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REFRACTIVE SURGERY

Modulation transfer function of intraocular collamer lens with a central artificial hole

Hiroshi Uozato · Kimiya Shimizu · Takushi Kawamorita · Fumiko Ohmoto

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Abstract
Background A modified implantable collamer lens (ICL) with a central hole (diameter 0.36 mm), "Hole-ICL", was created to improve aqueous humour circulation. The aim of this study is to investigate the effects of ICL power and the relationship between pupil size and modulation–transfer functions (MTFs) in a Hole-ICL in vitro.
Methods The ICL and intraocular lens (IOL) studied were the Collamer ICL (Model ICM, STAAR Surginal) and the monofocal IOL AF-1 (VA-60BBR, HOYA). The ICLs' powers were −20.0 diopters (D), −10.0 D, −5.0 D, +3.0 D, and +10.0 D. A modified ICL with a central hole (diameter 0.36 mm), "Hole-ICL", was created. The monofocal IOL, which was used as an artificial crystalline lens, was +30.0 D in power, and it was 13.0 mm in length with an optic diameter of 6.0 mm. The line-spread function (LSF) was recorded with the OPAL Vector System (Image Science Ltd.), and a model eye (Menicon Co.) was used that consisted of a wet cell. A conventional ICL or Hole-ICL was placed in the posterior chamber of the model eye. The MTF was calculated from the LSF using fast Fourier transform techniques. Furthermore, we investigated the relationship between pupil size and the MTF of the ICL for −5.0 D. The sizes of the effective aperture were 2.0, 3.0, 4.0, and 5.0 mm.
Results The in-focus contrasts of the conventional ICL at 100 cyc/mm for a 3.0-mm effective aperture were 37%, 40%, 39%, 38%, and 39% for −20.0 D, −10.0 D, −5.0 D, +3.0 D, and +10.0 D respectively. The in-focus contrasts of the Hole-ICL at 100 cyc/mm for a 3.0-mm effective aperture were 37%, 40%, 39%, 38%, and 38% for −20.0 D, −10.0 D, −5.0 D, +3.0 D, and +10.0 D respectively. The results for a 2.0-mm effective diameter showed that the in-focus MTF in the Hole-ICL was lower than in the conventional ICL, although the difference was small.
Conclusion These results suggest that differences in MTF between the Hole-ICL and the conventional ICL for various ICL powers and effective pupil diameters were small and clinically negligible.

Keywords Modulation transfer function · Pupil size · Phakic IOL · ICL · Hole ICL

Introduction

Posterior chamber (PC) phakic intraocular lenses (pIOLs) have many advantages for the treatment of refractive error, especially for high and moderate ametropia [1, 2]. However, cataract development has been noted after PC pIOL implantation [1]. The incidence of cataract formation with Staar intraocular collamer lenses (ICLs) is reported to be

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H. Uozato (✉) · T. Kawamorita
Department of Orthoptics and Visual Science,
Kitasato University School of Allied Health Sciences,
1-15-1 Kitasato, Minami, Sagamihara 252-0373, Japan
e-mail: uozatoh@ahs.kitasato-u.ac.jp

H. Uozato · K. Shimizu · T. Kawamorita · F. Ohmoto
Department of Ophthalmology and Visual Science,
Kitasato University Graduate School of Medical Sciences,
Sagamihara, Japan

K. Shimizu · F. Ohmoto
Department of Ophthalmology,
Kitasato University School of Medicine,
Sagamihara, Japan

between 0% [3] and 33.3% [4]. A secondary cataract may be caused by a change in the circulation of aqueous humour to the anterior surface of the crystalline lens. Therefore, Shimizu created a centrally perforated ICL (i.e., Hole-ICL) to improve aqueous humour circulation (Shimizu K. Implantable Contact Lens. The 31st Annual Meeting of the Japanese Society of Ophthalmic Surgeons, Yokohama, Japan, 2008). In addition, Fujisawa et al. [5] reported that the insertion of an ICL causes a change in the dynamics of the intraocular aqueous humour, reducing its circulation to the anterior surface of the crystalline lens. They concluded that space is needed for aqueous humour flow between the ICL and the crystalline lens to prevent a secondary cataract from appearing, and an ICL with holes may better maintain normal aqueous humour circulation. Also, Ohmoto et al. [6] confirmed the optical performance of the Hole-ICL (diameter 0.36 mm) in vitro and in optical simulations. They showed that the MTF in vitro and in an optical simulation study revealed no difference between the Hole-ICL (−14.5 D) and the conventional ICL for an effective pupil diameter of 3.0 mm. However, a change in thickness, in the curvature of the ICL, or in pupil size led to a change in optical aberration, which can decrease optical quality.

Therefore, the aim of this study is to investigate the optical performance of the Hole-ICL for various ICL powers and effective pupil diameters.

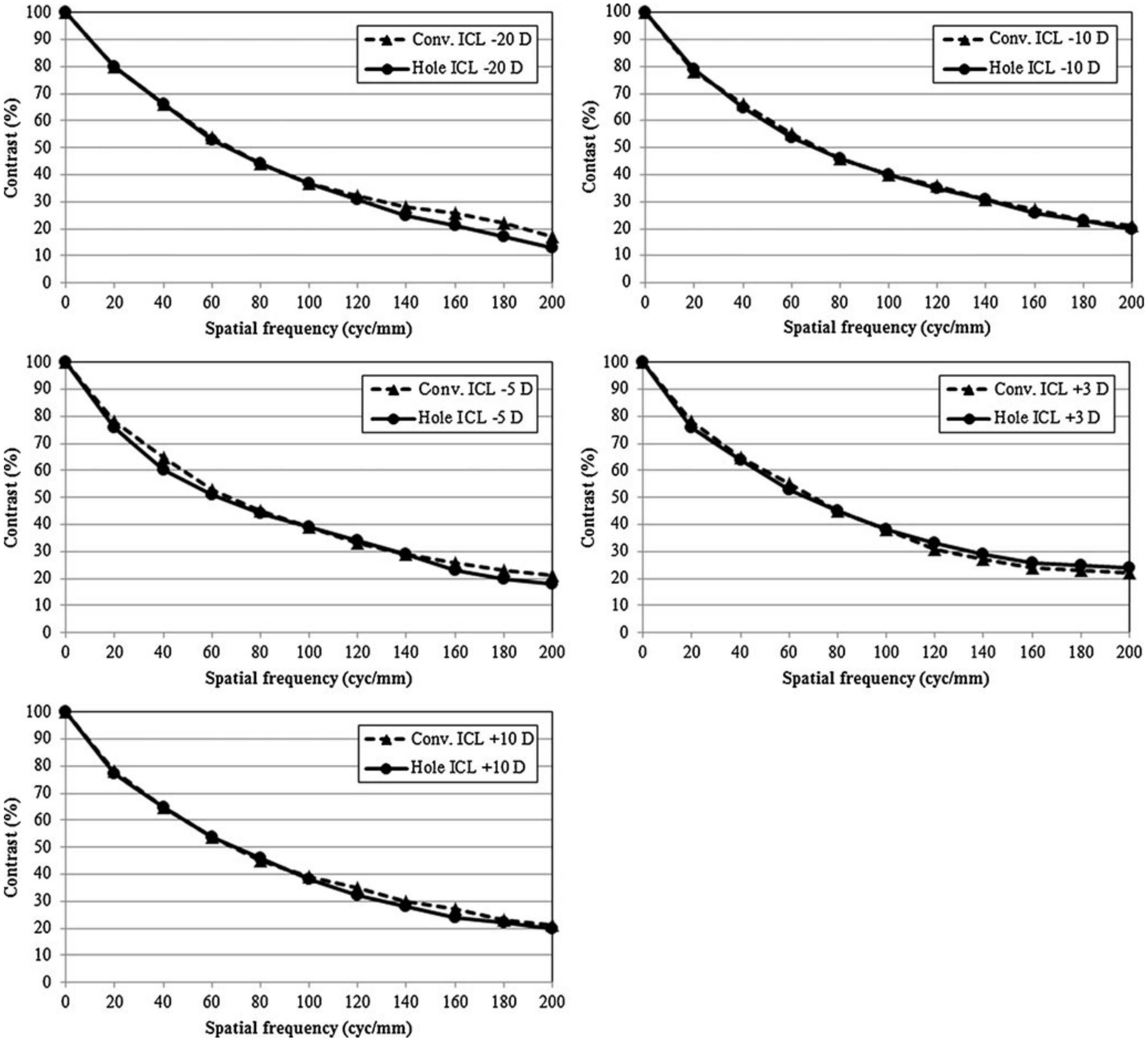

Fig. 1 For various ICL powers at an effective pupil diameter of 3.0 mm, the measured in-focus MTF values for the Hole-ICL and conventional ICL are presented

Materials and methods

The ICL and IOL studied were the Collamer ICL (Model ICM, STAAR Surgical) and the monofocal IOL AF-1 (VA-60BBR, HOYA). The ICL's powers were −20.0 D, −10.0 D, −5.0 D, +3.0 D, and +10.0 D. The length of the ICL was 13.0 mm, and the optic diameter was 6.0 mm. A modified ICL with a central hole (diameter 0.36 mm), "Hole-ICL", was created. The monofocal IOL's power was +30.0 D, and it was 13.0 mm in length, with an optic diameter of 6.0 mm. The IOL used was an artificial crystalline lens. The reason we used a high-power IOL was that the focal point of the optical system is confined to the optical rail in cases of high-power ICL, such as −20.0 D.

The line-spread function (LSF) was recorded with the OPAL Vector system (Image Science Ltd.) using a model eye (Menicon Co.) composed of a wet cell filled with a balanced salt solution. Either the conventional ICL or the Hole-ICL was placed in the posterior chamber of the model eye. The MTF was calculated from the LSF using fast Fourier transform techniques. The model eye consisted of a model cornea (Achromat, SSK4 and SF8) and a variable effective aperture (i.e., a real pupil) with BK7 windows. The sizes of the effective aperture were 2.0, 3.0, 4.0, and 5.0 mm. In the system, the light source was confined to 546 nm. The detector type used was the RETICON K series silicon linear photodiode array, which was 12.8 mm long and had 512 pixels. The contrast values were determined with an average of 16 array scans. With the exception of the effective aperture, these MTF measurements conformed to the requirements of the International Organization for Standardization.

Results

The in-focus contrasts of the conventional ICL at 100 cyc/mm for a 3.0-mm effective aperture were 37%, 40%, 39%, 38%, and 39% for −20.0 D, −10.0 D, −5.0 D, +3.0 D, and +10.0 D respectively (Fig. 1). The in-focus contrasts of the Hole-ICL at 100 cyc/mm for a 3.0-mm effective aperture were 37%, 40%, 39%, 38%, and 38% for −20.0 D, −10.0 D, −5.0 D, +3.0 D, and +10.0 D respectively (Fig. 1).

With increasing effective diameters, the in-focus contrast of the conventional ICL (−5.0 D) progressively decreased (Fig. 2), while the in-focus contrast of the Hole-ICL (−5.0 D) progressively decreased at values>3.0 mm (Fig. 2). The results for a 2.0-mm effective diameter showed that the in-focus contrast in the Hole-ICL was lower than that for the conventional ICL (Fig. 2), although the difference was small.

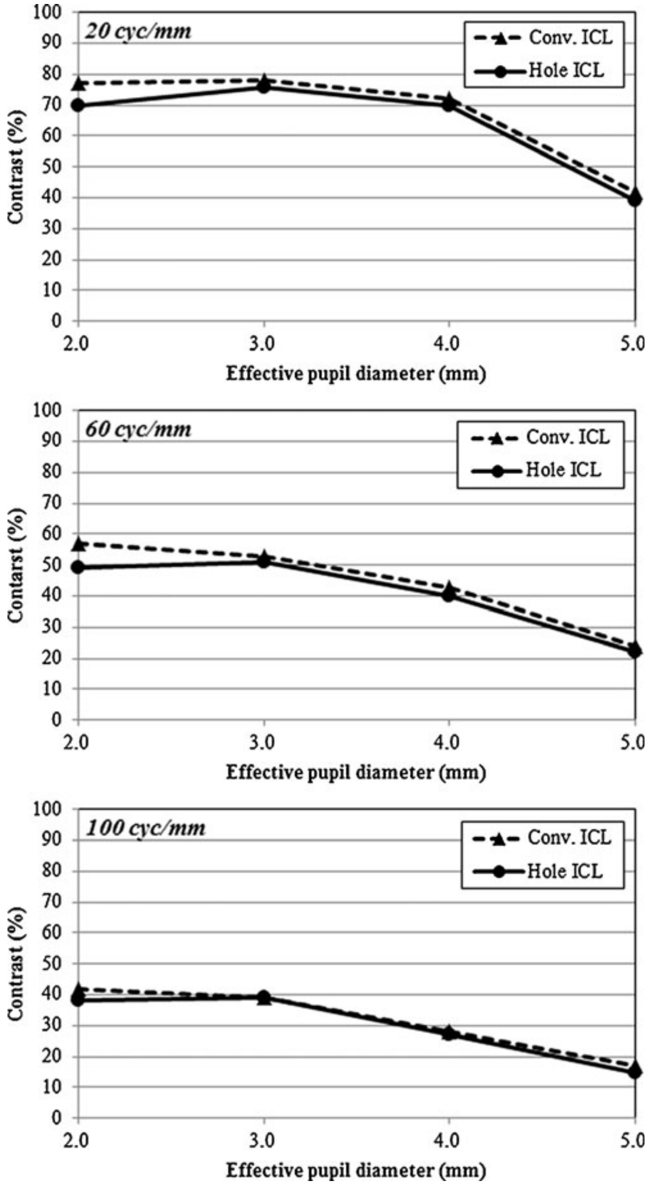

Fig. 2 In-focus MTF values for the Hole-ICL (−5.0 D) and conventional ICL (−5.0 D) are presented at 100, 60, and 20 c/mm for various effective pupil diameters ranging from 2.0 to 5.0 mm

Discussion

MTF measurements in vitro are the internationally accepted standard method for evaluating the performance of IOL image quality, and it has been reported that one can predict contrast sensitivity in vivo from contrast values in vitro [7]. Furthermore, Kawamorita et al. reported that this measurement has high repeatability [8].

Rawer et al. [9] showed that with increasing refractive power, the diffraction-limited MTF increased, and for lenses with aberration, the MTF decreased with increasing power above a certain limit. They showed that for powers up to approximately +25.0 D, the MTF remains almost constant, and for powers above approximately +25.0 D, there is a significant loss of modulation (constant). In the current study, although contrast at 100 cyc/mm for a power of −20.0 D slightly decreased compared to other powers, the difference was small. Furthermore, the optical performance of the Hole-ICL was almost the same as the performance of the conventional ICL. Some astronomical telescopes represent cases of an optical system with a centrally perforated lens. A Cassegrain telescope is one example that has a large concave paraboloidal primary form with a central hole. Shiratani et al. [10] reported that MTF, obtained using the Zemax optical simulation software, of an ICL with a central hole (diameter 1.0 mm) in the optic region was similar to an unperforated ICL. The size of the hole influenced the aqueous humour dynamics and increased the aqueous humour perfusion volume over the entire anterior surface of the crystalline lens. For all IOLs, the ISO standard requires a contrast above 28% at 100 cyc/mm with a 3.0-mm effective aperture diameter. Ohmoto et al. [6] reported that the differences between the two ICLs (−14.5 D) were small, and both ICLs achieved contrasts greater than 28%, which is required by the ISO. Our results showed that all Hole-ICLs at various powers fulfil the ISO criterion for MTF.

Variances of pupil diameter depend mainly on luminance levels [11]. A change in pupil diameter may lead to a change in wavefront aberration that affects retinal image quality and subjective visual performance [11, 12]. This is consistent with our current results. Furthermore, when pupil size in the Hole-ICL changes, the proprietary area ratio between the hole area and pupil area changes. Therefore, there was concern that MTF decreases with a small pupil for Hole-ICLs. While with large pupils, MTF decreased in both ICLs, the performance of the Hole-ICL was almost the same as the performance of the conventional ICL.

Chen et al. [1] reported that the analysis of cataract progression in eyes with a pre-existing cataract showed a progression rate of 29.5% after pIOL surgery. Several causes may be involved, including aqueous humour circulation [5], pIOL–crystalline lens contact [13] [14], low vaulting between the ICL and the crystalline lens [15] [16] [17], decreased anterior chamber depth with age [18], myopia [19], and surgical trauma [20]. After improving aqueous humour circulation in the Hole-ICL, Fujisawa [5] reported that no cataract formed when the Hole-ICL was used in porcine eyes. They concluded that the Hole-ICL allowed the aqueous humour to flow sufficiently, and was distributed over the anterior surface of the crystalline lens through its central hole. In addition, Shiratani et al. [10] suggested the possibility of preventing cataracts with the Hole-ICL. Therefore, to prevent secondary cataracts, safe vaulting and minimization of contact between the ICL and the crystalline lens using appropriate ICL size selection and accurate anterior chamber biometry are important.

Currently, many surgeons perform peripheral laser iridotomies (LI) prior to ICL implantation to prevent a pupillary block. However, LI may cause complications, such as iritis, intraocular haemorrhage, elevation of intraocular pressure, posterior iris synechia, and corneal decompensation, as in bullous keratopathy. Although further studies are needed to investigate the fluid dynamics of the aqueous humour and although the results of this study must be confirmed in vivo, the use of the Hole-ICL may eliminate the need for LI.

In regards to the limitations of the present study, we used the IOL as an artificial crystalline lens instead of a crystalline lens. An artificial crystalline lens might affect the results of this investigation. However, the difference between an IOL and a crystalline lens might have little influence on the relative contrast value difference between the Hole ICL and conventional ICL, as opposed to each absolute value.

In conclusion, our results suggest that a minimal central hole in an ICL might not have a great impact on optical performance for various ICL powers and effective pupil diameters.

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References

1. Chen LJ, Chang YJ, Kuo JC, Rajagopal R, Azar DT (2008) Metaanalysis of cataract development after phakic intraocular lens surgery. J Cataract Refract Surg 34:1181–1200, doi:10.1016/j.jcrs.2008.03.029
2. Lovisolo CF, Reinstein DZ (2005) Phakic intraocular lenses. Surv Ophthalmol 50:549–587, doi:10.1016/j.survophthal.2005.08.011
3. Jimenez-Alfaro I, Benitez del Castillo JM, Garcia-Feijoo J, Gil de Bernabe JG, Serrano de La Iglesia JM (2001) Safety of posterior chamber phakic intraocular lenses for the correction of high myopia: anterior segment changes after posterior chamber phakic intraocular lens implantation. Ophthalmology 108:90–99
4. Lackner B, Pieh S, Schmidinger G, Hanselmayer G, Dejaco-Ruhswurm I, Funovics MA, Skorpik C (2003) Outcome after treatment of ametropia with implantable contact lenses. Ophthalmology 110:2153–2161, doi:10.1016/S0161-6420(03)00830-3
5. Fujisawa K, Shimizu K, Uga S, Suzuki M, Nagano K, Murakami Y, Goseki H (2007) Changes in the crystalline lens resulting from insertion of a phakic IOL (ICL) into the porcine eye. Graefes Arch Clin Exp Ophthalmol 245:114–122, doi:10.1007/s00417-006-0338-y
6. Ohmoto F, Shimizu K, Uozato H, Kawamorita T, Uga S (2010) Optical performances of implantable collamer lenses with and without a central perforation. Kitasato Medical Journal 40:150–153, doi:10.1007/s00417-007-0759-2
7. Lang AJ, Lakshminarayanan V, Portney V (1993) Phenomenological model for interpreting the clinical significance of the in vitro optical transfer function. J Opt Soc Am A 10:1600–1610
8. Kawamorita T, Uozato H, Aizawa D, Kamiya K, Shimizu K (2009) Optical performance in rezoom and array multifocal intraocular lenses in vitro. J Refract Surg 25:467–469
9. Rawer R, Stork W, Spraul CW, Lingenfelder C (2005) Imaging quality of intraocular lenses. J Cataract Refract Surg 31:1618–1631, doi:10.1016/j.jcrs.2005.01.033

10. Shiratani T, Shimizu K, Fujisawa K, Uga S, Nagano K, Murakami Y (2008) Crystalline lens changes in porcine eyes with implanted phakic IOL (ICL) with a central hole. Graefes Arch Clin Exp Ophthalmol 246:719–728, doi:10.1007/s00417-007-0759-2
11. Charman WN, Chateau N (2003) The prospects for super-acuity: limits to visual performance after correction of monochromatic ocular aberration. Ophthalmic Physiol Opt 23:479–493
12. Campbell FW, Green DG (1965) Optical and retinal factors affecting visual resolution. J Physiol 181:576–593
13. Fechner PU, Haigis W, Wichmann W (1996) Posterior chamber myopia lenses in phakic eyes. J Cataract Refract Surg 22:178–182
14. Lindland A, Heger H, Kugelberg M, Zetterstrom C (2010) Vaulting of myopic and toric Implantable Collamer Lenses during accommodation measured with Visante optical coherence tomography. Ophthalmology 117:1245–1250, doi:10.1016/j.ophtha.2009.10.033
15. Schmidinger G, Lackner B, Pieh S, Skorpik C (2010) Long-term changes in posterior chamber phakic intraocular collamer lens vaulting in myopic patients. Ophthalmology 117:1506–1511, doi: S0161-6420(09)01417-1
16. Alfonso JF, Lisa C, Abdelhamid A, Fernandes P, Jorge J, Montes-Mico R (2010) Three-year follow-up of subjective vault following myopic implantable collamer lens implantation. Graefes Arch Clin Exp Ophthalmol 248:1827–1835, doi:10.1007/s00417-010-1322-0
17. Khalifa YM, Moshirfar M, Mifflin MD, Kamae K, Mamalis N, Werner L (2010) Cataract development associated with collagen copolymer posterior chamber phakic intraocular lenses: clinicopathological correlation. J Cataract Refract Surg 36:1768–1774, doi:10.1016/j.jcrs.2010.04.039
18. Yan PS, Lin HT, Wang QL, Zhang ZP (2010) Anterior segment variations with age and accommodation demonstrated by slit-lamp-adapted optical coherence tomography. Ophthalmology 117 (12):2301–2307, doi10.1016/j.ophtha.2010.03.027
19. Alio JL, de la Hoz F, Ruiz-Moreno JM, Salem TF (2000) Cataract surgery in highly myopic eyes corrected by phakic anterior chamber angle-supported lenses(1). J Cataract Refract Surg 26:1303–1311
20. Sanders DR, Vukich JA (2002) Incidence of lens opacities and clinically significant cataracts with the implantable contact lens: comparison of two lens designs. J Refract Surg 18:673–682