Assessment of Biosafety and Implantation Feasibility of Novel Phakic Refractive Lens

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Abstract

Purpose: To investigate the biosafety and implantation feasibility of newly developed phakic refractive lens (PRL) in rabbit eyes.

Methods: The PRLs, including short PRL (S-PRL), large PRL (L-PRL), and large grooved PRL (LG-PRL), were prepared by molding liquid medical silicon. The in vitro cytotoxicity of the above PRLs was evaluated by incubating them with human lens epithelial cells (HLECs) and then measuring cell viability by CCK-8 assay. In vitro cell adhesion of PRLs was assessed by culturing HLECs on PRL film surface and calculating the cell number and average cell area after stained with Calcein-AM and fluorescent. The implantation feasibility was appraised by observing the relative positions of S-PRL, L-PRL or LG-PRL implanted in the posterior chamber of rabbit eyes by optical coherence tomography, and calculating their retention ratio postoperatively. The intraocular pressure (IOP) of S-PRL, L-PRL, LG-PRL and control groups of rabbit eyes was compared to evaluate the biosafety of implantation.

Results: The results of in vitro cytotoxicity showed no significant difference of cell viability was observed in the S-PRL, L-PRL or LG-PRL groups compared to the control group throughout the whole experiment. The HLECs cultured on the PRL film surface presented similar cell number, but smaller average cell area (53.8% vs 100%) when compared to the control group, which implied obvious adhesion inhibition on HLECs caused by PRL film. After implantation of S-PRL, L-PRL or LG-PRL into the posterior chamber of rabbit eyes, no obvious inflammation and IOP elevation were observed at each time point in all sample groups compared to the control group, which indicated that PRL samples had good implantation biosafety. Most of the implanted L-PRL and LG-PRL kept in the correct location, while only less of the S-PRL was at the right site. That was, L-PRL and LG-PRL had proper relative position and high retention ratio in the posterior chamber of rabbit eyes. L-PRL and S-PRL samples tended to attach to iris surface, while LG-PRL sample constructed enough space on the iris surface by its grooves surrounding the central optical zone, which was conducive to circulation of aqueous humor.

Conclusions: The newly developed LG-PRL sample presented good biosafety in terms of the negligible in vitro cytotoxicity, ocular inflammation and IOP fluctuations. The LG-PRL provided the best implantation feasibility due to the more proper relative position, available space for aqueous humor circulation, and high retention ratio in the posterior chamber of rabbit eyes among the three kinds of PRL samples. Thus, LG-PRL is a promising alternative with appropriate size and surface structure to more effectively correct refractive errors.

1. Introduction

Myopia is one of the most common eye diseases worldwide^[1], with a prevalence of 10-30% in the adult population in many countries and 80–90% in young adults in some parts of East and Southeast Asia^[2]. Myopia, an error of visual focusing, makes distant objects appear blurred, not just imposes refractive ramifications but poses a serious risk for ocular complications, such as cataract formation, glaucoma,

myopic foveoschisis, retinal detachment, macular hole, choroidal/scleral thinning, myopic choroidal neovascularization^[3, 4], resulting in irreversible vision loss later in life. As a kind of avoidable blindness, myopia has become a global public health and socio-economic problems predominantly in East Asia^[5]. The epidemiology and pathophysiology of myopia and high myopia largely remain undiscovered^[6]. Optical interventions, pharmaceutical and behavioral modifications are studied to retard myopia onset and progression^[7], in which optical interventions are most popular, including spectacles, contact lens, corneal laser refractive surgery, refractive lens exchange and phakic intraocular lens (pIOL) implantation^[8].

Corneal laser refractive surgery is widely accepted by patients because it is clearly effective and convenient^[9], such as laser-assisted subepithelial keratectomy, laser in situ keratomileusis and photorefractive keratectomy. The goal of refractive surgery is to create a safe, stable and ideal state of refraction which does not cause new optical problems. However, it is not recommended in myopic patients with limited corneal thickness and highly myopic patients without sufficient residual stromal bed thickness^[10], which avoids poor quality of vision in scotopic condition^[11], low predictability^[12] and corneal ectasia^[13]. Fortunately, pIOLs implantation can preserve accommodative function and has great appeal to both surgeons and young patients^[14]. The pIOLs can be classified into three categories depending on their implant site in eyes, including anterior chamber angle-supported pIOL, anterior chamber iris-fixated pIOL, and posterior chamber pIOL^[15]. To date, only two kinds of posterior chamber pIOLs are available, respectively the implantable collamer lens (ICL) and phakic refractive lens (PRL). ICL surgery is currently the most widely used posterior chamber refractive treatment method and it's proven to be safe and effective^[16]. As a supplement, laser iridotomies or a surgical iridectomy is often used to preserve aqueous flow from the posterior to the anterior chamber, which increases treatment period, costs and risk of complications^[17]. To address this issue, a kind of centrally perforated ICL (Hole-ICL) has been developed to improve aqueous humor drainage, which showed good implantation safety and efficacy, and made iridectomy surgery less necessary^[18]. On the other side, PRL has also been developed to the third generation product, which is made of hydrophobic silicon and has the same density with aqueous humor^[19]. PRL suspends in the space between iris and lens^[19], and no pressure is applied to the ciliary structure or the anterior surface of crystalline lens. However, the PRL implantation still causes some complications, such as pigmentary glaucoma, secondary cataract, postsurgical flare and traumatic aniridia^[19], which may be related with the design shape and implantation location of PRLs.

Therefore, we designed and prepared a novel PRL with grooves surrounding the central optical zone (large and grooved PRL, LG-PRL) to improve aqueous humor drainage and decrease ocular complications. The PRL was implanted in the posterior chamber and occupied the slit potential space between the posterior surface of iris and the anterior surface of the crystalline lens. The schematic description of PRL samples and implantation location is shown in Figure 1. In order to investigate the biosafety and implantation feasibility of newly developed LG-PRL in rabbit eyes, another two kinds of PRLs, including short PRL (S-PRL) and large PRL (L-PRL) were also prepared. The biosafety of PRL

samples was assessed in terms of the in vitro cytotoxicity, in vivo ocular inflammation and IOP fluctuations. Their implantation feasibility was evaluated by observing the relative position, available space for circulation of aqueous humor, and the retention ratio in the posterior chamber of rabbit eyes.

2. Materials And Methods

2.1. Materials

Three kinds of PRLs, S-PRL with length of 12.3mm (short), L-PRL with length of 13.3mm (large) and LG-PRL with length of 13.3mm (large) and grooves surrounding the central optical zone, were designed and prepared with different parameters for comparative study. All PRL samples were sterilized by UV irradiation at 254 nm for 40 mins. Eagle's minimum essential media (EMEM) and fetal bovine serum (FBS) were supplied by Scientific Lab (Shanghai, China). Penicillin (100 units/mL) and streptomycin (0.1 mg/mL) were bought from Sigma Aldrich Co., Ltd (Shanghai, China). A CCK-8 Kit was bought from Dojindo Co., Ltd (Shanghai, China). All other chemicals were used in analytical grade without further purification. Other chemicals, drugs or materials included ofloxacin eye ointment (Shenyang Sinqi, China), Rinderon (0.1% betamethasone; Shionogi, Osaka, Japan), Cravit (0.5% levofloxacin; Santen, Osaka, Japan), topicamide eye drops (Alcon, China), oxybucaine hydrochloride eye drops (Santan, China) and pilocarpine eye drops (Bausch, China).

2.2 Characterization of PRL samples

Optical photos of the S-PRL, L-PRL and LG-PRL were taken with a digital camera (CANON EOS 60D; Tokyo, Japan). The transparency of PRL samples was examined by a UV-vis spectrophotometer (Biomate 3S, Thermo Scientific) within scanning wavelengths range of 250-800 nm.

2.3 In vitro cytotoxicity and cell adhesion

Human lens epithelial cell line (HLEC, SRA01/04) was obtained from Shanghai Genechem (Genechem Incorporation, Shanghai, China). HLECs were cultured in EMEM supplemented with FBS (10%), penicillin (100 units/mL) and streptomycin (0.1 mg/mL). The cells were incubated at 37°C in a humidified atmosphere of 5% CO₂. HLECs were seeded into 24-well plates at a density of 1×10⁵ cells per well and then incubated at 37°C for 24 h. The PRL sample was placed in the transwell and co-incubated with HLECs for another 24 h or 48 h. CCK-8 kit was used for the evaluation of the in vitro cytotoxicity. Absorbance at 450 nm was measured using a microplate reader (BioTek microplate reader, USA). Results are showed as the percentage of cell viability in comparison with the Ctrl group (24-well plates).

For cell adhesion test, the PRL film with a diameter of 1.5 mm was placed into 24-well plates and fixed with a polytetrafluoroethylene ring. HLECs were seeded into the above 24-well plates with the PRL film at a density of 1×10⁵ cells per well. Then the 24-well plates were incubated at 37°C for 24 or 48 h. The HLECs adhered on PRL film surface were stained by Calcein-AM and fluorescent images were acquired by a fluorescent microscopy.

2.4 Intraocular implantation of PRL samples

New Zealand white rabbits (male, 2.5 kg) were housed individually in a light-controlled room at $20 \pm 1^\circ\text{C}$ with no restriction of food and water intake. All animal experiments were approved by the Animal Ethics Committee of the Eye & ENT Hospital of Fudan University (China), and conformed to the ARVO Statement on the Use of Animals in Research.

Topiramide eye drops (Alcon, China) and oxybucaine hydrochloride eye drops (Santan, China) were topically administrated before surgery. After a viscosurgical device (OVD; Opegan; Santen, Osaka, Japan) was placed into the anterior chamber, S-PRL, L-PRL or LG-PRL was implanted in the posterior chamber through a 3 mm clear corneal incision using an injector cartridge. The OVD was washed out by a balanced salt solution, and pilocarpine eye drops (Bausch, China) were topically administrated. Postoperatively, Rinderon and Cravit medications were topically administered four times daily for 2 weeks. All surgeries were performed by the same experienced surgeon. All rabbit eyes underwent slit-lamp biomicroscopic examination before surgery and at day 1, 3, 5, 7, 10, and 15 postoperatively. IOP was measured by a handheld digital tonometer (Tonopen XL; Norwell, USA) under general and local anesthesia as described above. Ocular inflammation reaction and the relative location of PRLs were observed by normal and slit lamp modes at day 1, 3, 5, 7, 10 and 15. The relative positions of S-PRL, L-PRL or LG-PRL implanted in the posterior chamber were confirmed by an optical coherence tomography (OCT).

2.6. Statistical Analysis

All experiments were conducted in triplicate, and data were expressed as mean $\pm$ SD. An independent sample t-test was used for data analyses in the In vitro cytotoxicity and cell adhesion on PRL samples; one-way ANOVA was conducted for the statistical analysis of IOP value in different PRL samples. The chi-squared test was used for statistical comparisons of the retention ratio of implanted PRLs. Statistically significant difference was defined at a confidence level of 95% (* $p < 0.05$).

3. Results

3.1 Characterization of PRL samples

The S-PRL, L-PRL and LG-PRL were prepared by molding liquid medical-grade silicon, and the representative photos are shown in Figure 2A-C.

Figure 2D shows the light transmittance curve of the PRL. Visible light transmittance through the PRL optic column was more than 90% in the wavelength ranging of 500-700 nm, which was consistent with the similar measurements in the previous report^[20] and approximated that of the natural cornea^[21]. Under UV light with wavelengths ranging of 350-400 nm, the PRL optic column showed somewhat blocking ability to UV damage to internal eye tissue.

3.2 In vitro cell cytotoxicity and cell adhesion

The in vitro cytotoxicity of PRL samples on HLECs was investigated and cell viability was measured by CCK-8. The results are shown in Figure 3A. The cell viability of HLECs co-cultured with the PRL sample for 24 or 48 h had no significant difference with that in the Ctrl group (24-well plates).

The results of HLEC adhesion on the PRL film surface and the Ctrl (24-well plate) are shown in Figure 3B-E. The HLECs exhibited typical epithelial-like, cobblestone-like shape, long spindle-like cellular extensions and good spreading on the 24-well plate surfaces (Figure 3B). Whereas, HLECs showed small-aggregated and less cellular extensions on the PRL film surface which was different from those on the 24-well plate surfaces. Cell number and average cell area were calculated to describe HLEC adhesion ability on PRL surfaces. Cell number adhered on PRL surface was similar to that on the Ctrl surface (Figure 3D). However, the average cell area in the PRL group was smaller than that in the Ctrl group (53.8% vs 100%, $p < 0.05$, Figure 3E). This might result from the weaker adhesion ability of HLECs on soft PRL film surface which was supported by the previous report^[22].

3.4 Intraocular implantation of PRL samples

After intraocular implantation of three kinds of PRLs in rabbit eyes, ocular inflammation reaction and the relative location of PRL samples were observed, and the representative photos of ocular surfaces (column 1, 4 and 7), anterior chamber (column 2, 5 and 8) and posterior chamber (column 3, 6 and 9) are shown in Figure 4. Anterior chamber inflammation was visible at day 1 and 3 postoperative in all groups, and then the inflammation subsided after 5 day in all groups. No serious complications, such as corneal opacity, keratopathy, or posterior synechia, were observed over 15 days.

As shown in Figure 5A, all implanted S-PRLs were located in the posterior chamber of the rabbit eye at day 1. Then one S-PRL prolapsed into the anterior chamber and displayed a dislocation postoperatively at day 3, then two S-PRL dislocated at day 7, and another one dislocated at day 10 and 15, respectively. The retention ratio of S-PRL is approximately 16.7% until the final observation time point (day 15). All implanted L-PRLs were centered and stably located in the posterior chamber of the rabbit eye, and its retention ratio was 100%. Unfortunately, one LG-PRL sample dislocated at day 10 postoperatively which led to 87.5% retention rate in the LG-PRL group. Furthermore, the relative positions of S-PRL, L-PRL and LG-PRL implanted in the posterior chamber of the rabbit eye were also confirmed by OCT and the results are shown in Figure 5B. The implanted L-PRL and S-PRL samples were located in the posterior chamber and attached to the iris surface. However, the LG-PRL located in the posterior chamber still kept some gaps from the iris surface by its grooves surrounding the central optical zone, which constructed available spaces and provided an effective drainage channel of aqueous humor from posterior chamber to anterior chamber.

IOP was also periodically measured during the whole experimental period and the results are shown in Figure 6. The IOP change was just used as a rough reference index in the present normotensive IOP model. The normal rabbit eyes (Ctrl group) had a relatively stable IOP (~11 mmHg) which was set as a baseline. The Δ IOP is expressed as a difference of IOP values between the baseline and those in the PRL groups. The Δ IOP in all groups showed a little bit decrease from day 3, and then increased from day 10

until 15. There was no significant difference in Δ IOP among the S-PRL, L-PRL and LG-PRL groups compared with the Ctrl group at various time points.

4. Discussions

Surgical correction of high myopia is a controversial issue, and so far there is no completely satisfactory technique^[6]. The existing surgical methods used to treat high myopia are mainly corneal refractive surgery^[4]. Corneal refractive surgery has excellent correction effect, with high predictability of postoperative results, low complication rate and rapid visual recovery^[23]. However, it is limited to myopic patients with limited corneal thickness and highly myopic patients without sufficient residual stromal bed thickness. The pIOLs implantation for high myopia has aroused widespread concern, because it's a reversible and stable process without influencing accommodation, including ICL and PRL^[24]. The novel ICL (V4c) contains a central hole and provides sufficient aqueous humor to maintain the normal condition of the anterior segment^[25], showing better efficacy and safety with a reduced incidence of secondary cataracts^[26]. However, current PRL products still remain a little bit implantation complications which must be solved to improve surgery outcome in future^[19].

Hence, we designed and prepared three kind of PRLs, S-PRL, L-PRL and LG-PRL with different size or grooves to improve surgery outcome by enhancing aqueous humor circulation. LG-PRL, as a kind of fluted PRL, is suitable for patients who are sensitive to pupil block after PRL implantation. The design innovation lies in the grooves around the optical area which provides an effective channel for the circulation of aqueous humor, and their appropriate size which provides implantation stability (optical quality) and patient comfort. The PRL samples showed good optical quality due to >90% UV-vis light transmittance in the range of 500-700 nm. PRL materials (hydrophobic silicon) presented negligible in vitro cytotoxicity and good biocompatibility on HLECs. The anti-adhesion of intraocular implants on HLECs is a key parameter for success rate of intraocular surgery^[27]. The PRL film showed obvious inhibition effect on HLEC adhesion (Figure 3), and was thus a promising intraocular implant. After intraocular implantation of PRLs in rabbit eyes, no serious complications, such as corneal opacity, keratopathy, or posterior synechia, were observed over 15 days. When L-PRL and S-PRL attached to the iris surface after implantation, LG-PRL left enough space with the iris surface, which provided a more effective channel for aqueous humor circulation. LG-PRL is more suitable for rabbit eyes, with lower postoperative complications than the other two groups. Thus, LG-PRL can improve aqueous humor circulation and reduce the postoperative complications.

IOP is an important safety evaluation index of PRL surgery. Elevated IOP after PRL surgery may be associated with normal postoperative mechanisms, such as retention of viscoelasticity or steroid responses^[28, 29]. The IOP in all groups were measured and the Δ IOP were calculated. The Δ IOP in the S-PRL, L-PRL, LG-PRL and control groups was not statistically significant at each time point, which suggested pretty low possibility of glaucoma after PRL implantation. That was, the intraocular implantation of newly developed PRLs was safe, predictable and long-term stable.

It is noteworthy that the retention ratio of LG-PRL (87.5%) lower than L-PRL (100%) might be an accident. Accordingly, more work should be performed to improve the implantation stability of LG-PRL in future. Moreover, studies with optical quality and visual performance should be carried out in future to determine the long-term safety and efficacy of this intraocular lens implant.

5. Conclusions

The novel PRLs, including short PRL (S-PRL), large PRL (L-PRL), and large and grooved PRL (LG-PRL), were designed and prepared in this paper. The newly developed PRL samples presented good biosafety in terms of the negligible in vitro cytotoxicity, ocular inflammation and IOP fluctuations. The LG-PRL provided the best implantation feasibility due to the more proper relative position, available space for circulation of aqueous humor, and high retention ratio in the posterior chamber of rabbit eyes among the three kinds of PRL samples. Thereby, LG-PRL is a promising alternative with appropriate size and surface structure to more effectively treat moderate to high refractive errors.

Declarations

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Authors' contributions

Shaohua Zhang and Chang Huang: investigation, writing-original draft; Huamao Miao, Junyao Wu, Chao Xing: formal analysis and validation of data; Zhaoxing Dai and Jianguo Sun: conceptualization, supervision and project administration.

Data availability statement

The data supporting the findings of this study are available within the article and the supplementary data.

Competing interests

The authors declare that they have no competing interests.

References

1. Morgan IG, French AN, Ashby RS, Guo X, Ding X, He M, KA R (2018) The epidemics of myopia: aetiology and prevention. *Progress in Retinal Eye Research* 62:134–149
2. Paul N, Baird S-M, Saw C, Lanca JA, Guggenheim EL, Smith X, Zhou K-O, Matsui P-C, Wu P, Sankaridurg A, Chia M, Rosman EL, Lamoureux, Ryan Man, Mingguang He, Myopia, *Nature Reviews* 6(1) (2020) 99
3. Haarman AEG, Enthoven CA, Tideman JWL, Tedja MS, Verhoeven VJM, Klaver CCW (2020) The Complications of Myopia: A Review and Meta-Analysis. *Invest Ophthalmol Vis Sci* 61(4):49
4. Ikuno Y (2017) Overview of the Complications of High Myopia. *Retina-J Ret Vit Dis* 37(12):2347–2351
5. Dong L, Kang YK, Li Y, Wei WB (2020) J. JB, Prevalence and time trends of myopia in children and adolescents in China: a systemic review and meta-analysis. *Retina* 40(3):399–411
6. Holden BA, Fricke TR, Wilson DA, Jong M, Naidoo KS, Sankaridurg P, Wong TY, Naduvilath TJ (2016) R. S, Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology* 123(5):1036–1042
7. Kaiti R, Shyangbo R, Sharma IP, Dahal M (2021) Review on current concepts of myopia and its control strategies. *Int J Ophthalmol-Chi* 14(4):606–615
8. Modjtahedi BS, Ferris FL, Hunter DG, DS F (2018) Public health burden and potential interventions for myopia. *Ophthalmology* 125(5):628–630
9. Pesudovs K (2005) Wavefront aberration outcomes of LASIK for high myopia and high hyperopia. *J Refract Surg* 21(5):S508–S512
10. Holladay JT, Dudeja DR (1999) C. J, Functional vision and corneal changes after laser in situ keratomileusis determined by contrast sensitivity, glare testing, and corneal topography. *J Cataract Refract Surg* 25(5):663–669
11. Schallhorn SC, Kaupp SE, Tanzer DJ, Tidwell J, Laurent J, LB B (2003) Pupil size and quality of vision after LASIK. *Ophthalmology* 110(8):1606–1614
12. Dada T, Sudan R, Sinha R, Ray M, Sethi H (2003) V. RB, Results of laser in situ keratomileusis for myopia of -10 to -19 diopters with a Technolas 217 laser. *J Cataract Refract Surg* 19(1):44–47
13. Rabinowitz YS (2006) Ectasia after laser in situ keratomileusis. *Curr Opin Ophthalmol* 17(5):421–426
14. Pandey SK, Commentary SV (2019) Expanding indications of newer and economically viable phakic posterior chamber intraocular lens designs. *Indian J Ophthalmol* 67(7):1066–1067
15. Vargas V, Alio JL (2021) Refractive outcomes and complications following angle supported, iris fixated, and posterior chamber phakic intraocular lenses bilensectomy. *Curr Opin Ophthalmol* 32(1):25–30
16. Choi JH, Lim DH, Nam SW, Yang CM, Chung ES, Chung TY (2019) Ten-year clinical outcomes after implantation of a posterior chamber phakic intraocular lens for myopia. *J Cataract Refract Surg* 45(11):1555–1561

17. Xiang W, Li J, Chen W, Lin HT, Chen WR (2021) Microperipheral Iridectomy for Troublesome Posterior Synechiolysis in Secondary Intraocular Lens Implantation. *J Ophthalmol* 2021:6634871
18. Shimizu K, Kamiya K, Igarashi A, Shiratani T (2012) 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* 154(3):486–494
19. Pérez-Cambrodí RJ, Piñero DP, Ferrer-Blasco T, Cerviño A (2013) B. R, The posterior chamber phakic refractive lens (PRL): a review. *Eye* 27(1):14–21
20. Nakamura T, Isogai N, Kojima T, Yoshida Y, Sugiyama Y, Tanaka Y (2020) I. K, Long-term In Vivo Stability of Posterior Chamber Phakic Intraocular Lens: Properties and Light Transmission Characteristics of Explants. *Am J Ophthalmol* 219:295–302
21. Walsh JE, Bergmanson JP, Koehler LV, Doughty MJ, Fleming DP, JH H (2008) Fibre optic spectrophotometry for the in vitro evaluation of ultraviolet radiation (UVR) spectral transmittance of rabbit corneas. *Physiol Meas* 29(3):375–388
22. Jiménez-Alfaro I, Benítez del Castillo JM, García-Feijó J, Gil de Bernabé JG, S.d.L.I. JM, Safety of posterior chamber phakic intraocular lenses for the correction of high myopia: anterior segment changes after posterior chamber phakic intraocular lens implantation, *ophthalmology* 108(1) (2001) 90-99
23. Wen DZ, Mcalinden C, Flitcroft I, Tu RX, Wang QM, Alio J, Marshall J, Huang YY, Song BH, Hu L, Zhao YN, Zhu SM, Gao RR, Bao FJ, Yu AY, Yu Y, Lian HL, Huang JH (2017) Postoperative Efficacy, Predictability, Safety, and Visual Quality of Laser Corneal Refractive Surgery: A Network Meta-analysis. *Am J Ophthalmol* 178:65–78
24. Fernandes P, González-Méijome JM, Madrid-Costa D, Ferrer-Blasco T, Jorge J (2011) M.-M. R, Implantable collamer posterior chamber intraocular lenses:a review of potential complications. *J Refract Surg* 27(10):765–776
25. Montés-Micó R, Ruiz-Mesa R, Rodríguez-Prats JL (2021) T.-R. P, Posterior-chamber phakic implantable collamer lenses with a central port: a review. *Acta Ophthalmology* 99(3):e288–e301
26. Fernández-Vega-Cueto L, Alfonso-Bartolozzi B, Lisa C, Madrid-Costa D, JF A (2021) Seven-year follow-up of posterior chamber phakic intraocular lens with central port design. *Eye Vision* 8(1):23
27. Alió JL (2013) T. BT, Refractive Surgery With Phakic Intraocular Lenses: An Update. *Int Ophthalmol Clin* 53(1):91–110
28. B. SA, Complications of Phakic Intraocular Lenses, *International Ophthalmology Clinics* 56(2) (2016) 161–168
29. Senthil S, Choudhari NS, Vaddavalli PK, Murthy S, Reddy J, Garudadri CS (2016) Etiology and Management of Raised Intraocular Pressure following Posterior Chamber Phakic Intraocular Lens Implantation in Myopic Eyes. *Plos One* 11(11):e0165469

Figures

Figure 1

Schematic description of the intraocular implantation of phakic refractive lens (PRL)

Figure 2

Representative photos of PRLs and their UV-vis light transmittance. A) S-PRL; B) L-PRL; C) LG-PRL; D) UV-vis light transmittance curve

Figure 3

A) In vitro cell cytotoxicity of PRL samples at 24 or 48 h; B) and C) representative photos of the in vitro HLECs adhesion morphology on Ctrl (12 well plate) and PRL surface at 24 h; Cell number (D) and average cell area (E) of HLECs adhered on Ctrl and PRL surface.

Figure 4

Representative photos of rabbit eye postoperatively. Ocular surfaces (column 1, 4 and 7), anterior chamber (column 2, 5 and 8) and posterior chamber (column 3, 6 and 9) taken by normal and slit lamp modes at day 1, 3, 5, 7, 10 and 15 after the intraocular implantation of S-PRL, L-PRL or LG-PRL. The column 1, 4 and 7 adopted the method of diffuse illumination; column 2, 5 and 8 responded to the direct focal illumination; and column 3, 6 and 9 used the retro illumination.

Figure 5

PRL retention ratio (A) and relative positions (B) of S-PRL, L-PRL and LG-PRL implanted in the posterior chamber measured by OCT. The red arrows in the right OCT images show the observation direction and location, and the internal structures are shown in right images indicating the relative positions and available space between the implanted sample and the iris.

Figure 6

Postoperative intraocular pressure (IOP) in the S-PRL, L-PRL, LG-PRL and Ctrl groups at various time points.