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BASIC SCIENCE

Modulation transfer function of implantable phakic intraocular contact lens (IPCL) for myopia and presbyopia

Chunjing Yu[1] · Kazutaka Kamiya[1,2] · Takushi Kawamorita[1,2]

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Abstract

Purpose This study aimed to assess the optical quality of myopic and presbyopic IPCLs with different additional powers, and to investigate the effects of pupil size on the optical quality of these IPCLs using an in-vitro modulation transfer function (MTF) measurement system.

Methods Linear scatter functions (LSFs) were recorded using the OPAL Vector system and an eye phantom consisting of wet cells filled with a balanced salt solution. A myopic IPCL or a presbyopic IPCL was placed in the posterior chamber of this model. The MTF was calculated from the LSF using the fast Fourier transform techniques. The effective apertures were set at 2.0 to 5.0 mm in 1.0 mm steps.

Results The in-focus MTF values of the myopic IPCL and presbyopic IPCL with additional powers of + 2.0 and + 4.0 diopters at 100 cycles/mm for an effective aperture of 3.0 mm were 43%, 27%, and 24%, respectively. The in-focus MTF value of both myopic and presbyopic IPCLs was the highest when the effective aperture was set at 3.0 mm, and it gradually worsened when the effective aperture became larger than 3.0 mm at 20, 60, and 100 cycles/mm.

Conclusions Both myopic and presbyopic IPCLs provided excellent MTF values, but the additional power profile can deteriorate optical performance in presbyopic IPCL-implanted eyes, even with a low additional power. Pupil size can influence visual quality in IPCL-implanted eyes for both myopia and presbyopia.

Key Messages

What is known:

• Implantable phakic contact lens (IPCL) has been reported to be effective for the treatment of both myopia and presbyopia, with a noticeable advantage in reducing the patients' cost burden.

• The optical properties of IPCL have not yet been thoroughly investigated, neither for myopic IPCLs nor for presbyopic IPCLs.

What is new:

• The MTF of presbyopic IPCL was slightly lower than that of myopic IPCL even with a low additional power.

• The MTF values of both myopic and presbyopic IPCLs were the highest for a 3.0 mm-pupil size, with gradually worsened for a larger pupil size.

Keywords Modulation transfer function · Myopic IPCL · Presbyopic IPCL · Phakic IOL · IPCL · Pupil size

Introduction

Posterior chamber phakic intraocular lenses (pIOLs) have many advantages over excimer laser surgeries for the treatment of refractive errors, and thus are widely acknowledged as a safe, effective, and predictable surgical approach, especially for the correction of moderate to high myopia [1, 2]. Presbyopia is an inevitable age-related decline of accommodation and does occur over time, especially in patients

✉ Chunjing Yu
yucjdoctor@163.com

1 Department of Ophthalmology and Visual Science, Kitasato University Graduate School of Medical Sciences, 1-15-1 Kitasato, Minami, Sagamihara, Kanagawa 252-0373, Japan

2 Department of Orthoptics and Visual Science, Kitasato University School of Allied Health Sciences, Sagamihara, Japan

aged 40 or older, regardless of the type of refractive surgery. This natural phenomenon can cause one of the common dissatisfactions when post-surgical patients become older even if we simply correct refractive disorders. At present, there are many surgical options for the correction of presbyopia, such as monovision with IOLs or corneal laser surgery, simultaneous images with IOLs and corneal inlays, pinhole technology with IOLs and corneal inlays, crystalline lens softening with femtosecond laser, and restoring accommodation with IOLs and scleral expansion. There are certain curative effects, but due to their respective disadvantages, none of them has become dominant. As we all know, presbyopia correction is assumed to be the last frontier of refractive surgery in middle-aged patients [3, 4].

The posterior chamber implantable phakic contact lens (IPCL V2, Care Group Sight Solutions, India) has been developed as an alternative to the posterior chamber pIOL (Visian ICL, STAAR Surgical, Monrovia, CA, USA), with a noticeable advantage in reducing patients' cost burden. Indeed, Rateb et al. [5] showed, in a prospective, randomized comparative study, no statistically significant differences in postoperative uncorrected and corrected visual acuities at any time points between the IPCL- and ICL-implanted patients for the correction of myopia and myopic astigmatism, although the lens material and the lens architecture were different between these pIOLs. Vasavada et al. [6] found that IPCL showed good visual and refractive outcomes during the 3-year observation period. IPCL can also provide correction for a wide range of ametropia up to -30.0 D and astigmatism up to 10 D. Moreover, Schmid et al. [7] firstly demonstrated in a preliminary study that a presbyopic IPCL can provide good visual outcomes and spectacle independence for near to far distances. These previous findings indicate that IPCL may be one of the feasible surgical options for moderate to high myopic patients with and without presbyopia. However, there have been so far no relevant published studies on the optical properties of the IPCL, not only for myopia but also for presbyopia, and on optical changes depending on pupil size. It may contribute to better understanding of the optical characteristics and subsequent future prevalence of these promising pIOLs.

Fig. 1 Appearance of posterior chamber implantable phakic contact lens (IPCL V2) for myopia (left) and presbyopia (right)

The goal of the current study is twofold; to assess the optical performance of the current version of myopic IPCL as well as presbyopic IPCL, and to investigate the effects of pupil diameter on the optical performance of these myopic and presbyopic IPCLs with different additional powers, using an in-vitro modulation transfer function (MTF) measurement system. To our knowledge, this is the first study to assess detailed optical properties of the IPCLs not only for myopia but also for presbyopia.

Methods

The IPCL is made of reinforced hybrid acrylic material with medium water content and has 6 holes in the optic and optic-haptic vault to reduce light scattering and allow equalization of the pressure between the posterior and anterior chamber across the lens (Fig. 1). The presbyopic IPCL has a diffractive optical zone of 5.8 mm with an additional power ranging from + 1.0 D to + 4.0 D in 0.5 D steps (Fig. 1). We used the current version of the IPCL (IPCL Version 2.0) having a dioptric power of -5.5 D with additional powers of + 2.0 D and + 4.0 D for near vision (presbyopic IPCL) and without any additional power (myopic IPCL) as representative powers in the present study. We also used a hydrophilic acrylic monofocal IOL (VA-60BBR, HOYA. Japan) as an artificial crystalline lens, with a spherical power of + 30.0 D, a length of 12.5 mm, and an optical diameter of 6.0 mm.

Linear scatter functions (LSFs) were recorded using the OPAL Vector system (Image Science Ltd., Oxfordshire, UK) and an eye phantom consisting of wet cells filled with a balanced salt solution (Menicon Co., Nagoya, Japan) (Fig. 2). We placed a myopic IPCL or a presbyopic IPCL in the posterior chamber of the model at room temperature. The MTF was calculated from the LSF using the fast Fourier transform techniques from an average of 16 array scans hold. The eye model consisted of a cornea model (Achromat, SSK4 and SF8) and a variable effective iris with a BK7 window and follows ISO standards. The effective apertures were set at 2.0, 3.0, 4.0 and 5.0 mm. In this system, the light source was limited to 546 nm. The detector type used was the RETICON K series silicon linear photodiode array, with a length of 2.8 mm and 512 pixels. The contrast values were determined with an average of 16 array scans. These

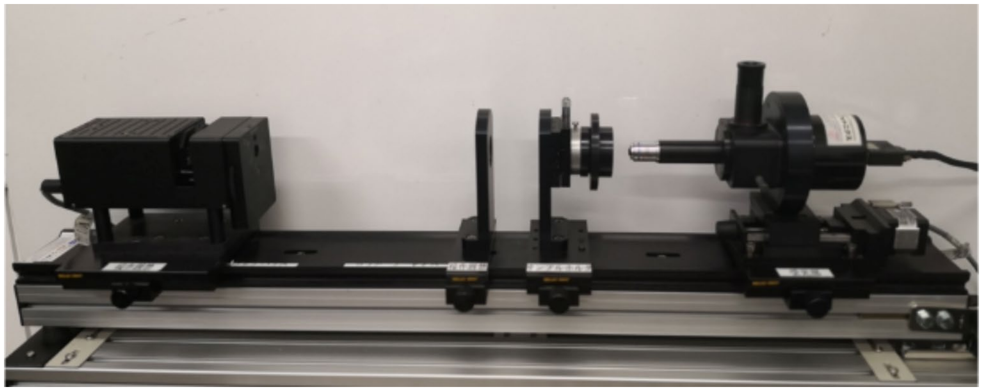

Fig. 2 Appearance of in vitro modulation transfer function (MTF) measurement system (OPAL Vector System)

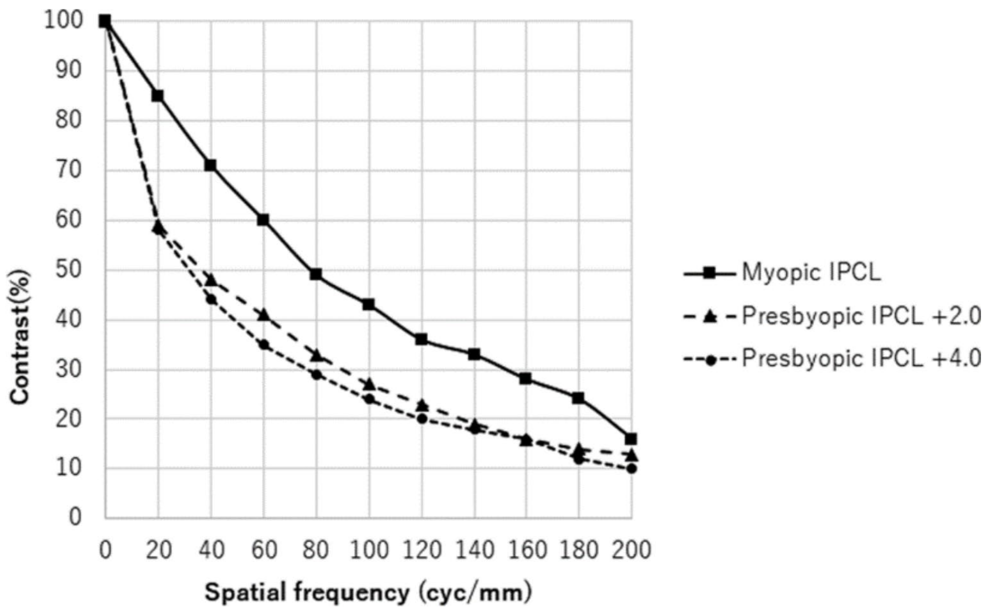

Fig. 3 In-focus modulation transfer function (MTF) values for the myopic IPCL (-5.5 D) and presbyopic IPCL (-5.5 D, with additional powers + 2.0 and + 4.0 D) at 100 cycles/mm for an effective aperture of 3.0 mm

MTF measurements comply with the standardized requirements of international organizations, except for the effective aperture.

Results

Figure 3 shows the in-focus MTF measurements of myopic and presbyopic IPCLs at 100 cycles/mm for an effective aperture of 3.0 mm. The in-focus contrast of the myopic IPCL was 43%. In contrast, the corresponding figures of the presbyopic IPCL with additional powers of + 2.0 and + 4.0 diopters (D) at 100 cycles/mm for an effective aperture of 3.0 mm were 27% and 24%, respectively.

Figure 4 shows the in-focus MTF measurements of the myopic and presbyopic IPCLs at 20, 60, and 100 cycles/mm for various effective apertures ranging from 2.0 to 5.0 mm. The in-focus MTF value of both myopic and presbyopic IPCLs was the highest when the effective aperture was set at 3.0 mm, and it gradually worsened when the effective aperture became larger than 3.0 mm at 20, 60, and 100 cycles/mm.

Discussion

In the present study, our findings demonstrated that both myopic and presbyopic IPCLs provided excellent MTF outcomes, although the MTF of the presbyopic IPCL was lower than that of the myopic IPCL, and that MTF with high additional power was slightly lower than that with low additional power, indicating that the additional power profile can deteriorate visual performance in presbyopic IPCL-implanted eyes, even when the additional power is low. Our findings also showed that the MTF values of both myopic and presbyopic IPCLs were highest for a 3.0 mm-pupil size, and that the MTF gradually worsened when the pupil size became larger than 3.0 mm, indicating that pupil size can affect the postoperative visual performance in IPCL-implanted eyes not only for myopia but also for presbyopia. In this study, we applied in vitro MTF measurements, which

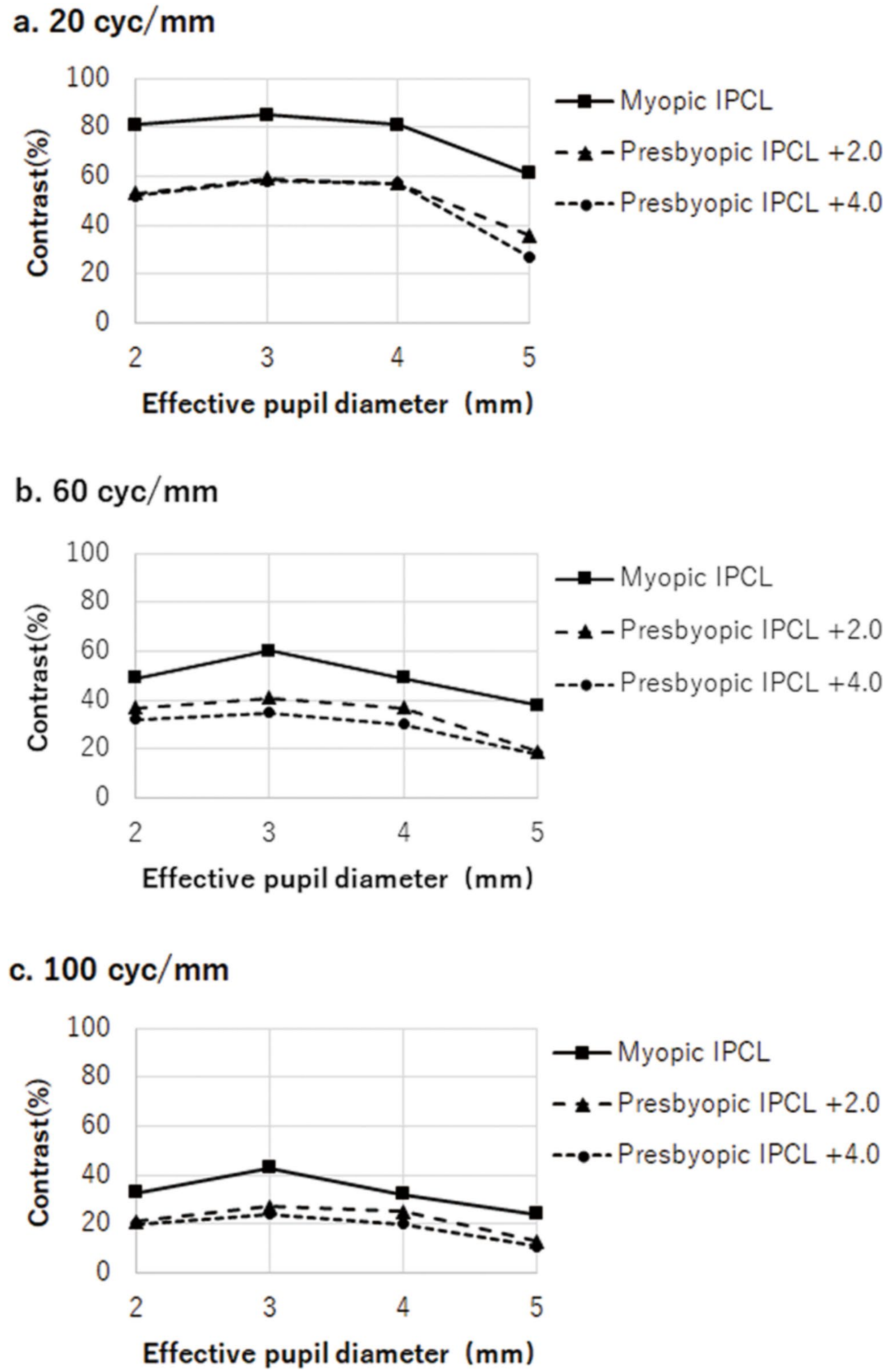

Fig. 4 In-focus modulation transfer function (MTF) values for the myopic IPCL (-5.5 D) and presbyopic IPCL (-5.5 D, with additional powers + 2.0 and + 4.0 D) at 20, 60, and 100 cycles/mm for various effective pupil diameters ranging from 2.0 to 5.0 mm

were internationally accepted as a standardized method for assessing the IOL image quality. It has been shown that we can predict in vivo contrast sensitivity and optical image based on in vitro contrast values [8, 9], and that these in vitro experiments had higher repeatability of the MTF measurements when using another pIOL model [10].

Although IPCL and ICL were classified into the same category as posterior chamber pIOLs, the optical quality may be somewhat different based on the fact that the lens material (hybrid acrylic vs. collamer), the refractive index (1.465 vs. 1.442), the and the overall architecture were different between them. Gros-Otero et al. [11] demonstrated, in a comparative study on the surface roughness of the ICL and the IPCL using atomic force microscopy, that the surface of the IPCL was significantly smoother and thus exhibited better optical properties in comparison with the ICL. The MTF of the myopic IPCL was overall as high as that of the similar myopic ICL. Uozato et al. [10] demonstrated that the in-focus contrasts of myopic ICLs for − 10.0 D and − 5.0 D at 100 cycles/degree for a 3.0-mm effective aperture were 40% and 39%, respectively. In the current study, the corresponding value of the myopic IPCL under same conditions was 43%, which was slightly better than that of the myopic ICL, presumably resulting from differences of the surface smoothness, the material, and the edge shape of the central hole between the two pIOLs.

It is reasonable that the MTF value of the presbyopic IPCL tended to be lower as the additional power was higher, although the differences of the MTF value was relatively small. These current findings are consistent with previous findings of multifocal IOL implantation in that contrast sensitivity function decreased especially when using a multifocal IOL with a higher additional power [12–14]. In clinical application, it is necessary to focus on the needs for overall vision of each presbyopic patients. It may be the decisive factor whether the visual improvement at all distances exceeds the adverse effects of multifocal IOL, as well as the motivation to achieve spectacle independence.

The difference in pupil size largely depends on the brightness level in a daily life. The changes in pupil size may cause changes in wavefront aberrations, resulting in a degradation of the retinal image quality and subjective visual performance [15]. This fact is especially important in consideration of multifocal IOL implantation, because optical performance as well as subsequent patient satisfaction varies with pupil size [16, 17]. Our results showed that the image quality of both the myopic and presbyopic IPCLs was highest, when the effective pupil diameter was set at 3.0 mm, and that it gradually worsened when the pupil size became larger than 3.0 mm, indicating that the optical performance of post IPCL-implanted patients at dim-light or night conditions may be inferior to that at daily light conditions. Actually, Stodulka et al. [18] reported that some patients undergoing presbyopic IPCL implantation had some difficulty in seeing under dim light conditions in a clinical setting, which was in line with our current findings. Wei et al. [19] also mentioned, in a study of patients undergoing ICL implantation, that both subjective and objective visual quality decreased significantly when the pupil diameter was 5.0 mm.

There are at least two limitations to this study. One is that we did not assess the effects of residual accommodation, spherical aberration, tilt or decentration of the crystalline lens in this model. We cannot deny the possibilities that it might affect the MTF results in the current study. However, this methodology has been well-established in other published studies [11, 16], and we aimed to essentially compare the optical properties of the myopic and presbyopic IPCLs under the same conditions. Another limitation is that we selected one representative power (-5.5 D) of IPCLs with or without additional powers (+ 2.0 and + 4.0 D) in consideration of daily practice.

In conclusion, our results demonstrated that both IPCLs for myopia and for presbyopia provided excellent MTF outcomes, but that the MTF of the presbyopic IPCL was slightly lower than that of the myopic IPCL, suggesting that the additional multifocal power profile for presbyopia can affect the optical performance, even when the additional power is low. Our results also confirmed that the MTF values of both myopic and presbyopic IPCLs were the highest for a 3.0 mm-pupil size, and that the MTF gradually worsened when the pupil size became larger than 3.0 mm. We should be aware that the image quality of these pIOLs might deteriorate under dim-light or night conditions, especially for post presbyopic IPCL-implanted patients.

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