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Research Article

## Visual Simulation of Retinal Images with Various Designs of Pinhole Contact Lenses

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### Abstract

**Purpose:** To determine the optimal design for pinhole type contact lenses (PCLs) without refractive power for obtaining a full range of resolution (clear vision) from far to near using a visual simulation system.

**Methods:** The PCLs had a 6.0-mm diameter black opaque central zone with varying clear central zones. The total diameter and the base curve of the PCL were 14.0 mm and 8.5 mm, respectively. The visual simulation system consisted of a model eye and a charge-coupled device camera. The different PCLs were placed in front of the model eye and evaluated. Visual simulations were performed using this system at 5, 1, and 0.3 meters through a 3-mm aperture using Landolt visual acuity (VA) charts with different PCLs (clear central zone sizes, 2.0, 1.8, 1.6, 1.4, and 1.2 mm). The contrast levels of the gaps of the Landolt VA charts in the simulated images were analyzed using Photoshop software to determine the optimal PCL design.

**Results:** The PCL's with a 1.2-mm and 1.4-mm clear central zone maintained the best resolution and contrast of the simulated images for all distances.

**Conclusions:** Our results suggested that a PCL without refractive power might be useful to obtain a full range of vision from far to near if designed optimally.

### ABBREVIATIONS

PCLs: Pinhole Contact Lenses; VA: Visual Acuity; CCD: Charge-Coupled Device

### INTRODUCTION

Presbyopia, which manifests from loss of accommodative

function of the crystalline lens, is a ubiquitous visual disability of the aging eye. The demand for clear, comfortable near vision is increasing with the widespread use of devices such as mobile phones, tablets and computers. It was recently reported that presbyopia is related to difficulties with activities of daily living and resulting social impediments (social impediments should be described) [1] and that both distance and near visual impairment

are independently associated with a poorer quality of life [2].

There have been many optical solutions to improve near vision for presbyopic patients. These solutions include not only the classic approaches of bifocals, trifocals, progressive-powered spectacles [3,4] or contact lenses (multifocal or mono vision) [5,6] but also a variety of surgical procedures, including corneal refractive surgeries [7,8] and intraocular lens [9-11] based surgeries. However, no procedures have gained general acceptance because of associated disadvantages, i.e., some have poor predictability, regression, limited effectiveness, and irreversibility, [12-14] while others are new and unproved over time.

Recently, a small aperture corneal inlay has been reported to be useful for treating Presbyopia [15-21]. The inlay is designed to increase the depth of field using the principle of small aperture optics. However, it is not a perfect method, because patients may have adverse symptoms postoperatively including dry eye, halo, glare, or night vision disturbances. The explanation of the small aperture inlay was reported in several cases previously [22]. There also may be a less than optimum effect [23]. Moreover, irreversibility without surgical procedures is a major concern.

Non-surgical correction using a small aperture contact lens may have an advantage. We could only find one study on a contact lens based pinhole system [16]; however, the aim of that study was to assess the effects of different artificial pupillary designs on visual performance using a pinhole-based system as a surrogate for corneal inlays, and the lens designs considered were small with nearly pupillary size, 3.5-mm, 2.5-mm, and 1.6-mm diameter, central apertures for an 8.0-mm diameter opaque zone and a 1.6-mm central aperture for a 4.0-mm diameter opaque zone. The current study assessed the optimal design of pinhole contact lenses (PCLs) without refractive power as a noninvasive treatment, to obtain a full range of vision from far to near using a visual simulation system and to evaluate the optical performance.

## MATERIALS AND METHODS

### Visual Simulation System

Our system simulates the retinal image in an eye with a contact lens. The schematic of this system is shown in (Figure 1). The fundamental approach in this system involves simulating retinal images in eyes with a contact lens under conditions that closely resemble the actual clinical environment. Our system consists of a model eye combining lenses with an artificial pupil and a charge-coupled device (CCD) camera (EO-1312CCD, Edmund Optics Inc., Barrington, NJ) with a pixel size of 4.65 by 4.65  $\mu\text{m}$ . The dimensions and refractive indexes of each surface in the model eye are provided in (Table 1). The total spherical aberration of this model eye was +0.32  $\mu\text{m}$  for a 6-mm aperture diameter. The contact lens can be held in front of the model eye and it is easily exchangeable. The centering of the contact lens can be almost perfectly secured using the special contact lens holder designed for this study. The size of the artificial pupil between the combined lenses is also exchangeable. The images formed by the system can be detected by the CCD camera and observed on the monitor of a personal computer. The different PCLs were placed in front of the model eye, and the images detected by the CCD camera were evaluated.

### Examination Settings

Visual simulations were performed using this system at 5, 1, and 0.3 meters through a 3-mm aperture using a Landolt visual acuity (VA) chart. Among the various sizes of Landolt charts, the 0.50 log MAR chart, which is equivalent to the telephone directory print size2 [4], was picked up to evaluate the contrast levels at each distance. The refraction of the model eye was set to -1.0 diopter [D], because it has been reported that the best compromise of depth of focus is obtained when the eyes have some residual myopic defocus (range -0.75 to -1.00 D) [17].

### PCLs

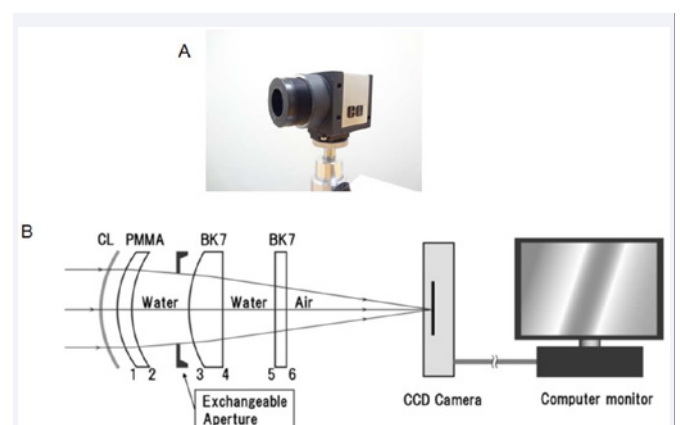
This PCL was designed to increase the depth of field and to decrease blur due to refractive error simultaneously without refractive correction using the principle of small aperture optics. The PCL had a clear central zone in a 6.0-mm diameter opaque zone, which was designed to achieve a pinhole effect to obtain the depth of field. The PCL itself had no refractive power (Figure 2). The contact lenses were made of silicone (water content, 0%). The overall diameter and the base curve of the PCL were 14.0 mm and 8.5 mm, respectively.

### Investigation of the Optimal Diameter of the Clear Central Zone

Visual simulations at near (0.3 m), intermediate (1 m), and distance (5m) were performed using PCLs with different clear central zones (2.0, 1.8, 1.6, 1.4, and 1.2 mm) to investigate the optimal diameter of the clear central zone to obtain the depth of field. As a control, visual simulation was also performed using a conventional contact lens with the same material, size, and curvature.

### Evaluation of Contrast Levels from Simulated Retinal Images

The contrast levels of the gaps of the Landolt VA charts in the simulated images were analyzed using Photoshop software (Adobe, San Jose, CA) to determine the optimal PCL design (Figure 3).



**Figure 1** Visual simulation system.

A: Eye model combined with lenses with an artificial pupil and a charge-coupled device (CCD) camera.

B: Schematic of the visual simulation system. CL, contact lens; PMMA, polymethylmethacrylate; BK7, barium borosilicate glass.

## RESULTS AND DISCUSSION

### Investigation of the Optimal Diameter of the Clear Central Zone

Figure 4 shows the simulated retinal images of the 0.5 log MAR chart with the PCLs and the control. Figure 5 shows the contrast levels of the gap of the Landolt's ring in the simulated retinal image of the 0.5 log MAR chart with the PCLs and the control. The results showed that the PCLs could improve resolution for distance compared to the control, and PCLs with the 1.2- and 1.4-mm clear central zones could obtain the depth of field from far to near although the resolution at near was poor.

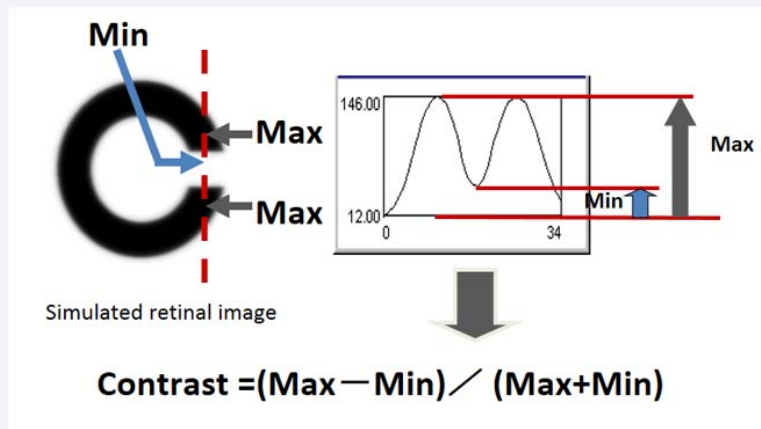
### DISCUSSION

In this study, the retinal images for eyes with variously designed PCLs without refractive power to obtain a full range of vision from far to near were simulated objectively using a newly designed visual simulation system in our lab. Only one previous report was found on visual function that used a contact lens based pinhole system [16]. In that report, visual performances with four different types of PCL designs were evaluated on the same patient. However, in that study, PCLs were worn only on the non-dominant eye, and the measurements were performed binocularly and subjectively. Therefore, the results did not directly reflect the optical performance of the PCLs themselves.

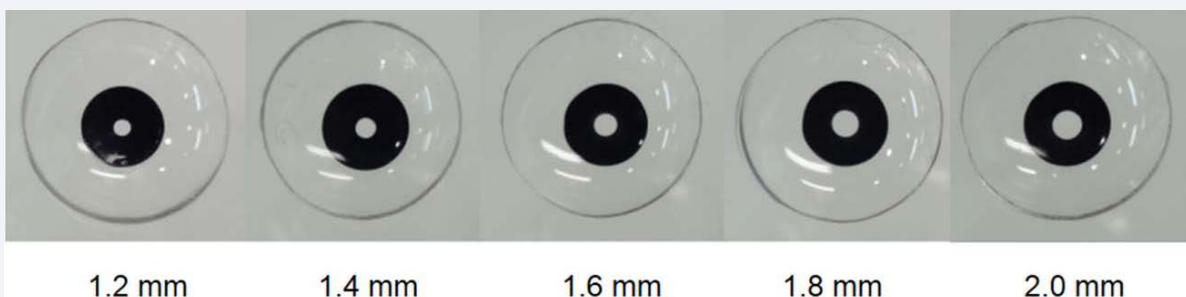
In addition, the diameters of the central aperture were 1.6 mm and over-notably different from our study

In our study we first assessed the optical performance of the PCLs themselves with various central zone sizes. Our results showed that the PCLs with only a 1.2- or a 1.4-mm clear central zone could keep the contrast level at all distances tested, although the contrast level at 0.3 m was relatively low.

Recently, a small aperture corneal inlay has been reported to be useful for treating Presbyopia [7,8,15,17-23]. Non-surgical correction of presbyopia has some advantages compared with surgical correction including a corneal inlay. First, the most important advantage is reversibility. Because PCLs are easily exchangeable, patients can try different designs and refractive powers of PCLs to determine the optimal prescription. Corneal inlays also are reversible; however, lifting a flap to remove the inlay or to modify the refraction may increase the risk of postoperative complications including for example, infection and epithelial in growth [25]. Thus, reoperation should be avoided. Another advantage is that PCLs do not require special equipment (e.g., surgical microscope, femtosecond laser, or other surgical instruments), because it is a non surgical treatment. Therefore, the technique can be performed easily in any setting, and it may be useful even in countries that do not have appropriate medical equipment.



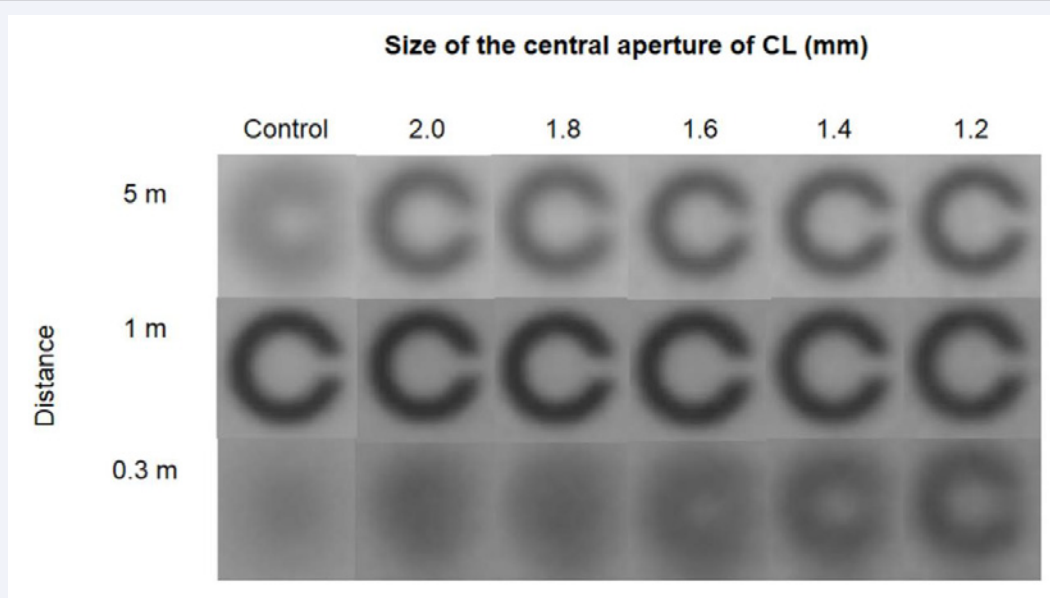
**Figure 2** Evaluation of the contrast level. The contrast level of the gap of the Landolt VA chart in the simulated image was analyzed using Photoshop software according to the formula: Contrast (%) = 100 \* (MAX-MIN)/(MAX+MIN). MAX, maximal luminance of the simulated retinal image; MIN, minimal luminance of the simulated retinal image.



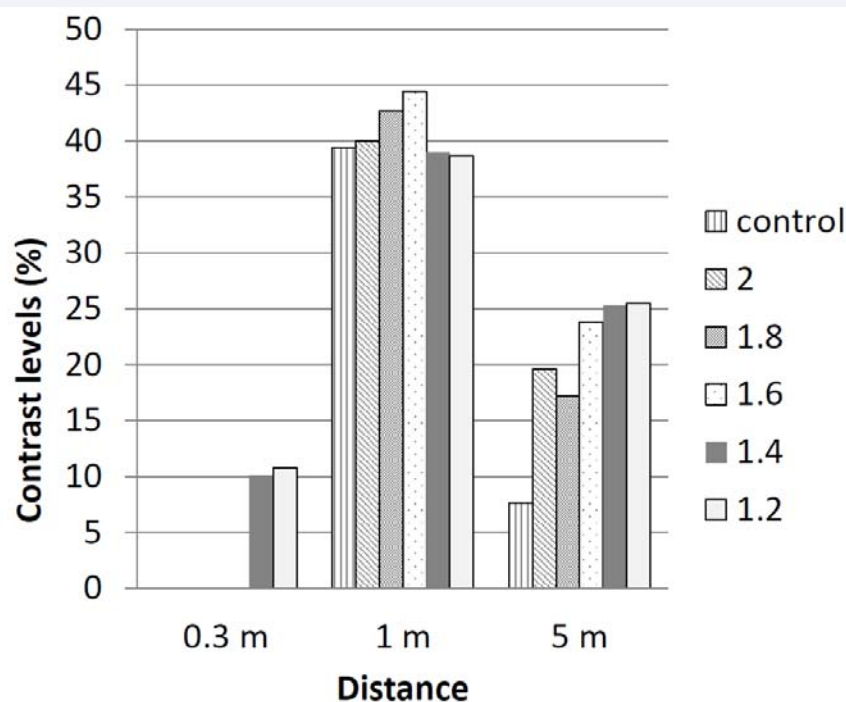
**Figure 3** Photograph of the pinhole contact lenses (PCLs). The PCL has a central clear zone for a 6.0-mm diameter opaque zone. The PCL itself has no refractive power. The overall diameter and the base curve of the PCL were 14.0 mm and 8.5 mm, respectively.

In contrast, the PCLs have some disadvantages. First, they require daily contact lens care. Therefore, patients who cannot care for their contact lens or are contact lens intolerant cannot use them. Another disadvantage is the difficulty of obtaining stable positioning of the PCL, because it usually moves after blinking. Tabernero and Artal [17] reported that decentration from the optimal position of about 0.5 mm could significantly reduce the retinal image quality and overall vision with a small

aperture corneal inlay. Gatinel et al [18] reported that two patients implanted with a small aperture corneal inlay that were recentered 2 weeks and 3 weeks postoperatively had significant improvements in the VA and quality of vision. Those reports suggested the importance of centration in the small aperture system. Upward movement of the typical soft contact lens at the vertical meridian was reported to be  $342 \pm 155 \mu\text{m}$  after blinking, [26] which might negatively affect the results.



**Figure 4** Simulated retinal images of the 0.5 log MAR chart with the PCLs and the control.



**Figure 5** Calculated contrast levels of the gap of the 0.5 the logarithm of the minimum angle of resolution (logMAR) chart in the simulated images with the pinhole contact lenses with clear central zone of 2.0, 1.8, 1.6, 1.4, and 1.2 mm.

M: Meters.



The current study had some limitations. First, we did not assess the effect of decentration. In this model eye, the PCLs and the corneal and pupillary centers were matched perfectly in the model eye. However, clinically, the pupillary center sometimes differs from the corneal center, which almost corresponds to the PCL center. In addition, a PCL may become decentered after blinking as mentioned previously. These primary and secondary decentrations may affect the optical performance of the PCLs. Another limitation of this study is that the tested refraction of the model eye was only -1.00 diopter, which is reported the best compromise of depth of focus [17]. Further investigations should be performed at other settings in refraction.

## CONCLUSION

In conclusion, a preliminary investigation utilizing a PCL without refractive power might be useful to obtain a full range of vision from far to near if designed optimally. The PCL's with a 1.2-mm or and 1.4-mm clear central zone maintained the best resolution and contrast of the simulated images at for all distances.

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