Posterior chamber phakic intraocular lens implantation after laser in situ keratomileusis

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Abstract
Background: To assess the multicenter outcomes of posterior chamber phakic intraocular lens implantation with a central hole (EVO-ICL, STAAR Surgical) for patients undergoing previous laser in situ keratomileusis (LASIK).

Methods: This case series enrolled 31 eyes of 21 consecutive patients undergoing EVO-ICL implantation to correct residual refractive errors after LASIK at 7 nationwide major surgical sites. We investigated safety, efficacy, predictability, stability, and adverse events at 1 week, 1, 3, and 6 months postoperatively, and at the final visit.

Results: The mean observation period was 1.6 ± 1.8 years. Uncorrected and corrected visual acuities were −0.14 ± 0.11 and −0.22 ± 0.09 logMAR at 6 months postoperatively. At 6 months postoperatively, 81% and 100% of eyes were within ± 0.5 D and ± 1.0 D, respectively, of the targeted correction. We found neither significant manifest refraction changes of 0.05 ± 0.38 D from 1 week to 6 months nor apparent intraoperative or postoperative complications in any case.

Conclusions: Our multicenter study confirmed that the EVO-ICL provided good outcomes in safety, efficacy, predictability, and stability, even in post-LASIK eyes. Therefore, EVO-ICL implantation may be a viable surgical option, even for correcting residual refractive errors after LASIK.

Trial registration University Hospital Medical Information Network Clinical Trial Registry (000045295).

Keywords: EVO ICL, Phakic IOL, Safety, Efficacy, Predictability, Stability, Intraocular pressure, Endothelial cell density, LASIK

Background
Laser in situ keratomileusis (LASIK) has been extensively recognized as an effective and predictable surgical procedure for correcting refractive errors worldwide. However, myopic regression of the initial surgical effect can influence the efficacy, predictability, and long-term stability of this surgery leading to deterioration in visual performance and subsequent patient dissatisfaction. While the LASIK procedure is largely standardized with predictable and stable outcomes, attributable to improvisations in laser settings, nomograms, and sophisticated centration and eye-tracking systems, it is well-known that some regression does occur after LASIK surgery, especially when the amount of refractive correction is large [1–7]. We previously demonstrated that conventional LASIK offered outcomes with a high degree of safety throughout a 12-year follow-up period, and that most eyes showed some amount (approximately 10%) of refractive regression at 12 years after LASIK [7]. Although the exact mechanism for refractive regression remains unanswered, anterior corneal bulging, epithelial hyperplasia,
advantages over enhanced LASIK in terms of maintaining biomechanical integrity of the cornea, especially in eyes with a thin cornea requiring enhancement surgery, since ICL surgery requires no surgical tissue subtraction. Indeed, we found no significant changes in corneal biomechanical parameters following ICL implantation, not only in normal eyes but also in keratoconic eyes, suggesting that ICL surgery may be a safer surgical approach than enhanced LASIK from a biomechanical standpoint [17]. Nevertheless, there are only a few studies that report detailed outcomes of current EVO-ICL implantation to correct residual refractive errors, possibly due to the limited number of ICL surgeries in post-LASIK eyes. Accordingly, it may give us essential insights into further understanding the prognosis of these sequential surgical outcomes. The goal of this study was to retrospectively evaluate the clinical outcomes of current EVO-ICL implantation to correct residual refractive errors after LASIK in a large cohort of patients presenting at major surgical facilities in Japan. This multicenter study was performed under the auspices of the Japan ICL Study Group. To our knowledge, this is the first multicenter study as well as the largest case series to investigate the outcomes of modern ICL implantation in post-LASIK eyes.

**Methods**

**Study population**

We registered the study protocol with the University Hospital Medical Information Network Clinical Trial Registry (000045295). Patients who underwent implantation of the EVO-ICL for the correction of residual refractive errors after LASIK at 7 major nationwide institutions (Kitasato University Hospital, Sanno Hospital, Sapia Tower Eye Clinic Tokyo, Nagoya Eye Clinic, Chukyo Eye Clinic, Tane Memorial Eye Hospital, and Fujimoto Eye Clinic) from January 2016 to December 2020, and who completed a 6-month follow up, were enrolled consecutively. We included patients with unsatisfactory correction with spectacles or contact lenses, 20 ≤ age ≤ 50 years at the time of ICL surgery, stable refraction and corneal shape, anterior chamber depth (ACD) ≥ 2.8 mm, and endothelial cell density (ECD) ≥ 1800 cells/mm² for ICL implantation. We excluded patients with a previous history of ocular surgery, except for previous LASIK, corneal diseases, cataract, glaucoma, uveitis, or other concomitant eye diseases. The Institutional Review Board at Kitasato University Hospital approved this retrospective review of the clinical charts. The study adhered to the tenets of the Declaration of Helsinki and written informed consent was obtained for this surgery from all patients after explaining the possible consequences.

**Outcomes measures**

Preoperatively, at 1 week, at 3, and 6 months postoperatively, and in the last visit (spanning more than 6 months), we measured the logarithm of the minimal angle of resolution (logMAR) of uncorrected distance visual acuity (UDVA), corrected distance visual acuity (CDVA), the intraocular pressure (IOP) using a non-contact tonometer, the ECD (preoperatively and 6 months postoperatively) using a non-contact specular microscope, and the vault between the anterior surface of the crystalline lens and the posterior surface of the ICL using an anterior segment optical coherence tomograph, in addition to routinely conducted ophthalmic examinations. We grouped all available visit data according to the closest time point.

**ICL power calculation and size selection**

ICL size (12.1, 12.6, 13.2, and 13.7 mm) was determined mainly based on the manufacturer’s nomogram using the white-to-white (WTW) distance and the ACD measured with a scanning-slit light corneal tomograph or the anterior segment optical coherence tomograph. ICL power was selected using an online calculation and ordering system provided by the manufacturer based on a modified vertex formula [18, 19]. We principally selected the toric model ICL in eyes with manifest astigmatism of 1 diopter (D) or more and the non-toric model ICL in eyes with that of less than 1 D.

**Surgical procedures**

Details of the surgical techniques were described in our preceding reports [20–23]. In brief, we applied dilating and topical anesthetic agents on the day of surgery then implanted a model V4c or V5 ICL through a 3- to 3.2-mm temporal clear corneal incision after injection of a viscosurgical substance into the anterior chamber. Next, we inserted the ICL into the posterior chamber, replaced the viscosurgical substance with a balanced salt solution, and administered a miotic agent. We topicaly applied antibiotic and steroidal medications 4 times daily for 1 week, and reduced the dose gradually.
Statistical analysis
Normality of all data samples was checked using the Shapiro-Wilk test. Data that did not fulfill the criteria for normal distribution, were analyzed using the Wilcoxon-signed rank test to compare the pre- and post-surgical data between the two groups. The Kruskal-Wallis test was used to evaluate the time-course of changes, with the Steel-Dwass test employed for multiple comparisons. Unless otherwise indicated, the results are expressed as mean ± standard deviation, and a value of P < 0.05 was deemed statistically significant.

Results
Study population
A total of 31 eyes from 21 patients (11 of men and 20 of women) met the inclusion criteria of our study. The mean duration from LASIK to ICL surgery was 13.9 ± 4.1 years (range, 9.0 to 23.0 years). The mean observation period was 1.6 ± 1.8 years. Table 1 shows the preoperative baseline demographics of the study population following LASIK. The preoperative spherical and cylindrical refraction were −1.68 ± 0.86 D (range, −0.50 to −4.25 D) and 0.39 ± 0.49 D (range, 0 to 1.75 D), respectively. Five eyes (16%) and 2 eyes (6%) showed residual corneal thickness of 450 µm and 400 µm or less, respectively. Figure 1 shows the distributions of the spherical and cylindrical ICL power. Non-toric and toric ICL models were used in 28 eyes (90%) and 3 eyes (10%), respectively.

Safety and efficacy outcomes
At one week, 1, 3, and 6 months postoperatively, and at the last visit, 90%, 97%, 94%, 81% and 71% of eyes, and 68%, 66%, 74%, 74%, and 64% of eyes, respectively, had a UDVA of 20/20, and 20/16 or better (Fig. 2a). UDVA was −0.14 ± 0.11, −0.14 ± 0.09, −0.15 ± 0.12, −0.14 ± 0.11, and 0.00 ± 0.18 logMAR, at 1 week, 1, 3, and 6 months postoperatively, and at the last visit, respectively (Kruskal-Wallis test, P = 0.158). The 6-month postoperative UDVA was significantly better than the preoperative UDVA (P < 0.001). The efficacy index (mean postoperative UDVA/mean preoperative CDVA) was 0.57 ± 0.16 at 6 months postoperatively. At 6 months postoperatively, 28 eyes (90%) showed no change in CDVA, and 2 eyes (6%) gained 1 line, while 1 eye (3%) lost 1 line, but no eyes had lost more than 1 line (Fig. 2b). The 6-month postoperative CDVA was 0/16 in the eye that lost 1 line. CDVA was −0.22 ± 0.09, −0.22 ± 0.08, −0.22 ± 0.09, −0.17 ± 0.07 logMAR, at 1 week, 1, 3, and 6 months postoperatively, and at the last visit, respectively (P = 0.539). We found no significant difference between the preoperative CDVA and the 6-month postoperative CDVA (P = 0.477). The safety index (mean postoperative CDVA / mean preoperative CDVA) was 1.04 ± 0.17 at 6 months postoperatively.

Predictability and stability outcomes
A scatter plot of the attempted versus the achieved manifest spherical equivalent correction, distribution of spherical equivalent refractive accuracy, and distribution of refractive astigmatism are shown in Fig. 2c–e, respectively. At one week, 1, 3, and 6 months postoperatively, and the last visit, 90%, 97%, 94%, 81% and 71% of eyes, and 97%, 100%, 97%, 100%, and 86% of eyes were within ± 0.5 D and ± 1.0 D, respectively, of the attempted spherical equivalent correction.

| Characteristic                  | Mean ± standard deviation (95% CI, range) |
|---------------------------------|------------------------------------------|
| Age                             | 41.4 ± 7.1 years (95% CI 27.5 to 55.3 years, range 30 to 57 years) |
| Gender                          | Male: Female = 11: 20                      |
| Manifest spherical equivalent   | −1.87 ± 0.91 D (95% CI −3.65 to −0.09 D, range −4.75 to −0.75 D) |
| Manifest cylinder               | −0.39 ± 0.49 D (95% CI 0.57 to −1.35 D, range 0 to −1.75 D) |
| UDVA                            | 0.51 ± 0.28 logMAR (95% CI 0.16 to 0.94 logMAR, range 0.00 to 1.00 logMAR) |
| CDVA                            | −0.21 ± 0.10 logMAR (95% CI −0.41 to −0.01 logMAR, range 0.10 to −0.30 logMAR) |
| White-to-white distance         | 11.7 ± 0.5 mm (95% CI 10.72 to 12.68 mm, range 10.8 to 12.8 mm) |
| Anterior chamber depth          | 3.12 ± 0.27 mm (95% CI 2.59 to 3.65 mm, range 2.80 to 3.72 mm) |
| Mean keratometric readings      | 39.27 ± 1.37 D (95% CI 36.58 to 41.96 D, range 34.97 to 41.75 D) |
| ICL size                        | 12.1 mm, 13 eyes (42%), 12.6 mm, 7 eyes (35%), and 13.2 mm, 7 eyes (23%) |
| ICL spherical power             | −2.38 ± 0.03 D (95% CI −4.39 to −0.37 D, range −5.00 to −1.00 D) |
| ICL cylindrical power           | 1.38 ± 0.48 D (95% CI 0.44 to 2.31 D, range 1.00 to 2.00 D) |

ICL = implantable collamer lens; CI = confidence interval; D = diopter; LogMAR = logarithm of the minimal angle of resolution; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity
The time-course change in the manifest spherical equivalent is shown in Fig. 2f. At one week, 1, 3, and 6 months postoperatively, and at the last visit, the manifest spherical equivalent was $-0.25 \pm 0.28$, $-0.15 \pm 0.27$, $-0.07 \pm 0.38$, $-0.20 \pm 0.35$, and $-0.20 \pm 0.35$ D, respectively ($P = 0.076$). Changes in manifest spherical equivalent refraction from 1 week to 6 months were $0.05 \pm 0.38$ D.

**Intraocular Pressure**

The IOP was $10.5 \pm 1.9$, $10.3 \pm 1.9$, $10.0 \pm 1.8$, $10.0 \pm 2.4$, and $9.8 \pm 2.3$ mmHg, at 1 week, and 1, 3, and 6 months postoperatively, and the last visit, respectively ($P = 0.576$). No significant increase in the IOP (> 25 mmHg) occurred in any case throughout the observation period.

**Endothelial Cell Density**

The ECD did not change significantly, from $2697 \pm 231$ cells/mm$^2$ preoperatively to $2701 \pm 226$ cells/mm$^2$ at 6 months postoperatively ($P = 0.554$). Thus, the mean percentage of endothelial cell loss was $-0.4 \pm 6.3\%$ at 6 months postoperatively.

**Vault**

The ICL vault was $354 \pm 178$, $327 \pm 162$, $292 \pm 150$, $281 \pm 152$, and $187 \pm 86$ µm, at 1 week, and 1, 3, and 6 months postoperatively, and the last visit, respectively ($P = 0.079$). Figure 3 shows the postoperative distribution of the ICL vault. Neither excessive-low vault (<45 µm) nor excessive-high vault (>1000 µm) requiring ICL exchange was found in any case.

**Secondary surgeries / adverse events**

We found no obvious intraoperative complications, such as an upside-down ICL insertion or traumatic cataract formation. We observed mild glare or halo in all eyes, especially at night in the early postoperative period, but no definite postoperative complications, such as symptomatic or asymptomatic cataract formation, pigment dispersion glaucoma, pupillary block, severe symptomatic glare or halos, retinal detachment, ICL re-rotation, ICL exchange, or significant endothelial cell loss (≥15%), throughout the follow-up period were noted in this series.

**Discussion**

According to our experience, modern EVO-ICL surgery performed well in safety, efficacy, predictability, and stability, even correcting residual refractive errors in post-LASIK eyes. In addition, no obvious intraoperative or postoperative complications were noted in any subject. Therefore, ICL implantation may be one of the feasible surgical options to correct residual refractive errors after LASIK surgery. This information will be clinically helpful.
Fig. 2  Standard graphs for reporting refractive surgery outcomes. a Cumulative percentages of eyes attaining specified cumulative levels of uncorrected distance visual acuity (UDVA); b Changes in corrected distance visual acuity (CDVA); c A scatter plot of the attempted versus the achieved manifest spherical equivalent correction; d Distribution of spherical equivalent refractive accuracy; e Distribution of refractive astigmatism; f Time course of changes in the manifest spherical equivalent
for the prognosis of these sequential approaches for correcting residual refractive errors after LASIK.

Table 2 shows a summary of the outcomes of ICL surgery following corneal-based refractive surgery. Until now, there have been only a few case reports [24–26] and a few case series on the outcomes of ICL implantation following corneal refractive surgery [27–29]. It has been demonstrated, in case reports, that ICL implantation was beneficial for correcting residual refractive errors following radial keratotomy (RK) [24, 25] and hyperopic LASIK [26]. Chen et al. showed in a case series of 19 eyes of 12 patients undergoing ICL implantation after corneal refractive surgery, that UDVA and CDVA at the last visit were 0.64±0.24 and 0.79±0.24, respectively, and that 52.63% and 73.68% of eyes were within ±0.5 D and ±1.0 D of the predicted spherical equivalents, respectively [27]. Alfonso et al. described, in a study of 20 eyes undergoing excimer laser surgery or RK following cataract surgery, that the efficacy and safety indices were 0.98 and 1.13 after excimer laser ablation, 1.04 and 1.14 after RK, and that the virgin cornea, excimer laser, and RK groups showed better predictability and accuracy, with 96.2% spherical equivalent within ±1.0 D [28]. Moshirfar et al. recently reported, in a study of 13 eyes of 7 patients undergoing ICL implantation after LASIK or PRK, that the efficacy and safety indices were 0.99±0.42 and 1.15±0.38, respectively, at 1 year postoperatively [29]. Our findings were in good agreement with all previous results of ICL surgery in post-corneal refractive surgery eyes. Although the possible risk of complications such as cataract formation and the subsequent prognosis were decreased by the introduction of lens models incorporating a central port (such as the V4c and V5 models) [30], a further long-term follow-up is still necessary to confirm these findings. Pérez-Vives et al. simulated visual quality using an adaptive optics visual simulator, showing that ICL surgery is one of the favorable alternatives to correct myopic residual errors after LASIK, especially for high myopia [31]. Hence, ICL implantation can be viable treatment alternatives to correct residual refractive errors in post-LASIK eyes, especially when the residual corneal thickness is insufficient for the enhanced ablation.

This study has several limitations. Firstly, we performed this study in a retrospective fashion. Although this is a multicenter study in a successive cohort of post-LASIK patients undergoing ICL implantation, a prospective randomized controlled study would be better to obtain robust outcomes. Secondly, the sample size was relatively small, possibly due to the limited number of general ICL surgeries in post-LASIK eyes; this was one of our motivations in performing a multicenter study under the auspices of the Japan ICL Study Group. It should be noted that this is also the largest case series to assess the ICL surgical outcomes in post-LASIK patients. A multicenter study may reflect the actual status more accurately than a single-center study because the former may be less influenced by their individual surgical skills and experiences than the latter. Thirdly, the follow-up period was limited. A prolonged observation is still necessary to confirm the long-term outcomes in this study population. Fourthly, we included both eyes of the same patient undergoing ICL implantation following LASIK. However, we obtained similar outcomes when only one eye was chosen randomly from each patient (Additional file 1: Fig. S1). Hence, we enrolled both eyes when applying for this analysis, which was not uncommon for most published studies on refractive surgery considering that the number of patients undergoing ICL surgery after LASIK is limited. Fifthly, we did not perform dilation to check the degree of toric ICL rotation as the postoperative UDVA was excellent. Therefore, this study has no data on toric lens stability.

Conclusions

In conclusion, our multicenter study showed that the current EVO-ICL provided good outcomes for correcting residual refractive errors in post-LASIK eyes without significant complications throughout the follow-up period. Our findings support the view that current ICL implantation is one of the feasible surgical options for correcting residual refractive errors after LASIK. However, we should be aware that the cost-effectiveness and the long-term outcomes of ICL surgery remain to be answered; additional prolonged careful follow-up in a large cohort of post-LASIK patients will be necessary to clarify these points.
Table 2 Summary for the outcomes of implantable collamer lens (ICL) implantation following laser in situ keratomileusis (LASIK)

| Author          | Year  | Type                  | Previous surgery | Period (months) | Eyes | Age (years) | MSE (D)   | UDVA                  | CDVA                  | Within ± 0.5 D | Within ± 1.0 D | Complications |
|-----------------|-------|-----------------------|------------------|----------------|------|-------------|-----------|-----------------------|-----------------------|---------------|---------------|---------------|
| Srinivasan et al. [24] | 2008  | V3 (non-hole)         | RK               | 3 to 7         | 4    | 33 to 45    | +5.31     | 20/24                  | 20/24                  | 100%          | 100%          | None          |
| Kamiya et al. [25]       | 2008  | V4 (non-hole)         | RK               | 12             | 1    | 49          | +1.75     | 0.8 decimal           | 1.2 decimal           | 100%          | 100%          | None          |
| Kamiya et al. [26]       | 2010  | V4 (non-hole) with LRIs | LASIK            | 10             | 1    | 48          | +1.75     | 1.0 decimal           | 1.2 decimal           | 100%          | 100%          | None          |
| Chen et al. [27]         | 2016  | V4 (non-hole)         | RK, PRK, LASIK, TOGCA, LASEK | 39.05 ± 19.22  | 19   | 37.54 ± 7.59 | −4.45 ± 3.36 | −1.23 ± 1.18 sphere −1.02 ± 1.37 cylinder | 0.61 ± 0.24 decimal | 0.68 ± 0.13 decimal | 52.63%        | 73.68%        | 1 eye cataract RD |
| Alfonso et al. [28]      | 2018  | V3 to V5 (non-hole and hole after IOL implantation) | LASIK, PRK | 19.02 ± 22.98 | 12   | 59.34 ± 11.44 | −1.23 ± 1.18 sphere −1.02 ± 1.37 cylinder | 0.73 ± 0.19 decimal | 0.78 ± 0.16 decimal | 91.7%         | 91.7%         | None          |
| Moshirfar et al. [29]    | 2020  | N.A (non-hole)        | LASIK, PRK       | 12             | 13   | 33.7        | −12.42 ± 1.81 | 0.99 ± 0.42 efficacy index | 5.0 ± 0.05 safety index | 7 eyes (100%) | 7 eyes (100%) | None          |
| Current                   |       | V4c, V5 (hole) | LASIK            | 6              | 31   | 41.4 ± 7.1  | −1.87 ± 0.91 | −0.14 ± 0.11 logMAR | −0.22 ± 0.09 logMAR | 81%           | 100%          | None          |

MSE = manifest spherical equivalent; D = diopter; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; RK = radial keratotomy; LRIs = limbal relaxing incisions; LASIK = laser-assisted in situ keratomileusis; logMAR = logarithm of the minimal angle of resolution; TOGCA = topography-guided customized ablation; LASEK = laser-assisted subepithelial keratomileusis; RD = retinal detachment; IOL = intraocular lens
Abbreviations
LASIK: Laser in situ keratomileusis; ICL: Implantable collamer lens; ACD: Anterior chamber depth; ECD: Endothelial cell density; logMAR: Logarithm of the minimal angle of resolution; UDVA: Uncorrected distance visual acuity; CDVA: Corrected distance visual acuity; MSE: Manifest spherical equivalent; IOP: Intraocular pressure; D: Diopter; ANOVA: Analysis of variance.

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s40662-022-00282-6.

Additional file 1: Figure S1. Standard graphs for reporting refractive surgery outcomes when only one eye was chosen randomly from each patient. a Cumulative percentages of eyes attaining specified cumulative levels of uncorrected distance visual acuity (UDVA); b Changes in corrected distance visual acuity (CDVA); c A scatter plot of the attempted versus the achieved manifest spherical equivalent correction; d Distribution of spherical equivalent refractive accuracy; e Distribution of refractive astigmatism; f Time course of changes in the manifest spherical equivalent.

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Authors’ contributions
KK, KS, and AI were involved in the design and conduct of the study. KK, AI, KY, TK, TN, KI, SF, and KF were involved in the collection, management, analysis, and interpretation of data, and all authors were involved in preparing the review. All authors read and approved the final manuscript.

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Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations
Ethics approval and consent to participate
This retrospective review of the clinical charts was approved by the Institutional Review Board of Kitasato University Hospital and adhered to the tenets of the Declaration of Helsinki. The Institutional Review Board waived the requirement for informed consent for this retrospective study.

Consent for publication
Not applicable.

Competing interests
Kimiya Shimizu and Yoishiro Kitazawa are paid consultants for STAAR Surgical. Kazutaka Kamiya, Akihito Igarashi, Takashi Kojima, Tomoaki Nakamura, Kazuo Ichikawa, Sachiko Fukuoka, and Kahoko Fujimoto, declare that they have no conflict of interest related to this work.

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References
1. Knorz MC, Liermann A, Seibert V, Steiner H, Wiesinger B. Laser in situ keratomileusis to correct myopia of −6.00 to −29.00 diopters. J Refract Surg. 1996;12(5):575–84.
2. Pérez-Santana JJ, Bellot J, Clarosmonte P, Ismail MM, Alió J, Laser in situ keratomileusis to correct high myopia. J Cataract Refract Surg. 1997;23(3):372–85.
3. Lohmann CP, Guell JL. Regression after LASIK for the treatment of myopia: the role of the corneal epithelium. Semin Ophthalmol. 1998;13(1):79–82.
4. Chayet AS, Assl KK, Montes M, Esposanto-Lasaia M, Schreffler A. Tisloius G. Regression and its mechanisms after laser assisted keratomileusis in moderate and high myopia. Ophthalmology. 1998;105:1194–9.
5. Hersh PS, Brint SF, Maloney RK, Durie D, Gordon N, Michelson MA, et al. Photorefractive keratometry versus laser assisted keratomileusis for moderate to high myopia. A randomized prospective study. Ophthalmology. 1998;105(8):1512–22.
6. Magallanes R, Shah S, Zadok D, Chayet AS, Assl KK, Montes M, et al. Stability after laser in situ keratomileusis in moderately and extremely myopic eyes. J Cataract Refract Surg. 2001;27(7):1007–12.
7. Ikeda T, Shimasaki M, Oguchi A, Kasahara S, Kamiya K. Twelve-year follow-up of laser in situ keratomileusis for moderate to high myopia. Biomed Res Int. 2017;2017:939147.
8. Miyata T, Shimizu K, Nakashashi T, Tanabe T, Tokunaga T, Amano S, et al. Time course of change in corneal forward shift after excimer laser photorefractive keratectomy. Arch Ophthalmol. 2002;120(7):896–900.
9. Kamiya K, Ohshika T. Corneal forward shift after excimer laser keratorefractive surgery. Semin Ophthalmol. 2003;18(1):17–22.
10. Kamiya K, Ohshika T, Amano S, Takahashi T, Tokunaga T, Miyata K. Influence of excimer laser photorefractive keractomy on the posterior corneal surface. J Cataract Refract Surg. 2000;26(6):867–71.
11. Gauthier CA, Holden BA, Epstein D, Tengroth B, Fagerholm P, Hamberg-Nystrom H. Role of epithelial hyperplasia in regression following photorefractive keractomy. Br J Ophthalmol. 1996;80(6):545–8.
12. Gauthier CA, Holden BA, Epstein D, Tengroth B, Fagerholm P, Hamberg-Nystrom H. Factors affecting epithelial hyperplasia after photorefractive keractomy. J Cataract Refract Surg. 1997;23(7):1042–50.
13. Moller-Pedersen T, Li HF, Petroll WM, Cavanagh HD, Jester JV. Confocal microscopic characterization of wound repair after photorefractive keractomy. Invest Ophthalmol Vis Sci. 1998;39(3):487–501.
14. Lohmann CP, Reischl U, Marshall J. Regression and epithelial hyperplasia after myopic photorefractive keractomy in a human cornea. J Cataract Refract Surg. 1999;25(5):712–5.
15. Park CK, Kim JH. Comparison of wound healing after photorefractive keractomy and laser in situ keratomileusis in rabbits. J Cataract Refract Surg. 1999;25(6):842–50.
16. Moller-Pedersen T, Cavanagh HD, Petroll WM, Jester JV. Stromal wound healing explains refractive instability and haze development after photorefractive keractomy: a 1-year confocal microscopic study. Ophthalmology. 2000;107(7):1235–45.
17. Ali M, Kamiya K, Shimizu K, Igarashi A, Ishii R. Clinical evaluation of corneal biomechanical parameters after posterior chamber phakic intraocular lens implantation. Cornea. 2014;33(5):470–4.
18. Sanders DR, Vukich JA, Gaston M; Implantable Contact Lens in Treatment of Myopia Study Group. U.S. Food and Drug Administration clinical trial of the Implantable Contact Lens for moderate to high myopia. Ophthalmology. 2003;110(2):255–66.
19. Sanders DR, Doney K, Poco M; ICL in Treatment of Myopia Study Group. United States Food and Drug Administration clinical trial of the Implantable Collamer Lens (ICL) for moderate to high myopia: three-year follow-up. Ophthalmology. 2004;111(9):1683–92.
20. Shimizu K, Kamiya K, Igarashi A, Shintani T. Early clinical outcomes of implantation of posterior chamber phakic intraocular lens with a central hole (Hole ICL) for moderate to high myopia. Br J Ophthalmol. 2012;96(3):409–12.
21. Shimizu K, Kamiya K, Igarashi A, Shintani T. Intraindividual comparison of visual performance after posterior chamber phakic intraocular lens with and without a central hole implantation for moderate to high myopia. Am J Ophthalmol. 2012;154(3):486–94.
22. Shimizu K, Kamiya K, Igarashi A, Kobashi H. Long-term comparison of posterior chamber phakic intraocular lens with and without a central hole (Hole ICL and Conventional ICL) implantation for moderate to high myopia.
myopia and myopic astigmatism: consort-compliant article. Medicine (Baltimore). 2016;95(14):e3270.
23. Kamiya K, Shimizu K, Igarashi A, Kitazawa Y, Kojima T, Nakamura T, et al. Posterior chamber phakic intraocular lens implantation: comparative, multicentre study in 351 eyes with low-to-moderate or high myopia. Br J Ophthalmol. 2018;102(2):177–81.
24. Srinivasan S, Drake A, Herzig S. Early experience with implantable collamer lens in the management of hyperopia after radial keratotomy. Cornea. 2008;27(3):302–4.
25. Kamiya K, Shimizu K. Implantable Collamer lens for hyperopia after radial keratotomy. J Cataract Refract Surg. 2008;34(8):1403–4.
26. Kamiya K, Shimizu K, Komatsu M. Implantable Collamer Lens implantation and limbal relaxing incisions for the correction of hyperopic astigmatism after laser in situ keratomileusis. Cornea. 2010;29(1):99–101.
27. Chen X, Wang XY, Zhang X, Chen Z, Zhou XT. Implantable collamer lens for residual refractive error after corneal refractive surgery. Int J Ophthalmol. 2016;9(10):1421–6.
28. Alfonso JF, Lisa C, Alfonso-Bartolozzi B, Fernández-Vega-Cueto L, Montés-Mico R. Implantable Collamer Lens® for management of pseudophakic ametropia in eyes with a spectrum of previous corneal surgery. J Refract Surg. 2018;34(10):654–63.
29. Moshirfar M, Thomson RJ, West Jnr WB, McCabe SE, Sant TM, Shmunes MH, et al. Visual outcomes after sequential posterior chamber phakic IOL with corneal refractive surgery (bioptics) for the treatment of myopic astigmatism. Clin Ophthalmol. 2020;14:4337–46.
30. Packer M. The Implantable Collamer Lens with a central port: review of the literature. Clin Ophthalmol. 2018;12:2427–38.
31. Pérez-Vives C, Belda-Salmerón L, García-Lázaro S, Ferrer-Blasco T, Montés-Mico R. Optical and visual simulation of standard and modified spherical aberration implantable collamer lens post myopic LASIK surgery. J Refract Surg. 2014;30(5):330–7.