lens position (PLP).

● **METHODS:** This retrospective study recruited 52 eyes of 49 patients. All of the cases with cataract had undergone phacoemulsification combined with IOL implantation. SRK-T, Haigis formula, and Sirius ray-tracing method were all used for each eye's IOL calculation. The mean absolute value of prediction error (prediction error=predicted refraction-postoperative refraction) was defined as mean absolute prediction error (MAPE) and was determined for each method. Calculation of PLP was optimized by effective lens position (ELP). Optimized PLP was entered to Sirius internal software again to verify whether the method was improved.

● **RESULTS:** Compared with SRK-T and Haigis formulas, less accuracy was shown in Sirius ray-tracing method (P=0.001). The ELP of the IOL moved forward compared to PLP (P<0.001). The MAPE of the ELP-inputted Sirius ray-tracing method was reduced. ELP and PLP were well correlated. Taking ELP as y and PLP given by Sirius soft as x, a linear regression formula y=0.1637x+3.1741 was concluded (R^2=0.1066, P=0.018). It was shown that the optimized Sirius ray-tracing method (optimized PLP entered), compared with SRK-T and Haigis formulas, worked with the same accuracy (P=0.038).

● **CONCLUSION:** The original Sirius ray tracing method is not satisfactory enough. However, in normal eyes, the optimized Sirius ray-tracing method in IOL calculation was as accurate as SRK-T and Haigis formulas.

● **KEYWORDS:** Sirius; ray-tracing; IOL-Master; cataract; refractive error; predicted IOL position

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INTRODUCTION

Refractive status after cataract surgery is one of the most important factors determining the patients' visual acuity and also directly affects their satisfaction. The precision of intraocular lens (IOL) calculation becomes increasingly important. At present, the optimized standard IOL power calculation formulas are recognized as the most commonly used and relatively reliable calculation methods in clinical practice[1-2]. Although the routine accessible formulas lead to fairly accurate results usually, they may be less precise under certain conditions[3]. Newer ray-tracing method by some commercial software provides reliable and satisfactory postoperative results, which are comparable to theoretical thin-lens formulas in IOL power calculations in normal eyes and eyes after refractive surgery[4-5]. Sirius 3D topography system (CSO. Software Version: phoenix.2) as one of the most advanced corneal measuring tools has its own ray-tracing software. However, the accuracy of ray tracing-assisted IOL calculation function in the Sirius system has rarely been reported except Savini Giacomo's research[6], which found that ray-tracing method in Sirius 3D topography system can offer precise IOL power calculation in a series of cases after myopic excimer laser surgery. However, the accuracy of the method in normal eyes is unclear.

In this article, a complementary study was performed to compare the accuracy of ray-tracing method using Sirius internal software with SRK-T and Haigis formulas in normal eyes.

Table 1 Mean absolute prediction error of three formulas Median (Q1, Q3)

IOL formula	Sirius	SRK-T	Haigis	*P*
MAPE	0.39 (0.24, 0.74)	0.28 (0.16, 0.51)	0.28 (0.19, 0.51)	0.002

MAPE: Mean absolute prediction error.

SUBJECTS AND METHODS

Ethical Approval The study was conducted in accordance with the tenets of the Declaration of Helsinki. The study protocol was submitted and approved by the Ethics Committee of Wenzhou Medical University.

Patients This study was retrospective in design. There were 52 eyes of 49 patients (22 males and 27 females, mean age=72.86y, SD=7.51; aged 52 to 84y) was included. The candidates with cataract who underwent phacoemulsification combined with IOL implantation from September 1, 2017 to April 30, 2018 were analyzed. Eyes with axial length (AL) more than 26 mm or less than 21 mm and cases with keratopathy, previous ocular trauma, glaucoma, or previous ocular surgery were excluded from this study. Patients were also excluded with astigmatism more than ±2 D and with intraoperative and postoperative complications.

Preoperative Examination For all patients, ophthalmoscope, B ultrasonic, and optical coherence tomography (OCT) were used to check vitreous and retina. AL, anterior chamber depth (ACD), and keratometry were obtained with the IOL Master 500 device (Carl Zeiss Meditec AG) by the same physician. The two IOL power calculation formulas (SRK-T and Haigis) were used to determine the IOL power. Target refraction was set according to patients' age, education background, living habits, AL, fundus, and refraction of the contralateral eye. Dates of anterior segment parameters were obtained by Sirius 3D topography system at the same time. Optically measured AL of the eyes by IOL Master 500 device, A-constant of the IOL and the target refraction were manually imported to Sirius software to predict IOL position and calculate the IOL power. Pupil diameter in all patients was set to 3 mm. Record the predicted IOL position (PLP) and predicted refraction with the same IOL power as IOL Master.

Surgical Technique Microincision phacoemulsification combined with IOL implantation was done by the same surgeon. Transparent corneal incision (2 mm) and auxiliary incision (1 mm) were made. After cataract extraction, implantation with a hydrophobic acrylic monofocal IOL into the capsular bag was performed. The optical surface of IOL was in the middle and the corneal incision was closed with water.

Postoperative Examination The postoperative manifest refraction spherical equivalent was obtained at the follow-up visit 3mo after operation. The mean absolute value of prediction error (prediction error= predicted refraction-postoperative refraction) was defined as MAPE. Postoperative ACD, known as effective lens position (ELP), was measured by Sirius 3D topography system 3mo after surgery. Input ELP to Sirius 3D topography system instead of PLP to verify if the error results from the inaccuracy of the PLP. The correlation between PLP and ELP was identified using linear regression. Calculation of PLP was optimized by ELP. Input the optimized PLP to Sirius 3D topography system to calculate the IOL power again.

Statistical Analysis Statistically, nonparametric Wilcoxon sign rank test was used to evaluate formula differences. Linear regression was used to optimize PLP [PLP as independent variable (x), ELP as dependent variable (y)]. The data was analyzed by SPSS statistics version 20 (IBM, Chicago, IL, USA), and *P* value of less than 0.05 was considered statistically significant.

RESULTS

The MAPE of Sirius ray-tracing method, SRK-T, and Haigis methods were shown in Table 1 and Figure 1. Compared with SRK-T and Haigis formulas, less accuracy was shown using the Sirius ray-tracing method. The difference in MAPE was statistically significant between Sirius ray-tracing method and SRK-T formula, so was the difference between Sirius ray-tracing method and Haigis formula (P=0.001).

It was shown that ELP was different from PLP in Figure 2. The ELP of the IOL moved forward compared to the predicted position (P<0.001).

To study if the inaccuracy of Sirius ray-tracing method was related to the drift of ELP, we input ELP to Sirius soft to calculate the IOL power instead of PLP. As expected, the MAPE of the ELP-inputted Sirius ray-tracing method was reduced. And there was no statistical difference in MAPE of ELP-inputted Sirius ray-tracing method, SRK-T, or Haigis formula.

Scatter plots displayed in Figure 3 show a positive correlation between ELP and PLP (P=0.018). Taking ELP as y and PLP given by Sirius soft as x, a linear regression formula $y=0.1637x+3.1741$ was concluded (R^2=0.1066, P=0.018). The value of ELP calculated by the linear regression formula was considered as the optimized PLP.

We entered the optimized PLP to Sirius soft instead of the original PLP to verify the validity of this formula. It was shown that optimized Sirius ray-tracing method reduced MAPE when compared to the original software in Figure 4 (P=0.038). The optimized Sirius ray-tracing method works with the same accuracy as the formulas of SRK-T and Haigis (P=0.475).

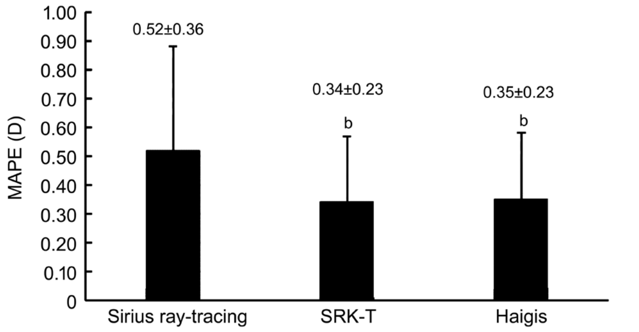

Figure 1 MAPE of each IOL power calculation formula MAPE: Mean absolute prediction error; IOL: Intraocular lens; [b]P<0.01.

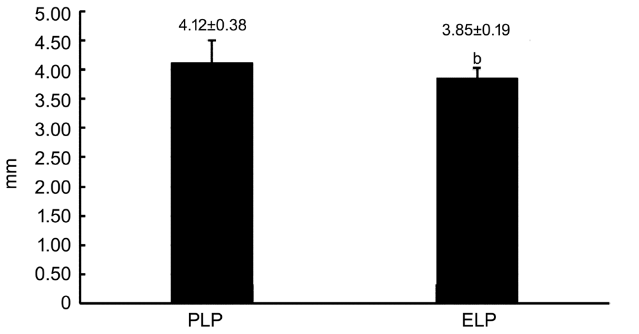

Figure 2 The ELP and PLP of the IOL ELP: Effective lens position; PLP: Predicted lens position; IOL: Intraocular lens; [b]P<0.01.

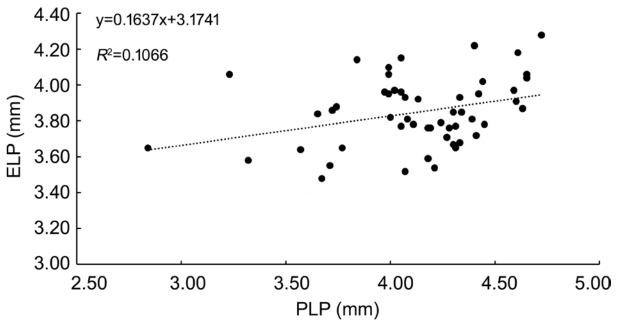

Figure 3 ELP plotted against the PLP ELP: Effective lens position; PLP: Predicted lens position.

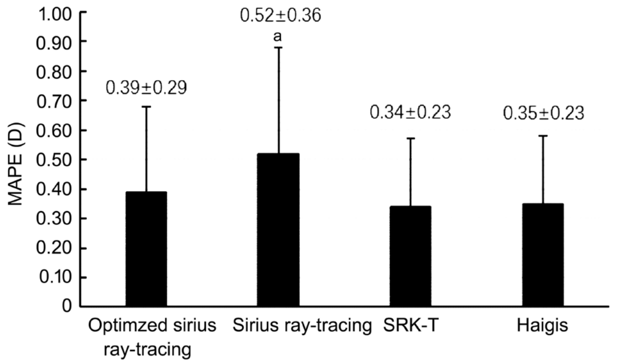

Figure 4 MAPE of each IOL power calculation formula MAPE: Mean absolute prediction error; IOL: Intraocular lens; [a]P<0.05.

DISCUSSION

Cataract surgery has gradually shifted to refractive surgery rather than blindness relief treatment with the development of various new biological measuring instruments and the improvement of the accuracy of various IOL calculation formulas. Accurate refractive prediction still remains a challenging task after uneventful cataract surgery, especially in eyes with abnormal AL and keratometry[7-9]. At present, there are two methods to calculate the IOL power 1) Traditional IOL calculation formulas based on optical biometrics; 2) Ray-tracing method[10].

The first method is based on the Gaussian optics[11], assuming that the cornea is a plane and the lens thickness is zero. The model evaluates the refraction of the whole cornea by measuring the anterior surface of the cornea[2,10]. However, this hypothetical corneal model is effective for normal eyes, but fails in some patients with special corneas, such as keratorefractive surgery patients, keratoconus patients and so on.

Over the past years, the technology of keratometry measurement can only examine the anterior surface of the cornea. Curvature abnormalities (such as astigmatism) on the posterior surface cannot be detected. Inspection techniques for measuring the posterior corneal surface were developed in recent years. Sirius topographer, which combines a rotating Scheimpflug camera with Placido ring, realizes the separate measurement of the anterior and posterior surfaces[12-13]. According to the special ray-tracing algorithm, we can obtain the real refraction of the anterior and posterior surfaces of cornea, respectively. It is the basis of the realization of ray-tracing technology.

What is ray tracing? In short, we use the real refractive index (n_{air}=1, n_{cornea}=1.376, $n_{aqueous\ humor}$=1.336) to calculate instead of the previous virtual refractive index of 1.3375[14-15]. Then, based on the data, total corneal power is calculated by ray tracing techniques following Snell's law. The required IOL power on the intermediate path can be calculated reversely.

The ray-tracing method offers great advantages: 1) The ray-tracing calculation may calculate keratometry more accurately based on real keratometric index and real corneal curvature data; 2) The calculation of IOL power is unaffected by corneal irregularities, including corneal surgery, back surface astigmatism, *etc.*

Of course, the prediction of IOL position also plays an important role in calculating IOL power. The third-generation IOL master formulas (such as SRK-T, Hoffer Q, and Holladay) rely on corneal curvature to predict postoperative ELP[16]. Haigis formula predicts postoperative ELP by preoperative ACD and ocular AL[17-18]. Therefore, accurate preoperative measurement is crucial to the prediction of ELP.

The accuracy of ELP prediction directly affects the accuracy of postoperative refraction[19]. More detailed information about the anterior chamber obtained by the three-dimensional corneal topography can be very useful. The Sirius ray-tracing method uses a proprietary algorithm to calculate PLP by anterior segment parameters and A constant of the IOL. The accurate calculation of PLP is full of importance in IOL calculation by ray-tracing method. In the calculation software of Sirius ray-tracing method, we need to input AL and A constant for calculation. PLP is automatically calculated by the software and can be modified manually. The calculation result of the power of IOL will change with the modification of PLP.

In theory, IOL calculation by Sirius ray-tracing method may work more accurately in comparison with the third-generation IOL master formulas, for the value of keratometry can be measured more accurately by Sirius ray-tracing method[15]. However, the actual result is unsatisfactory that the Sirius ray-tracing method showed less accuracy compared to SRK-T and Haigis formulas. It suggested that the patent PLP estimation method might be inaccurate and needed further optimization. In our study, this hypothesis was confirmed by the data. By measuring the actual ELP and comparing the differences with PLP, we found that there was a linear relationship between them. We optimized the PLP data using the linear regression formula and then substituted the improved PLP into the software for recalculation. The optimized Sirius ray-tracing method showed the same accuracy as the other two formulas.

Since the advent of the ray-tracing technology of calculating the power of IOL, some researches have been carried out to study the accuracy of this method. It was shown in Hoffmann and Lindemann's[3] research that ray-tracing based on biometry data improved IOL prediction accuracy over conventional formulas in normal eyes. The result diverges greatly from ours. It suggests that the accuracy of refractive results may vary in different ray-tracing commercial software, which maybe resulted from different algorithms. Olsen and Hoffmann[4] optimized the C constant which could simply predict the ELP of IOL in Olsen's ray-tracing assisted IOL power calculation. It was shown that Olsen's ray-tracing method obviously improved accuracy using the optimization of the C constant compared to the conventional IOL-Master formulas. Consistent with this study, our study improved the accuracy of IOL calculation by optimizing PLP. In addition, in eyes after refractive surgery, the ray-tracing method seems to have more obvious superiority in IOL power calculation for its accurate corneal power measurement. In Savini *et al*'s[20] study, the accuracy of Barrett, TCP 1, a ray-tracing program, and the Shammas formula were studied in IOL power calculation in eyes with a history of myopic excimer laser surgery. It was found the most precise method without referring to history was paraxial ray tracing. All of these findings suggested that ray tracing can be a reliable and satisfactory method, which works comparably with thin-lens formulas especially in eyes with excimer laser surgery. With regard to the Sirius ray-tracing method, the accuracy of IOL power calculation has rarely been reported. The refractive outcome of Sirius ray-tracing method in IOL calculation has only been investigated in the research of Savini *et al*[6], which found that ray-tracing method provided by Sirius 3D topography system displayed accurate result in IOL calculation in a series of eyes after myopic excimer laser surgery. Our study provides clinical evidence of Sirius internal ray-tracing software used in normal eyes. It can be considered as a complementary tool to the conventional formulas, especially when the predictive refraction diverges greatly among the routine formulas.

In conclusion, the original Sirius ray-tracing method is not satisfactory enough. However, in normal eyes, the optimized Sirius ray-tracing method in IOL calculation was as accurate as SRK-T and Haigis formulas. Considering that there is no obvious advantage over the commonly used conventional formulas in normal eyes, it cannot replace the previous IOL Master formulas in the clinical application. However, it can be used as a reference formula to improve the accuracy of IOL calculation, especially in abnormal keratometry issues. Benefit from its accurate corneal curvature measurement and not being limited by corneal refractive surgery, its application in patients after excimer laser surgery can be more developed. A large number of clinical studies are still needed to evaluate and optimize its accuracy in more challenging IOL power calculation issues.

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Authors' contributions: Wei LQ was responsible for the conception of the study, design of the research protocol, data analysis, interpreting results, writing the report and updating reference lists; Fu YH was in charge of the critical revision of the manuscript; Pan WH was responsible for the final manuscript approval; Nie L and Chen Y did the analysis of data and writing the report; Liu GF did the acquisition of data for the work; Qian ZB was responsible for the review and revision of the manuscript.

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