• Clinical Research •

Postoperative effective lens position and refraction changes with three different types of intraocular lens

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Abstract
● **AIM:** To evaluate and compare alterations in the effective lens position (ELP) and refractive outcomes among three distinct intraocular lens (IOL) types.
● **METHODS:** Patients with cataracts were enrolled and allocated to 3 groups: Group A (implanted with the SN6CWS), Group B (implanted with the MI60), and Group C (implanted with the Aspira-aA). ELP measurements were obtained with swept-source optical coherence tomography (SS-OCT) at 1d, 1wk, 1mo, and 3mo postoperatively. Subjective refraction assessments were conducted at 1wk, 1mo, and 3mo following surgery.
● **RESULTS:** The study included 189 eyes of 150 cataract patients (66 males). There were 77 eyes in Group A, 55 eyes in Group B, and 57 eyes in Group C. The root mean square of the ELP (ELP_{RMS}) within the initial 3mo was significantly lower for Group A than for Groups B and C. Refractive changes within Group A were not significant across the time points of 1wk, 1mo, and 3mo. Conversely, both Group B and Group C demonstrated statistically significant shifts toward hyperopia from 1wk to 3mo postsurgery.
● **CONCLUSION:** Among the three IOLs examined, the SN6CWS IOL showes the greatest stability during the first 3mo postoperatively. Between 1wk and 3mo after surgery, notable hyperopic shifts are evident in eyes implanted with the MI60 and Aspira-aA IOLs, whereas refractive outcomes remain relatively constant in eyes implanted with SN6CWS IOLs.
● **KEYWORDS:** effective lens position; refraction; intraocular lens; swept-source optical coherence tomography
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INTRODUCTION

In recent years, advancements in surgical techniques and intraocular lens (IOL) technology have transformed modern cataract surgery into a refractive procedure. The primary objective of such procedures is to attain the optimal predicted postoperative refraction, particularly when premium IOLs—such as aspheric, toric, or multifocal lenses—are implanted. Postoperative refractive inaccuracies can significantly impair visual acuity and negatively impact patients' quality of life[1-2]. Consequently, achieving precise refractive predictions is crucial in clinical practice and is a cornerstone of successful cataract surgery[3]. Nevertheless, research indicates that refractive corrections exceeding 1.00 diopters (D; spherical equivalent) after surgery are still needed for approximately 10% of eyes[1]. Furthermore, it has been reported that only 70%-80% of patients achieve postoperative refraction within ±0.50 D of the predicted value[2], with even lower percentages observed in smaller studies[2,4].

To optimize postoperative refractive outcomes, an accurate IOL power calculation formula, precise ocular biometry, and determination of the effective lens position (ELP) are vital[5-7]. In 2007, Olsen[8] reported that incorrect estimations of postoperative anterior chamber depth, axial length (AL), and mean keratometry contributed to 42%, 36%, and 22% of IOL power prediction errors, respectively. Norrby[9] estimated in 2008 that 35% of IOL power calculation errors were due to inaccuracies in predicting the ELP.

Although recent advancements in optical biometric devices have increased the accuracy of biometric measurements, accurately predicting the ELP remains challenging[10-11] due to its association with a number of factors, including preoperative

Table 1 Characteristics of the three types of IOL

Parameters	SN6CWS	MI60	Aspira-aA
Material-optic and haptic	Hydrophobic acrylic	Hydrophilic acrylic	Hydrophilic acrylic
Optic configuration	Biconvex	Biconvex	Biconvex
Optic diameter	6.0 mm	6.0 mm	6.0 mm
Overall diameter	13 mm	11.0 mm (+0 to +15 D), 10.7 mm (+15.5 to +22 D), 10.5 mm (+22.5 to +30 D)	12.5 mm
Haptic configuration	2 modified L-loops	4 plate-loops	2 C-loops
Haptic angulation	0°	10°	0°

IOL: Intraocular lens; D: Diopter.

capsule size, cataract severity, and the presence of postsurgical capsule contraction. Deviations from the estimated ELP can result in myopia (forward) or hyperopia (backward displacement)[2]. One study reported that inaccurate ELP predictions accounted for 22% to 38% of the total refractive prediction error[12] and that postoperative shifts in the ELP can induce unexpected refractive changes beyond prediction errors. The interplay between capsular fibrosis and bag fusion may explain the changes in ELP after surgery[13].

Research has shown that several IOL characteristics, including the material and design of the optic and haptics and optic-haptic angulation, can affect IOL stability within the capsular bag[11,14]. However, many aspects of IOL movement and postoperative refraction remain unknown and warrant further investigation. Therefore, this study was conducted to assess changes in ELP and refraction with three types of IOL and to quantify the relationship between them.

PARTICIPANTS AND METHODS

Ethical Approval The present study adhered to the principles outlined in the Declaration of Helsinki and received approval from the Research Ethics Office (No.2020-066-K-58) at the Eye Hospital of Wenzhou Medical University. Written informed consent was obtained from all participants. The study was registered under the clinical trial number NCT04443101.

Participants This observational study enrolled patients diagnosed with age-related cataracts who were scheduled for cataract surgery involving in-the-bag IOL implantation. According to the Lens Opacities Classification System III, the cataract grades of the patients ranged from 2 to 4. AL measurements were confined to the range of 22–24.5 mm. The participants were categorized into three groups based on the type of IOL used: Group A (SN6CWS, USA), Group B (MI60, USA), and Group C (Aspira-Aa, Germany).

Exclusion Criteria Individuals were excluded if their AL was less than 22 mm or exceeded 24.5 mm, if they had a history of ocular trauma, ocular diseases (such as corneal pathologies, uveitis, presumed zonal instabilities such as pseudoexfoliation syndrome, or glaucoma), prior corneal or intraocular surgeries, or any intraoperative or postoperative complications (including capsulorhexis issues such as capsule tears or ruptures and postsurgical capsule contraction). Additionally, those who failed to return for scheduled examinations or follow-ups were also excluded. Prior to enrollment, a thorough examination including slit-lamp microscopy, noncontact tonometry, optical biometry with an IOL-Master 700, and fundus examination after pupil dilation was conducted.

Surgical Procedures and IOLs All eyes underwent phacoemulsification and in-the-bag IOL implantation through a 2.2-mm clear corneal incision. The surgeries were performed by three experienced surgeons (Zhao YE, Wang DD, and Chang PJ). The selection of the IOL type and target refraction for each eye was determined by the respective surgeon, accounting for ocular parameters and the patient's economic situation. The refractive targets were generally aimed at emmetropia, falling within the range of -0.5 to +0.15 D. However, for some myopic patients who were accustomed to their myopia and preferred better near vision, refractive targets aimed at slight or moderate myopia were chosen. In this study, the SRK/T formula was used for IOL power calculation. Optimized constants specific to our study were applied: 119.2 for Group A, 118.6 for Group B, and 118.9 for Group C. These A-constants were optimized *via* the SRK/T formula according to the optimization process accessible at https://iolcon.org/.

During the surgery, a central continuous curvilinear capsulorhexis with a diameter of approximately 5 mm was created, and one of three types of one-piece IOL were implanted: the SN6CWS (Group A), the MI60 (Group B), and the Aspira-Aa (Group C). The characteristics of these IOLs are detailed in Table 1. Finally, the ophthalmic viscosurgical device (medical sodium hyaluronate gel) was entirely removed.

Equipment and Examination Protocol A commercially accessible swept-source optical coherence tomography (SS-OCT) system (Casia SS-1000; Tomey) utilizing a swept-source laser with a wavelength of 1310 nm was employed in this study. Operating at a rapid rate of 30 000 A-scans per second and capturing 512 A-scan lines per image, it boasts axial and transverse resolutions of approximately 10 μm and 30 μm, respectively. Each eye underwent three standardized SS-OCT scans executed by the same skilled operator (Xiang LF) at 1d, 1wk, 1mo, and 3mo postoperatively. Statistical analysis was based on the mean of these three scans. Furthermore, subjective refraction measurements were collected at 1wk, 1mo, and 3mo post cataract surgery.

In this study, ELP was defined as the distance from the cornea's anterior surface to the midpoint of the IOL (including the corneal thickness), as illustrated in Figure 1, with the corneal vertex serving as the reference point[15]. The total variations in the ELP were quantified with the root mean square error (RMS)[16-17], which was calculated with the following formula:

$$ELP_{RMS}=\sqrt[2]{\frac{\sum_{i=1}^{n}(ELP_i-ELP_{i+1})^2}{n}},$$

where n is the number of examination intervals, and it takes the values from 1 to *n*. Here, *n* was 3. The ELP_{RMS} was determined by considering the ELP measurements obtained at 1d, 1wk, 1mo, and 3mo postoperatively. For the analysis of postoperative refraction, the spherical equivalent was computed. At each postoperative time point, the difference between the achieved refraction and targeted refraction was designated the refractive error (RE) after accounting for the initial systematic error. The IOL power was calculated with the SRK/T formula.

Statistical Analysis Statistical analyses were conducted with IBM SPSS Statistics software (IBM Corp., Armonk, NY, USA, Version 19.0). Continuous variables that followed a normal distribution are summarized as the means and their standard deviations. To assess differences across the three groups, one-way ANOVA was employed. A generalized estimating equation model was used to evaluate group differences while accounting for the effects of time and the potential nonindependence of data points. Statistical significance was set at a *P* value less than 0.05 throughout the analysis. The determination of sample size was carried out with PASS 15 software (NCSS, USA) according to a statistical power of 80% and a significance level of 0.05. The primary indicator for sample size calculation was the ELP; the results indicated that a minimum of 51 eyes per group was necessary.

RESULTS

The study included 189 eyes from 150 cataract patients (66 males and 84 females), distributed as follows: 77 eyes in Group A (SN6CWS), 55 eyes in Group B (MI60), and 57 eyes in Group C (Aspira-aA). Table 2 presents the clinical characteristics of the eyes in each group, showing that no significant differences were observed among them. Additionally, the median target refraction (with interquartile range) was -0.24 (-0.37, -0.07) D for Group A, -0.29 (-0.45, -0.17) D for Group B, and -0.36 (-0.43, -0.19) D for Group C. No statistically significant differences were found among these three groups (P=0.186).

Figure 2 displays the alterations in the ELP over the 3-month period following surgery. The findings indicated that, across all groups, the IOLs exhibited a notable forward shift during the initial week postsurgery. They subsequently retreated significantly by the one-month mark and remained relatively stable until the three-month timepoint.

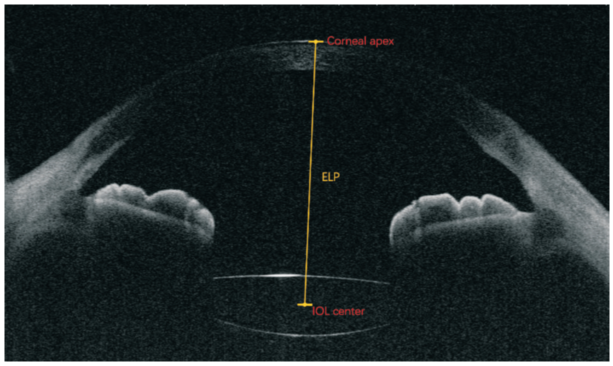

Figure 1 Definition of the ELP, measured as the distance measured from the corneal apex (anterior surface) to the center of the IOL
ELP: Effective lens position; IOL: Intraocular lens.

Table 2 Demographic characteristics and preoperative parameters of the 3 groups mean±SD

Parameters	SN6CWS (*n*=77)	MI60 (*n*=55)	Aspira-Aa (*n*=57)	*P*
Age (y)	72.86±7.60	74.51±7.65	71.70±8.11	0.156
AL (mm)	23.12±0.62	23.28±0.77	23.29±0.60	0.255
ACD (mm)	2.97±0.37	2.89±0.35	2.97±0.33	0.356
K (D)	44.25±1.15	44.17±1.45	44.05±1.16	0.599
LT (mm)	4.51±0.48	4.61±0.43	4.47±0.42	0.166
WTW (mm)	11.63±0.35	11.71±0.52	11.64±0.42	0.572

SD: Standard deviation; AL: Axial length; ACD: Anterior chamber depth; K: Keratometry; LT: Lens thickness; WTW: White to white.

Figure 3 shows that the ELP_{RMS} in Group A was statistically lower than that in both Group B and Group C (both P<0.05). however, no significant difference of the ELP_{RMS} was observed between Group B and Group C (P>0.05). Thus, it was shown that the IOLs in Group A presented the least movement and the best stability in 3mo after the surgery.

Figure 4 illustrates the alterations in refraction that occurred between 1wk and 3mo postsurgery. Across all three groups, hyperopic shifts were observed from the first week to the first month, with magnitudes of 0.067±0.039 D in Group A, 0.191±0.054 D in Group B, and 0.094±0.050 D in Group C. Among these, only the shift in Group B was statistically significant. Similarly, from the first week to the third month, hyperopic shifts were noted in all groups: 0.013±0.047 D in Group A, 0.195±0.055 D in Group B, and 0.149±0.058 D in Group C. Here, the differences in Group B and Group C were statistically significant. Figure 5 depicts the changes in RE within the first 3mo after surgery. During the period from 1wk to 1mo postsurgery, the hyperopic shift in Group B was statistically significant, whereas that in Groups A and C was not. Over the interval from 1wk to 3mo, significant hyperopic

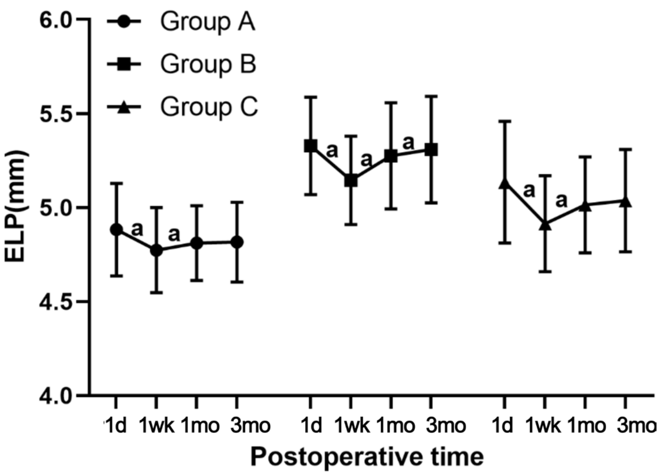

Figure 2 Postoperative changes in the ELP across the three groups, assessed at 1d, 1wk, 1mo, and 3mo The symbols denote the mean values, and the bars represent the SDs. [a]Statistically significant differences. ELP: Effective lens position; SD: Standard deviation.

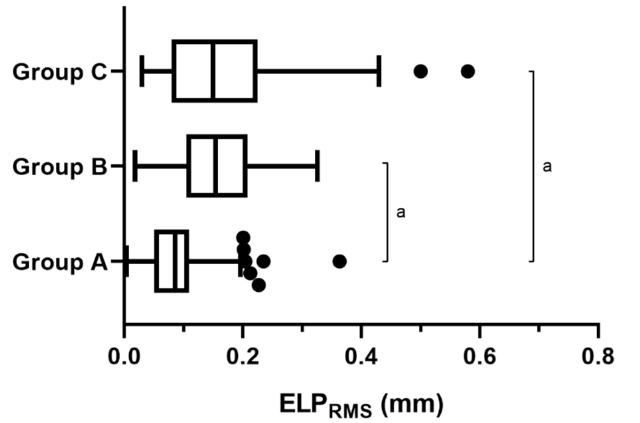

Figure 3 The root mean square of the effective lens position (ELP$_{RMS}$) in the 3 groups 3mo after surgery [a]Statistically significant differences.

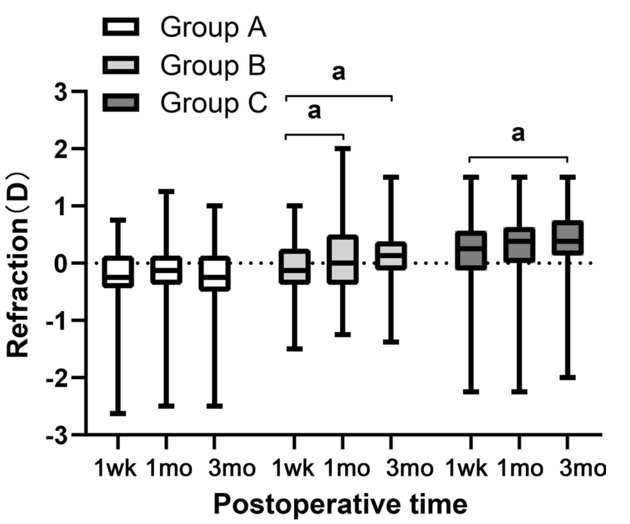

Figure 4 Refractive changes following surgery evaluated in the three groups at 1wk, 1mo, and 3mo postoperatively [a]Statistically significant differences between the designated time points.

shifts were evident in both Group B and Group C but not in Group A.

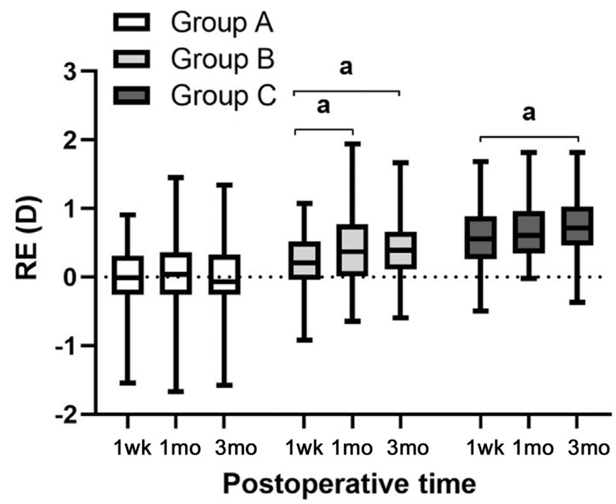

Figure 5 Refractive change assessed at 1wk, 1mo, and 3mo postoperatively after accounting for the initial systematic error RE was defined as the discrepancy between the postoperative refraction and the targeted refraction. [a]Statistically significant differences between the corresponding time intervals. RE: Refractive error.

DISCUSSION

In contemporary cataract surgery, precise determination of IOL optical power is crucial for ensuring favorable clinical outcomes, particularly for multifocal IOLs. Despite advances in biometry and topography devices that offer reliable measurements for IOL power calculations, predicting the ELP still relies on specific ocular parameters. The introduction of new IOL calculation formulas has increased the precision of the prediction of postoperative refraction, although postoperative refractive changes still occur occasionally. Studies have indicated that postoperative IOL shifts can induce refractive changes, resulting in a particular relationship between them[2,11]. Additionally, haptic design has been reported to exert a greater influence on stability than material properties[18]. To comprehensively explore postoperative IOL movements and their impact on refractive outcomes, this study assessed IOL stability and refraction with three distinct IOL types: SN6CWS, MI60, and Aspira-aA. To mitigate the influence of other parameters, the study enrolled cataract patients classified as Grade 2 to Grade 4 according to the Lens Opacities Classification System III staging system. Furthermore, central continuous curvilinear capsulorhexis with a diameter of approximately 5 mm was performed, and eyes with postsurgical capsule contraction were excluded.

In this study, IOLs of all three types exhibited significant forward shifts between 1d and 1wk, followed by a notable retraction until 1mo (Figure 2). After 1mo, the lenses remained stable for 3mo (Figure 2). Consistent with our findings, several studies[13,19] have also reported significant (and the most pronounced) forward IOL movement in the first postoperative week. Moreover, Eom *et al*[14] reported that the AcrySof IQ

C-loop IOL was highly stable starting at 1wk postsurgery, whereas the Akreos MI-60 4-plate IOL showed significant forward movement between 1wk and 1mo, remaining stable until 3mo. They also noted that the AcrySof IQ SN60WF IOL had the least amount of postoperative axial movement on the basis of the ELP_{RMS}[14]. Our findings align with these observations, showing that the ELP_{RMS} of Group A (SN6CWS, 0.095 mm) was significantly lower than that of Group C (Aspira-Aa, 0.172 mm) or Group B (MI60, 0.158 mm). However, no significant differences were found between the ELP_{RMS} values of Group C and Group B. Thus, we concluded that the SN6CWS C-loop IOL (hydrophobic) might exhibit greater stability than the Aspira-Aa or MI60 IOL.

Furthermore, Group A (SN6CWS) demonstrated the most stable postoperative refraction among the three groups, as illustrated in Figure 4. This is in accordance with the fact that group A had the smallest total ELP changes. Notably, the hyperopic shifts of 0.195 D in group B and 0.149 D in group C (Aspira-Aa) were both statistically significant from 1wk to 3mo postsurgery, corresponding with the obvious backward IOL movement during this period (Figure 2). Although hyperopic shifts of 0.195 or 0.149 D may not be clinically significant, they are relevant in refractive cataract surgery, especially in the context of multifocal IOL implantation. To eliminate the effects of initial systematic error, RE shifts (Figure 5) were also analyzed among the three groups, yielding results similar to those seen for the postoperative refraction changes. Consequently, we hypothesize that ELP changes might be a crucial factor in determining postoperative refraction 3mo after cataract surgery. A previous study reported significant postoperative IOL shifts and refractive changes with the AcrySof IOL in the early postoperative period, suggesting that eye surgeons might benefit from waiting until week 1 to select the IOL power for the second eye. However, another study[20] indicated that long-term refractive changes are attributed primarily to corneal curvature changes, while the role of IOL position shifts is limited. Fukumitsu *et al*[19] reported that refractive changes from 1 to 6mo after cataract surgery with single-piece monofocal IOLs (AcrySof IQ SN60WF and Akreos MI60L) are unrelated to IOL positional instability. Therefore, postoperative refractive changes are closely associated with IOL movements in the early period, with this relationship weakening over time.

The stability of hydrophobic IOLs with nonangulated C-loop haptics surpasses that of hydrophilic IOLs with angulated plate haptics[14]. The longer the overall length of the IOL is, the more it thrusts against the capsule's equator, resulting in a more stable axial position[21]. Additionally, hydrophobic and one-piece IOLs demonstrate relatively minimal axial shift combined with stable postoperative refraction[14,22]. However, a sharp optic edge IOL design has minimal influence on axial position stability[23]. On the basis of these findings, we speculate that the postoperative ELP and refraction of Group A (SN6CWS) were more stable than those of the other two groups for two main reasons: the hydrophobic material of the SN6CWS IOL and its greater overall length (13 mm) among the three groups. However, the effect of haptic angulation on IOL stability remains unclear and may not be a crucial factor that warrants further investigation. This study has several limitations. First, this was an observational study lacking randomization. A prospective, randomized study is necessary to validate these findings, and a longer follow-up is needed to assess long-term postoperative refractive changes. Second, this study investigated only the influence of postoperative IOL movement on refractive changes. Corneal curvature changes may also affect postoperative refraction and should be evaluated in future studies. Third, this study examined only three types of monofocal IOL. Future research should investigate more IOLs with different materials and designs, particularly multifocal IOLs.

In summary, the SN6CWS, MI60, and Aspira-Aa IOLs all exhibited significant forward shifts in the first week, remaining stable after 1mo. In the first 3mo postsurgery, the SN6CWS IOL demonstrated the greatest stability among the three types. From 1wk to 3mo after surgery, significant hyperopic shifts were observed for both the MI60 and Aspira-Aa IOLs, whereas the postoperative refraction was relatively stable with the SN6CWS IOLs.

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