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Effect of improved anterior capsule polishing on visual quality after cataract surgery

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改良囊膜抛光对白内障手术后视觉质量的影响

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摘要

目的:评估改良囊膜抛光对飞秒激光辅助白内障超声乳化手术(FLACS)并植入多焦点人工晶状体(MIOL)患者视力和视觉质量的影响。

方法:研究纳入37例患者74眼,其中男17例,女20例,平均年龄为51.74±7.80岁。使用抛硬币法,随机选取每位患者的一眼进行改良囊膜抛光,另一眼则接受常规的灌注/抽吸(I/A)抛光,抛光组包含37眼,其中右眼21只,左眼16只,对照组则为抛光组同一患者的对侧眼。评估术前以及术后1 wk、1、6、12 mo患者的视力和视觉质量。采用OPD-Scan III评估高阶像差,利用光学质量分析系统(OQAS)评估调制传递函数(MTF cutoff)、斯特列尔比(SR)和客观散射指数(OSI)评估视觉质量。运用配对t检验和重复测量方差分析(ANOVA)对结果进行比较,并采用SNK-q事后检验确定差异是否显著。

结果:抛光组患者术后1 wk的裸眼远视力(UDVA)和裸眼近视力(UNVA)较对照组表现更优(均$P<0.05$)。术后12 mo时,抛光组的UDVA、UNVA和最佳矫正远视力(CDVA)均优于对照组($P<0.05$)。术后12 mo时,与对照组相比,抛光组的MTF cutoff、SR、OSI和高阶像差均有改善($P<0.05$)。

结论:改良囊膜抛光对FLACS并植入MIOL的患者1 a内维持视力和视觉质量有益。

关键词:囊膜抛光;视觉质量;白内障手术;飞秒激光

Abstract

• AIM: To assess the visual acuity and visual quality of cataract patients who received femtosecond laser-assisted cataract surgery (FLACS) and multifocal intraocular lens (MIOL) implantation with an improved polishing technique during a 1-year follow-up period.

• METHODS: This study included 74 eyes from 37 patients, comprising 17 males and 20 females, with a mean age of 51.74±7.80 years. Using a coin toss method, one eye per patient was randomly selected for improved anterior capsular polishing, while the other eye received standard irrigation/aspiration (I/A) polishing. The polishing group consisted of 37 eyes, including 21 right and 16 left eyes, while the control group comprised the contralateral fellow eyes of the same individuals in the polishing group. Visual acuity and quality of the patients were evaluated before surgery and at 1 wk, 1, 6, and 12 mo after surgery. The OPD-Scan III was utilized to assess high-order aberrations, while the optical quality analysis system (OQAS) was employed to evaluate modulation transfer function (MTF cutoff), Strehl ratio (SR), and objective scatter index (OSI) for the purpose of visual quality assessment. Paired t-tests and repeated measures analysis of variance (ANOVA) were utilized to compare the results, and the SNK-q post hoc test was applied to identify significant differences.

• RESULTS: The polishing group's uncorrected distant visual acuity (UDVA) and uncorrected near visual acuity (UNVA) significantly improved 1-week post-surgery (all $P<0.05$). At 12-months, UDVA, UNVA, and corrected distant visual acuity (CDVA) were better than the control group ($P<0.05$). The MTF cutoff, SR, OSI, and high-order aberrations in the polishing group also showed significant improvements compared to the control group at 12 mo ($P<0.05$).

• CONCLUSION: The improved capsular polishing method has been demonstrated to effectively maintain visual acuity and visual quality in patients with MIOL after FLACS within 1 a.

• KEYWORDS: anterior capsule polishing; visual quality; cataract surgery; femtosecond laser
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INTRODUCTION

Cataracts notably diminish visual acuity in the elderly, and surgical intervention is the only reliable method for their complete elimination and the restoration of patients' sight. As living standards have significantly improved, cataract surgery has advanced into an era of refractive procedures, incorporating multifocal intraocular lenses (MIOLs) that facilitate clear vision at multiple distances-far, intermediate, and near-thus improving the overall quality of life for patients. Moreover, state-of-the-art technologies, such as femtosecond laser-assisted cataract surgery (FLACS), have ushered in a "bladeless" era for cataract surgery.

Residual lens epithelial cells (LECs) are primarily responsible for capsular contraction and fibrosis following cataract surgery[1]. The development of capsular contraction and fibrosis can lead to anterior capsule opacification (ACO) and posterior capsule opacification (PCO), potentially affecting postoperative visual quality. Preserving high postoperative visual quality is essential for patients who opt for MIOLs. Reducing the number of residual LECs could be a strategy to maintain postoperative visual quality.

Polishing is a mechanical technique employed to eliminate LEC, thereby ensuring that the capsule membrane attains maximum cleanliness and transparency. Additionally, it can minimize the presence of residual LECs in the anterior capsule and equator to reduce the occurrence of ACO and capsular phimosis[2]. And it contributes to maintaining the effective lens position (ELP) for long-term visual stability[3]. However, some scholars argue that polishing may not effectively inhibit the growth of residual cells; instead, it could promote cell proliferation in bag cultures or have limited impact on reducing PCO occurrence[4-6]. One possible reason for the controversy regarding the effectiveness of polishing could be the variation in polishing methods employed across studies, which may result in differing levels of polishing efficiency. In light of this, our research team has optimized the conventional usage protocols of polishing instruments, aiming to reduce polishing time, enhance efficiency, thereby observing whether polishing contributes to preserving the highly visual quality of cataract patients after surgery.

The objective of this study is to investigate the postoperative visual quality following an improved polishing technique in cataract patients with MIOL. To ensure the comparability of the results, a femtosecond laser was used to assist in the capsulorhexis procedure. The study employed measurements of visual acuity and objective indicators of visual quality, including the modulation transfer function (MTF), objective scattering index (OSI), Strehl ratio (SR), and higher-order aberrations, to evaluate the effect of the improved polishing method on visual quality after surgery.

SUBJECTS AND METHODS

Ethical Approval From January 2022 to May 2023, this prospective, the caregivers, and the outcome statisticians-masked clinical trial recruited 37 consecutive patients (74 eyes) with bilateral age-related cataracts who were scheduled for FLACS and MIOL implantation (AT LISA tri 839MP, Carl Zeiss AG, Oberkochen) in both eyes at the Xi'an People's Hospital (Xi'an Fourth Hospital). The study followed the tenets of the Helsinki agreement, and the protocol was reviewed and approved by the Ethics Committee of Xi'an People's Hospital (Xi'an Fourth Hospital) (No.20220126).

Subjects Patients with axial length ≥22 mm and ≤26 mm were enrolled and monitored for a period of one year. The exclusion criteria were as follows: 1) progressive and aggravated retinal diseases, such as diabetic retinopathy, macular degeneration, preretinal membrane, vitreous macular traction syndrome, Stargardt disease, retinitis pigmentosa, *etc.*, and serious optic nerve diseases; 2) short axial length (axial length < 22 mm), ultra-high myopia (spherical equivalent ≥-8.00 D or axial length >26.0 mm), obvious pupil abnormalities, severe corneal lesions, severe irregular astigmatism (a complex refractive error where the cornea or lens has highly uneven curvature, causing distorted or blurred vision that cannot be fully corrected with standard glasses or soft contact lenses), chronic uveitis, glaucoma, obvious abnormalities of lens capsule membrane and zonules, major degree alternating strabismus (magnitude of deviation is typically ≥30 prism diopters, and the deviation alternates between both eyes rather than being confined to a single eye) and other ocular organic diseases and amblyopia; 3) severe mental and psychological diseases; 4) history of intraocular surgery; 5) posterior capsule rupture or uneventful in-the-bag IOL implantation. All enrolled patients underwent a comprehensive ophthalmic examination, including slit-lamp anterior segment examination, non-contact tonometry (TX-20/20P, Canon), fundus examination, optical biometry (IOL Master 700, Carl Zeiss AG), and corneal endothelium assessment (SP-3000P, Topcon).

Surgical Procedures According to the principle of pre-surgical randomization, the eye selected for polishing was determined using a coin toss method by a single team member. The polished eye was assigned to the polishing group, while the other eye of the same patient was allocated to the control group. The interval between surgeries on each eye was at least 2 wk, and all surgeries were completed within a month.

Half an hour prior to surgery, patients received three doses of 0.5% tropicamide phenylephrine eye drops (manufactured by Sinqi Pharmaceutical Co., LTD, China) at 5-minute intervals to achieve optimal pupil dilation. The femtosecond platform (LENSAR, USA) was utilized to construct a 5.4 mm capsulotomy (centered on the scanned capsule) and lens fragmentation[7]. All surgeries were performed by the same experienced surgeon (Wang CY) on the Stellaris platform (Bausch & Lomb, USA). Following topical anesthesia, ophthalmic viscosurgical devices (OVDs) were applied to distend the anterior chamber. The direct chop technique was then used for the emulsification of the pre-fragmented nuclear segments, and the cortex was subsequently removed *via* automated irrigation/aspiration (I/A).

Improved Anterior Capsule Polishing In the polishing group, utilize the OVDs to partially fill the peripheral capsule, causing the central posterior capsule to protrude, subsequently, employ the double-ended Whitman Shepherd capsular polisher (Figure 1) to meticulously polish both the anterior and equator of the capsule. This technique also facilitates the simultaneous polishing of a segment of the posterior capsule (Figure 2). By rotating the polisher 180° along one side, and then switching ends to encompass the remaining 180°, even the primary incision site can be effectively treated due to its curved tip design (Figure 3). The control group did not receive improved polishing; instead, they underwent the conventional I/A polishing.

A plate haptic IOL (AT LISA tri 839MP, Carl Zeiss AG, Oberkochen) was implanted within the capsular bag, ensuring a 360° capsular overlay. AT LISA tri 839MP is a preloaded diffractive trifocal IOL made of hydrophilic acrylic with hydrophobic surface properties. It features a four-haptic design, a 360-degree square edge, and a hydrophobic barrier ring around the optic for continuous optic-haptic transition[8]. The technical documents provided by the manufacturer clearly confirm this(CN_IOL_202012_Consumables List V1. Printed in China. Carl Zeiss Meditec AG, 2014.)[9].

Postoperative medication protocols were standardized across all cases. Eye drops were immediately applied following surgery. Levofloxacin (0.5%, Santen, Japan) was administered four times daily for duration of 2 wk post-surgery. Tobramycin Dexamethasone (0.1%, Alcon, USA) was given three times daily for one-week post-surgery. Bromfenacsodium (0.1%, Stuton, Japan) was administered twice daily over a two-week period following surgery.

Parameters The examinations were conducted pre-operatively and in 1-week, as well as in 1-, 6-, and 12-months post-surgery. These encompassed a slit-lamp evaluation, visual acuity tests utilizing both the standard logarithmic and Snellen charts, manifest refraction assessment, and detailed analyses with the optical quality analysis system(OQAS; Visiometrics SL, Terrassa, Spain) and OPD-Scan III (Nidek Technologies, Japan) analyzers. During the OQAS examination, a 4.0 mm pupil diameter was employed to derive parameters such as the SR, MTF cutoff frequency (MTF cutoff, cycles/degree), and the OSI. The

Figure 1 One end of the double-ended Whitman Shepherd capsular polisher. The opposite side exhibits the same characteristics but in the reverse orientation.

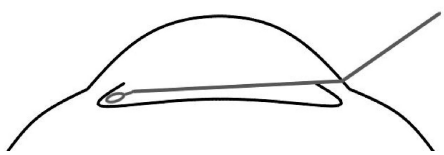

Figure 2 Schematic diagram of the improved anterior capsule polishing. Use ophthalmic viscosurgical devices to partially fill the peripheral capsule, making the central posterior capsule protrude. Then, use the double-ended capsular polisher to polish the anterior and equatorial capsule, while simultaneously polishing part of the posterior capsule.

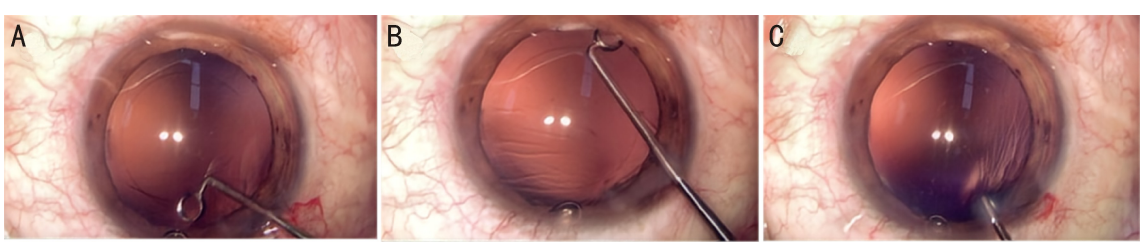

Figure 3 Surgical images for improved capsular polishing. Using the double-ended Whitman Shepherd capsular polisher polish the 180° along one side (A), followed by switching ends to cover the remaining 180° range (B), even the main incision site can be effectively addressed due to its curved tip design (C).

SR is the ratio of light intensity at the Gaussian image point with aberration to that without aberration, used to indirectly measure optical system aberrations. A higher value means fewer aberrations. For healthy eyes, values above 0.16 are typically normal. The MTF cutoff is the ratio of the difference between the phase after passing through the optical system and the original object. This metrics ranges from 0 to 60. Higher values indicate greater similarity between the retinal image and the original object. For healthy eyes, values above 30 are typically normal. The OSI measures the total ocular scattering caused by light passing through the eye's optical system. Higher OSI values indicate stronger scattering and poorer retinal image quality. In healthy eyes, OSI is usually ≤2. OSI can objectively evaluate posterior capsular opacity[10-11]. Similarly, the OPD-Scan III analyzer was utilized with a 4.0 mm pupil diameter to obtain data on ocular wavefront aberrations, including total high-order aberration (THOA), spherical aberration (SA), coma aberration (CA), and trefoil aberration (TA). High-order aberrations (*e.g.*, spherical, coma, trefoil) and low-order aberrations (*e.g.*, myopia, hyperopia, astigmatism) are types of wavefront aberrations. These distort incoming light, reducing image quality and visual acuity. High-order aberrations affect vision more than low-order ones, with SA being the most impactful, followed by CA and TA[12-13]. Each examination was meticulously performed by the same technicians.

Statistical Analysis To achieve a statistical power of 80% at a significant level of 0.05, a total of 29 participants were required. The statistical analysis was conducted using the SPSS version 29.0 for Windows (SPSS Inc., Chicago, IL, USA). Descriptive statistics were computed, presenting quantitative variables as means and standard deviations, and categorical variables as frequencies and proportions. The normal distribution of variables was assessed using the Kolmogorov-Smirnov test. In accordance with the experimental design, paired *t*-tests were applied to compare paired groups. When the data did not conform to a normal distribution, nonparametric tests, specifically the Mann-Whitney *U* test, were employed to compare medians. A repeated measures analysis of variance was utilized to evaluate variations across different visits. To further investigate any observed differences, SNK-*q* post hoc testing was applied. A *P*-value of less than 0.05 was deemed statistically significant.

RESULTS

This study involved 37 patients (74 eyes), including 17 males, with a mean axial length of 23.42±1.12 mm. The mean axial lengths in the polishing group and the control group were 23.26±1.36 mm and 23.78±0.95 mm, respectively, and the difference between the two groups was not statistically significant (P=0.735). The average white-to-white corneal diameter was 11.69±0.15 mm, with values of 11.66±0.16 mm and 11.72±0.14 mm observed in the polishing group and the control group, respectively; this intergroup difference also lacked statistical significance (P = 0.698). All patients underwent cataract surgery and received the AT LISA tri 839MP (Carl Zeiss AG, Oberkochen) MIOL implantation aimed at achieving emmetropia (calculated by the Barrett Universal II formula), from January 2022 to May 2023. The participants had a mean age of 51.74 ± 7.80 years. The polishing group was made up of 37 eyes, consisting of 21 right eyes and 16 left eyes, whereas the control group included the corresponding opposite eyes of those in the polishing group. There were no instances of intraoperative posterior capsule rupture in either the polishing group or the control group of patients.

Visual and Refractive Outcomes Table 1 presents the uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), uncorrected near visual acuity (UNVA) in LogMAR, and manifest refraction spherical equivalent (MRSE) at various visits for each group. There were no significant differences in preoperative UDVA and MRSE between the groups (P > 0.05). However, significant differences were noted in UDVA, UNVA, and MRSE at 1 wk post-surgery (P=0.000, 0.000, and 0.031, respectively), as well as in UDVA, CDVA, UNVA, and MRSE at 12 mo post-surgery (P=0.040, 0.028, 0.002, and 0.004, respectively). No significant differences in the observed indicators were found at other time points (P > 0.05).

Figure 4 depicts the trends of UDVA, CDVA, UNVA, and MRSE over time for both groups. In the polishing group, consistent stability was observed at each follow-up time point, in contrast to the significant variability seen in the control group. The polishing group demonstrated good stability in postoperative UDVA and CDVA, but there was a notable difference in postoperative UNVA from 1 to 6 mo (P=0.01). In the control group, significant changes were observed from 1 wk to 1 mo (UDVA, CDVA, UNVA, MRSE: P = 0.00, 0.02, 0.03, 0.00, respectively), from 1 to 6 mo (UNVA, MRSE: P=0.03, 0.03, respectively), and from 6 to 12 mo (CDVA: P=0.00).

Visual quality outcomes The data presented in Table 2 regarding OQAS reveals a substantial statistical disparity between the two groups concerning the MTF cutoff at 1 wk (P= 0.003). Moreover, the MTF cutoff, SR, and OSI demonstrate significant variances between the two groups at the 12-month mark (P = 0.003, 0.033, and 0.001 respectively). However, no statistically significant differences were detected between the two groups at other time intervals (P>0.05).

Table 3 presents the outcomes of the OPD-Scan III, indicating a significant statistical disparity in THOA, CA, TA, and SA between the two groups at the 12-month follow-up (P = 0.045, 0.016, 0.036, and 0.032 respectively). Nonetheless, no statistically significant differences were noted at the other follow-up intervals (P>0.05).

Table 1 Comparison of uncorrected distance visual acuity, corrected distance visual acuity, uncorrected near visual acuity and manifest refraction spherical equivalent between the two groups

Parameters	Pre	1 wk	1 mo	6 mo	12 mo	*P*
UDVA ($\bar{x}\pm s$, LogMAR)						
Polishing group	0.77±0.47	0.04±0.09	0.03±0.09	0.05±0.09	0.05±0.14	0.000[a]
Control group	0.72±0.37	0.13±0.10	0.08±0.05	0.09±0.06	0.10±0.07	0.000[a]
P	0.601	0.000[a]	0.051	0.055	0.040[a]	
CDVA($\bar{x}\pm s$, LogMAR)						
Polishing group		0.02±0.03	0.02±0.04	0.02±0.04	0.03±0.05	0.246
Control group		0.04±0.05	0.02±0.04	0.03±0.05	0.07±0.06	0.000[a]
P		0.227	0.947	0.528	0.028[a]	
UNVA($\bar{x}\pm s$, LogMAR)						
Polishing group		0.13±0.11	0.14±0.10	0.16±0.09	0.15±0.11	0.230
Control group		0.23±0.06	0.19±0.14	0.21±0.10	0.23±0.05	0.012[a]
P		0.000[a]	0.106	0.061	0.002[a]	
MRSE($\bar{x}\pm s$, D)						
Polishing group	−2.64±2.45	−0.42±0.37	−0.31±0.19	−0.30±0.19	−0.34±0.10	0.000[a]
Control group	−1.83±1.99	−0.56±0.31	−0.32±0.25	−0.38±0.06	−0.47±0.09	0.000[a]
P	0.443	0.031[a]	0.860	0.135	0.004[a]	

[a]Significant at $P<0.05$. UDVA: Uncorrected distant visual acuity; CDVA: Corrected distant visual acuity; UNVA: Uncorrected near visual acuity; MRSE: Manifest refraction spherical equivalent.

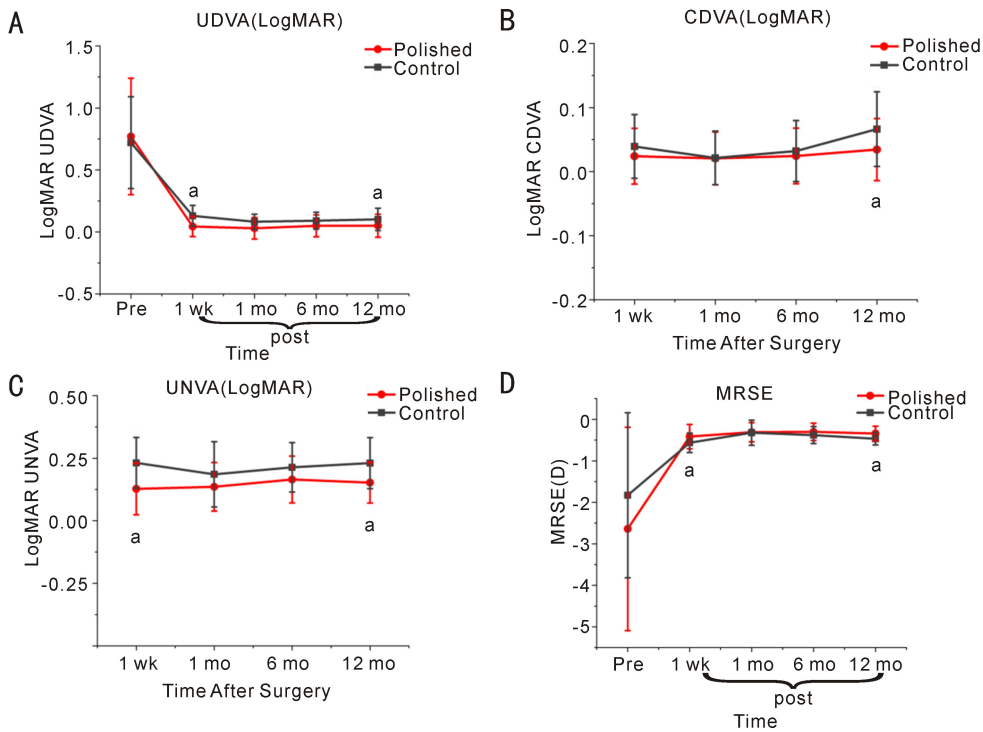

Figure 4 Evolution of visual acuity and refractive outcomes over the period of the study in both groups. [a]Significant at $P<0.05$. UDVA: Uncorrected distant visual acuity; CDVA: Corrected distant visual acuity; UNVA: Uncorrected near visual acuity; MRSE: Manifest refraction spherical equivalent.

The trend of the OQAS and OPD-Scan III observation indicators over time are depicted in Figures 5 and 6, respectively.

The polishing group's OQAS data revealed a consistent and progressive improvement, with a statistically significant increase in the MTF cutoff from the 6 to the 12 mo postoperative period ($P=0.002$), similarly, a statistically significant improvement in SR was noted from the 1-month to the 6-month postoperative interval ($P=0.018$), with no statistically significant variations at other time points. In contrast, the control group demonstrated significant differences primarily between 1 wk and 1mo post-surgery, with *P*-values for MTF cutoff, SR, and OSI being 0.000, 0.031, and 0.045, respectively. Furthermore, MTF cutoff showed significant differences from 1 to 6 mo post-surgery ($P=0.004$), and OSI displayed significant differences from 6 to 12 mo post-surgery ($P=0.042$). No significant differences were observed in other parameters across various time points. (Figure 5).

The polishing group dataset from the OPD-Scan III revealed a consistent and progressively improving pattern, with no statistically significant variations in any parameters at each time point. In contrast, the control group exhibited a statistically significant difference in THOA and CA between 6 and 12 mo postoperative periods (P = 0.012 and 0.008, respectively). No other time points showed statistically significant differences (Figure 6).

Table 2 Comparison of modulation transfer function cutoff, Strehl ratio and objective scatter index between the two groups

Parameters	1 wk	1 mo	6 mo	12 mo	P
MTF cutoff					
Polishing group	33.36±11.13	33.88±10.12	34.80±8.78	35.90±7.89	0.175
Control group	25.59±7.50	29.49±6.73	30.78±7.76	30.40±5.93	0.000[a]
P	0.003[a]	0.055	0.065	0.003[a]	
SR					
Polishing group	0.18±0.08	0.18±0.07	0.19±0.07	0.19±0.06	0.480
Control group	0.16±0.06	0.17±0.06	0.17±0.07	0.16±0.05	0.342
P	0.239	0.393	0.393	0.033	
OSI					
Polishing group	1.86±0.88	1.86±0.68	1.83±0.49	1.75±0.45	0.508
Control group	2.18±0.75	2.01±0.54	2.00±0.43	2.13±0.43	0.046[a]
P	0.138	0.343	0.162	0.001[a]	

[a]Significant at P<0.05. MTF: Modulation transfer function; SR: Strehl ratio; OSI: Objective scatter index.

Table 3 Comparison of total high-order aberration, coma aberration, trefoil aberration and spherical aberration between the two groups

Parameters	1 wk	1 mo	6 mo	12 mo	P
THOA					
Polishing group	0.27±0.14	0.27±0.11	0.27±0.12	0.26±0.08	0.872
Control group	0.29±0.12	0.27±0.12	0.28±0.11	0.30±0.09	0.176
P	0.665	0.862	0.830	0.045[a]	
CA					
Polishing group	0.07±0.04	0.07±0.03	0.07±0.03	0.06±0.03	0.048
Control group	0.06±0.03	0.07±0.03	0.07±0.04	0.08±0.03	0.002[a]
P	0.366	0.915	0.620	0.016[a]	
TA					
Polishing group	0.25±0.14	0.23±0.11	0.23±0.12	0.22±0.08	0.221
Control group	0.27±0.12	0.24±0.10	0.25±0.10	0.27±0.10	0.062
P	0.546	0.705	0.409	0.036[a]	
SA					
Polishing group	0.02±0.01	0.02±0.01	0.02±0.01	0.01±0.01	0.014[a]
Control group	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.065
P	0.963	0.824	0.553	0.032[a]	

[a]Significant at P<0.05. THOA: Total high-order aberration; CA: Coma aberration; TA: Trefoil aberration; SA: Spherical aberration.

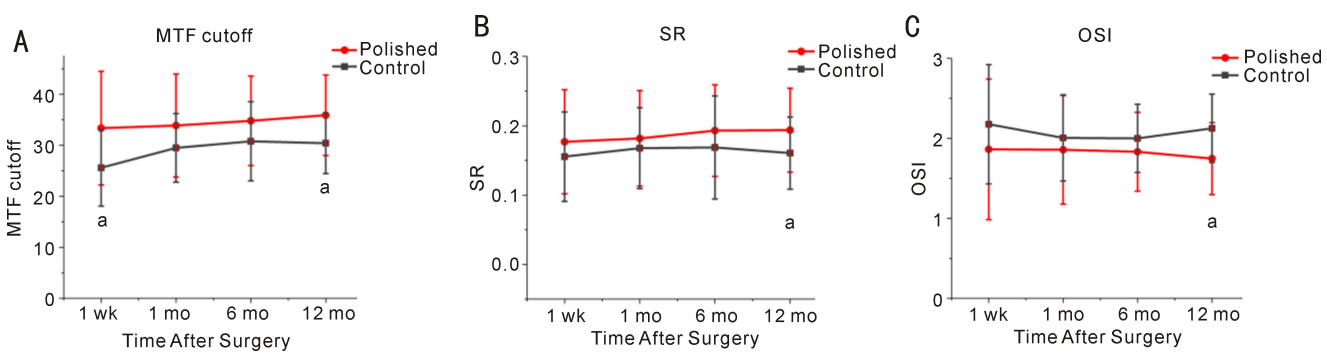

Figure 5 Alterations in optical quality analysis system data at 12 months following surgery in both groups. [a]Significant at P<0.05. MTF: Modulation transfer function cutoff; SR: Strehl ratio; OSI: Objective scattering index.

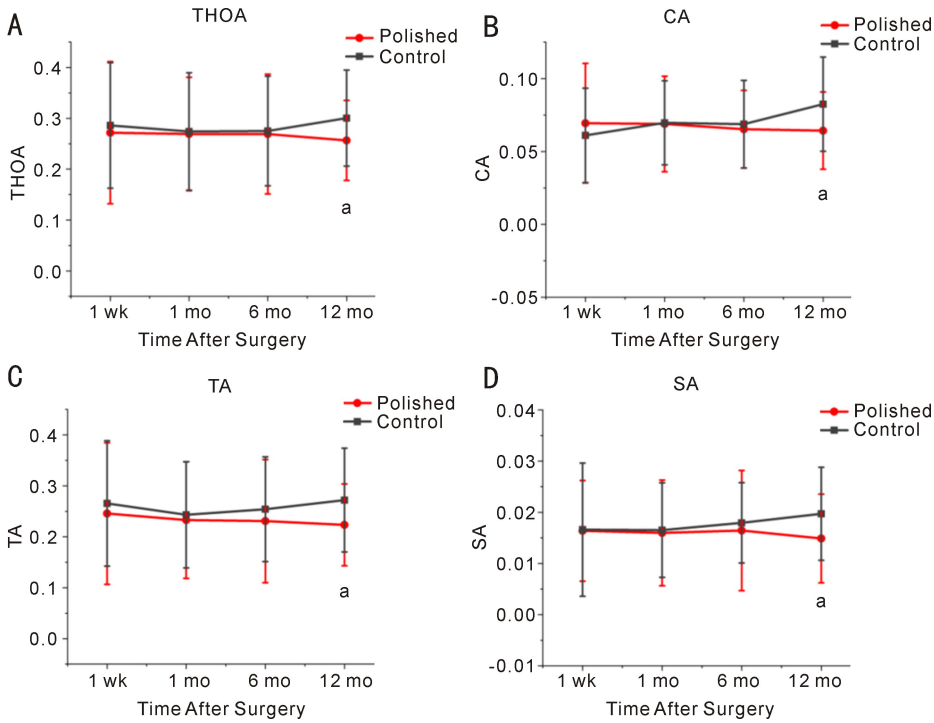

Figure 6 Alterations in OPD-Scan III data at 12 months following surgery in both groups. [a]Significant at $P<0.05$. THOA: Total high-order wavefront aberration; CA: Coma aberration; TA: Trefoil aberration; SA: Spherical aberration.

DISCUSSION

Patients who choose MIOLs typically have elevated expectations for postoperative visual quality. Thanks to the application of FLACS and ongoing advancements in the design of MIOL, an increasing number of patients are experiencing positive visual outcomes post-surgery. However, sustaining long-term high-quality visual performance remains challenging due to capsular opacification. Capsule opacification, which includes both ACO and PCO, results from the proliferation, migration, and differentiation of LECs[1,14]. The occurrence of ACO is due to the differentiation or epithelial-mesenchymal transition of LEC, which leads to fibrotic changes in the residual anterior capsule, causing capsule contraction/retraction and fibrous opacity; these changes will reduce the functional optical zone[15]. The development of PCO is considered a wound healing response of the residual LECs[1]. PCO can be categorized into fibrotic PCO and regenerative PCO. Among these two types, regenerative PCO has a more pronounced impact on visual quality. These conditions will have a profound impact on postoperative visual quality[16].

Over the past few decades, researchers have suggested a range of methods designed to reduce the incidence of ACO and PCO, including strategies to minimize the presence of residual LECs[1]. The clinical practice has primarily relied on the mechanical removal of LECs through anterior lens capsule polishing, while other physical or pharmacological approaches have not been widely adopted due to concerns regarding safety and specificity within the human body[17-18]. Various polishing techniques exist. Mathey *et al*[19] compared five polishing tools: Rentsch curettes, Kratz cannulas, silicone scrapers, I/A systems, and ultrasonic I/A. They found that ultrasonic I/A was the most effective for cleaning, removing up to 99.9% of LECs. However, a significant drawback is that ultrasonic energy may cause greater damage to the capsular bag. Several novel polishing techniques have emerged, including the viscoelastic grindstone effect[20] and the two-handed I/A system[21]. Although these methods have demonstrated efficacy, their clinical adoption remains limited. The Whitman Shepherd double-headed capsular polisher is widely used in clinical practice. Gao *et al*[22] demonstrated that its use improves the long-term axial stability of IOLs within the capsular bag. However, the current polishing techniques lack standardized protocols. When using the double-ended capsular polisher, inexperienced surgeons may inadvertently apply pressure to the posterior capsule, risking rupture or inducing zonular traction during anterior capsule polishing. There has been no consensus on OVD application during capsule polishing. Based on our team's experience, we propose improvements for using OVDs during polishing. By circularly injecting OVDs beneath the anterior capsule, the posterior capsule slightly protrudes upward, reducing pressure on the posterior capsule and zonular ligament during polishing. This technique enables simultaneous polishing of the anterior capsule, equator, and part of the posterior capsule, enhancing safety and efficacy.

Our study demonstrates that, under the improved capsular polishing technique, the polishing group exhibited significantly better UDVA, UNVA (LogMAR), and MRSE values at both 1-week and 12-month follow-ups compared to the control group. Two previous meta-analyses reported the polishing groups also showed enhanced long-term

postoperative UDVA stability lasting from 1 to 3 a relative to the control group[23-24]. In our study, at 12 mo, the polishing group experienced less myopic shift (MRSE: −0.34±0.10 D in polishing group *vs* −0.47±0.09 D in controls, $P=0.004$), potentially reflecting improved capsular bag stability. This aligns with reports by Gao *et al*[22] and Wang *et al*[3] which indicate that polishing reduces intraocular ELP variability. The reduced myopic shift in the polishing group may indicate improved capsular bag stability, enhancing ELP predictability. Sachdev *et al*[25] evaluated the 1-year visual outcomes associated with varying degrees of traditional I/A polishing following FLACS. They found no significant difference in CDVA between the polished, semi-polished, and unpolished groups. Variations in results may stem from differences in tools and media used. Sachdev's study lacked detailed descriptions of the polishing process but noted that the traditional I/A polishing head has smooth, rounded edges with limited curvature, restricting its ability for 360° polishing, especially near the incision site[19]. In contrast, the double-ended capsular polishing device features a small, abrasive round head designed for comprehensive 360° polishing, including at the incision site. During I/A polishing, irrigation fluid serves as both a supporting agent and medium, whereas our technique uses OVD to enhance support and cushioning.

Our research findings indicate that, under a 4 mm pupil measurement, the polishing group exhibited significantly better visual quality during the 12-month postoperative period. A 4-mm pupil approximates typical daytime illumination and reflects real-world conditions. Normal adult pupil sizes range from 2 mm to 4 mm[26]. Pupils that are too small may be subject to diffraction effects, which can lead to a reduction in the light signal and consequently degrade the accuracy of image measurement results[27]. Larger pupils are linked to higher-order aberrations, which may degrade image quality[28]. A fixed pupil size reduces variability due to factors like age or light adaptation, improving repeatability. The visual quality of the polishing group exhibited a more stable trend, with some indicators even showing slight improvement, although these changes were not statistically significant (*e.g.*, OSI and HOA). This may be attributed to several factors: first, the polishing technique effectively removed LECs from the anterior capsule and equatorial region in the early postoperative period, thereby reducing light scattering caused by cell debris or inflammation. Second, the use of OVDs during polishing likely minimized mechanical damage to the capsular bag, further enhancing the smoothness of the optical interface. Third, after polishing, the capsular bag adhered more tightly to the IOL, reducing micro-displacements caused by capsular contraction and decreasing irregular aberrations such as CA and SA, which improved retinal imaging clarity. Additionally, the reduction in residual LECs lowered the risk of ACO and capsular bag contraction, preventing IOL decentration or tilt due to capsular shrinkage and maintaining long-term optical system stability[29-30]. The polishing group, through simultaneous treatment of the anterior capsule, equatorial region, and partial posterior capsule, may have slowed the migration of LECs toward the posterior capsule, thereby delaying the development of PCO. Of course, this remains a speculative assumption on our part and necessitates further substantiation through extended follow-up studies as well as meticulous morphological observations of PCO. A study by Zhu *et al*[31] from China showed that wavefront aberrations in the polishing group were significantly reduced at 6 mo postoperatively ($P<0.001$). This indicates that polishing effectively mitigated IOL decentration and tilt, thereby enhancing its positional stability. Nevertheless, further verification through extended follow-up observations remains essential to consolidate these conclusions.

Some scholars express reservations about the effectiveness of polishing in reducing the incidence and severity of ACO and PCO previously. An *ex vivo* study by Liu *et al*[4] revealed that anterior capsular polishing significantly removed a substantial quantity of LECs, yet it did not yield a decrease in residual cell proliferation. On the contrary, it resulted in an upsurge of cellular growth within the capsular bag cultures. In contrast to our study, the researchers assessed *ex vivo* ocular tissues, which precluded the evaluation of visual acuity and visual quality outcomes. Additionally, they utilized the conventional I/A polishing technique. Menapace *et al*[6] reported that while the incidence of fibrotic opacification was lowered, there was an unforeseen rise in the rate of regenerative PCO, with a considerable number of eyes in the study group necessitating Nd:YAG capsulotomy compared to the control eyes that did not undergo polishing, especially within 1 to 3 a after surgery. The distinction between this study and ours lies in: First, variations in the observation time may result in differences in the progression stages of capsular opacity. The study by Menapace *et al*[6] revealed that anterior capsular polishing may decrease adhesion between the anterior and posterior capsules, thereby facilitating LECs migration toward the posterior capsule. Consequently, during the 1- to 3-year follow-up period, while anterior capsular polishing effectively reduced fibrotic changes, it was associated with an increase in regenerative PCO, ultimately leading to a higher incidence of posterior capsulotomy. Previous studies also have indicated that PCO tends to develop within 2 to 5 a following cataract surgery[32]. In contrast, during the one-year observation period, our findings demonstrated that the polished group exhibited superior visual quality compared to the control group. Thus, there is also a need for extended follow-up observation over a longer timeframe. Second, differences in polishing techniques may explain these findings. Menapace *et al*[6] used the Menapace aspiration curette to target the posterior surface of the anterior LECs by scraping and aspirating simultaneously. Our study employed a double-

ended capsular polishing device for mechanical scraping on the posterior surface of the anterior capsule, equatorial region, and peripheral posterior capsule, potentially achieving higher efficiency.

We use FLACS to standardize the size of the anterior capsular opening, reducing impact on visual outcomes. This method ensures complete coverage of the IOL's optical surface, preventing PCO and resisting radial tension. It maintains refractive power stability, reduces off-axis effects, tilting, and high-order aberrations, while ensuring IOL stability and minimizing ELP deviation[33-34].

Previous studies reported a 15.8% PCO incidence for the 839MP IOL within 12 mo, with 3.3% requiring Nd:YAG capsulotomy, comparable to other IOL types[8]. The plate-haptic IOL exhibits superior capsular bag stability compared to other designs, while its incidence of PCO shows no significant difference when compared with C-loop and three-piece IOL[35-36]. In addition, a three-year study demonstrated that eyes implanted with the diffractive MIOL (AT LISA tri 839MP) were more likely to require Nd:YAG laser posterior capsulotomy than those implanted with refractive MIOL (SBL-3)[5]. Therefore, the material composition of IOLs, the design of the posterior surface, the angles between the optical zone and haptics, as well as the shape of the haptics, all exert complex influences on ACO, PCO, and IOL stability[37]. Future research should assess polishing effects across IOL designs to validate generalizability.

Diffractive multifocal IOLs achieve far, intermediate, and near vision through spectral separation[38-39]. Capsular opacification can cause light scattering and reduce image contrast, indicating a complex interaction between multifocal design and capsular opacification. The spectral effect of multifocal IOLs becomes apparent immediately after surgery, particularly in dark environments. It is characterized by a reduction in contrast sensitivity. However, this effect gradually diminishes as patients adapt to the IOL and typically does not compromise far, intermediate, or near vision. Previous studies have demonstrated that 839MP exhibits similar contrast sensitivity and visual quality compared with monofocal IOLs and bifocal IOLs but exhibit pupil dependence[40-41]. Optical interference caused by capsular opacification typically emerges after some time following surgery and affects vision similarly in bright and dark environments. The degree of opacification can be quantified using the OSI value from OQAS[42]. Our improved polishing technique effectively reduces scattering associated with capsular opacification, as evidenced by a reduction in OSI values. For patients with multifocal IOLs, maintaining capsule clarity is critical for achieving optimal visual outcomes. Future studies could further validate these results through morphological analysis and subjective questionnaires.

Our study is designed to refine the capsular polishing technique and preliminarily assess postoperative visual quality. However, as noted above, this study has certain limitations. Specifically, the 12-month follow-up duration may not be sufficiently extensive to comprehensively evaluate the long-term effects of polishing on LECs proliferation and PCO. Additionally, the singularity of the IOL utilized in this study might constrain the assessment of polishing efficacy. Furthermore, no morphological analysis, such as evaluation of posterior capsule opacification (EPCO), was implemented to facilitate a more intuitive evaluation of polishing effectiveness. Owing to the utilization of trifocal IOL, a control group without any capsular polishing intervention was not included in the study design. Therefore, in future investigations, it is imperative to consider extending the follow-up period, expanding the sample size, and incorporating diverse IOLs to enhance the generalizability and robustness of the research findings. The integration of intraoperative visualization systems [*e.g.*, optical coherence tomography (OCT)], postoperative morphological assessments, and subjective visual quality questionnaires could provide a more holistic and comprehensive evaluation framework.

In summary, this improved capsular polishing technique proves advantageous for stabilizing postoperative visual acuity and visual quality in patients who have undergone FLACS with plate-shaped trifocal artificial lenses during a 1-year follow-up period after surgery. Extended follow-up periods and comparative studies incorporating diverse IOL designs are warranted to validate these findings.

Conflicts of Interest: Dang GX, None; Zhou X, None; Wang CY, None; Li Y, None; Wu LA, None; Ma B, None.
Authors' contributions: Dang GX performed the data collection and the statistical analysis; Zhou X participated in the clinical and research protocol, performed the data collection, statistical analysis and drafted the manuscript; Wang CY, Li Y, Wu LA and Ma B participated in the design of the study, participated in the clinical and research protocol, performed the data collection, and critically revised the manuscript. All authors read and agreed to the published version of the manuscript.

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