Quantitative Analysis of Functional Changes Caused by Pinhole Glasses

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PURPOSE. To quantify the visual functional changes caused by pinhole glasses.

METHODS. Healthy subjects underwent ophthalmic examinations including uncorrected distance visual acuity (UDVA) and corrected near visual acuity (CNVA), pupil size, depth of focus (DOF), accommodative amplitude, visual field (VF) test, contrast sensitivity (CS), and stereopsis. Subjects underwent the same examinations while wearing pinhole glasses 1 week later.

RESULTS. Forty-eight eyes of 48 subjects (24 male and 24 female) with a mean age of 35.5 ± 6.7 years and a mean spherical equivalent of −2.4 ± 3.3 diopters (D) were enrolled. The pinhole glasses significantly improved UDVA and CNVA (logMAR) from 0.44 ± 0.46 and 0.26 ± 0.40 to 0.19 ± 0.25 and 0.14 ± 0.22, respectively. The pinhole glasses markedly enlarged pupils from 3.6 ± 0.5 mm photopic size to 6.0 ± 0.5 mm, very close to the mesopic size of 6.2 ± 0.6 mm. Mean DOF and accommodative amplitude also significantly increased by approximately 50%, while VF featured a general reduction of sensitivity. Mean deviation (MD) significantly decreased from −0.48 ± 1.57 to −4.22 ± 1.66 dB, and visual field index (VFI) decreased from 99.4 ± 0.7% to 98.4 ± 1.3%. The CS decreased significantly at all four spatial frequencies, and stereopsis deteriorated with pinhole glasses.

CONCLUSIONS. The pinhole glasses improved visual acuity, DOF, and accommodative amplitude; however, they resulted in decreased visual quality including general reduction of VF sensitivity, CS, and stereopsis. Therefore, particular attention is needed when wearing pinhole glasses while driving, playing sports, or working with instruments. (ClinicalTrials.gov number, NCT02111356.)

Keywords: accommodative amplitude, functional changes, pinhole glasses, visual acuity, visual field test

Advertisements have suggested that these types of pinhole glasses help exercise and relax eye muscles. However, there is no scientific evidence that continuously wearing these glasses will result in permanent correction of ametropia and presbyopia. Furthermore, there are few clinical studies regarding visual functional changes with pinhole glasses.

Accordingly, the purpose of this study was to evaluate the influence of pinhole glasses on visual function as measured by visual acuity, pupil size, depth of focus, accommodative amplitude, visual field, contrast sensitivity, and stereopsis.

METHODS

This study was approved by the Chung-Ang University Hospital Institutional Review Board and adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all participants. Clinical trial registration was done at www.ClinicalTrials.gov (Identifier: NCT02111356). We recruited subjects who visited our clinic for ocular examination. Subjects were included if they were between 20 and 50 years of age and had spherical equivalents within ±6.0 diopters (D), correctable distance and near visual acuity by glasses up to 20/20, normal intraocular pressure, optic discs with a healthy appearance, and normal ocular alignment. Subjects were excluded if they had disturbance of accommodation due to an Adie’s pupil or...
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Parkinson’s disease, previous ocular surgery, a history of ocular trauma, a history of systemic or topical medication that might affect accommodation, corneal pathologic features, glaucomatous optic disc, glaucoma, cataracts of grade II or greater by the Lens Opacities Classification System III (LOCS III),
18 vitreous opacity, or retinal abnormalities that might limit the accuracy of testing.

All healthy participants underwent ophthalmic examination including manifest refraction, uncorrected distance visual acuity (UDVA), uncorrected near visual acuity (UNVA), corrected distance visual acuity (CDVA), corrected near visual acuity (CNVA), pupil size, depth of focus (DOF), accommodative amplitude, standard automated perimetry, contrast sensitivity (CS), and stereopsis. Subjects underwent the same examinations while wearing pinhole glasses 1 week later. Although both eyes of subjects were examined, only right eye data were included in the analysis for all measurements except stereopsis.

Applied pinhole glasses (Trynay Pinhole Glasses; Trynay Glasses, Ivybridge Devon, UK) had two 5.2-cm opaque black plastic discs of 1.7-mm thickness with 125 pinholes in each glass lens. The pinholes are lined up in 11 parallel horizontal rows, with each row displaced laterally by one-half spacing between holes. Pinholes had a 0.9-mm aperture and were separated by 5 mm horizontally and vertically and 3.5 mm diagonally (Fig. 1).

Ophthalmic Examination

Uncorrected distance visual acuity, CDVA, and distance visual acuity with the pinhole glasses (PinholeDVA) were measured using Snellen chart (Precision Vision, La Salle, IL, USA) at 4 m. Uncorrected near visual acuity, CNVA, and near visual acuity with the pinhole glasses (PinholeUNVA) were measured using Logarithmic Visual Acuity Chart 2000 (Precision Vision) at 40 cm. Visual acuity was converted to a logarithm of the minimal angle of resolution score (logMAR).

Pupil size was measured using a WASCA Analyzer (Carl Zeiss Meditec, Oberkochen, Germany) at photopic and mesopic conditions (85 and 5 cd/m², respectively). In addition, pupil size while wearing pinhole glasses under photopic conditions was measured with the ruler attached to the lateral rim of the glasses (Fig. 1). Pinhole pupil size was measured indirectly from the side; therefore, the measurement was inevitably approximate.

The monocular DOF was measured with a 4-m logMAR Snellen chart under distance correction without cycloplegics. Spherical defocus was induced by adding spherical lenses from −3.0 to +3.0 D in 0.5-D increments in a randomized order. The range of added lenses that maintained visual acuity of 20/25 or better during defocus was recorded. For example, if a subject could read 20/25 or better with an added lens from −1.5 to +1.0 D, his or her DOF was 2.5 D.¹⁹

The monocular near point of accommodation (NPA) was obtained using Donders’ push-up method.²⁰ The subject was instructed to view the target letter (20/20 reduced Snellen number), which initially was positioned at approximately 40 cm. The target then was moved progressively closer to the patient’s eye at approximately 5 cm/s until the subject noticed the target starting to blur. The distance between the point of blurring and the spectacle plane in meters was measured, and the inverse of the distance was calculated as diopters. Measured accommodative amplitude while wearing pinhole glasses was a combination of pseudocommodation induced by pinhole glasses and real accommodation. Real accommodation was included in both conditions, with and without pinhole glasses. Therefore, the difference between accommodative amplitude with and without pinhole glasses represents the pseudocommodation power induced by pinhole glasses. We defined this pseudocommodation power as an accommodative amplitude pinchhole (AApinhole).

Visual field (VF) test was performed with a Humphrey Visual Field Analyzer (Carl Zeiss Meditec, Inc., Dublin, CA, USA) using the 30–2 Swedish interactive threshold algorithm. Test time, visual field index (VFI), mean deviation (MD), and pattern standard deviation (PSD) were recorded.

The monocular CS test was performed using a CSV-1000E Contrast Testing Instrument (VectorVision, Dayton, OH, USA) at 2.5-m distance under standard brightness (85 cd/m²). This test was composed of the following four spatial frequencies: A (3 cycles per degree [cyc/deg]), B (6 cyc/deg), C (12 cyc/deg), and D (18 cyc/deg). The result was converted to a log scale.

For the measurement of stereopsis, the Randot Stereotest (Stereo Optical Co., Chicago, IL, USA) was used. This test was performed at 40 cm with the subject wearing the polarizing spectacles. The booklet was held at 40 cm perpendicular to the subject’s visual axis, especially while wearing pinhole glasses. Subjects were asked to identify the one circle that popped out of the page in each set. Threshold of stereopsis was recorded in seconds of arc.

Statistical Analysis

Paired t-test was used to compare the differences between wearing and not wearing the pinhole glasses in all exams.
Table 1. Clinical and Demographic Characteristics of the Subjects

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
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<td>Number of subjects</td>
<td>48</td>
</tr>
<tr>
<td>Male:female</td>
<td>24:24</td>
</tr>
<tr>
<td>Mean age, y (range)</td>
<td>35.5 ± 6.7 (27–44)</td>
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<td>Mean spherical equivalent, D (range)</td>
<td>−2.4 ± 3.5 (−6.0 to +2.0)</td>
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<tr>
<td>Mean UDVA/UNVA, logMAR</td>
<td>0.44/0.46</td>
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<tr>
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Values are expressed as mean ± standard deviation.

Correlation between pupil size and visual acuity change was evaluated using Pearson correlation test. Statistical analyses were performed using SPSS software (ver. 19.0 for Windows; SPSS, Inc., Chicago, IL, USA). Statistical significance was accepted for P values < 0.05.

RESULTS

Table 1 shows the characteristics of the 48 eligible subjects. Thirty-four of 48 subjects (71%) had myopia, 8 (17%) had emmetropia, and only 6 (12%) had hyperopia. All subjects had 20/20 CDVA and CNVA. Mean pupil size with pinhole glasses under photopic conditions was considerably enlarged compared with photopic pupil size (6.0 vs. 3.5 mm, P < 0.001). Furthermore, pinhole pupil size was very close to the mesopic pupil size (6.2 mm); the difference between the two values was not statistically significant.

Visual Acuity

Mean UDVA and PinholeDVA were 0.44 ± 0.46 and 0.19 ± 0.25, respectively. Distance visual acuity improved significantly while wearing pinhole glasses (P < 0.001). Visual acuity of all subjects with pinhole glasses was better or the same when compared to that without pinhole glasses. Visual acuity of 12 subjects did not show any change. Ten of these had spherical equivalents in the −0.50 to +0.50 D range, and their UDVA was 20/20.

Mean UNVA and PinholeNVA were 0.26 ± 0.40 and 0.14 ± 0.22, respectively. Near visual acuity improved significantly while wearing pinhole glasses (P = 0.002). No subject had decreased near visual acuity with pinhole glasses. Twenty-two subjects with 20/20 UNVA showed no change with pinhole glasses (Table 1; Fig. 2).

Depth of Focus and Accommodative Amplitude

Mean DOF with and without the pinhole glasses was 3.90 ± 1.68 and 2.60 ± 1.66 D, respectively. All subjects showed increased DOF with pinhole glasses, and the average DOF increase was 1.30 D (P < 0.001) (Fig. 3).

Mean accommodative amplitude without pinhole glasses was 8.35 ± 2.53 D. With pinhole glasses, it increased to 12.34 ± 3.26 D (P < 0.001), which is a mean AApinhole in all subjects of 4.09 D. All 48 subjects experienced improvement in NPA while wearing pinhole glasses.

Participants were subdivided into two groups according to age: a 20- to 39-year-old (younger) group and a 40- to 50-year-old (older) group. The younger group consisted of 32 subjects with a mean age of 30.4 ± 2.8 years, and the mean AApinhole was 3.56 D (from 9.56 ± 2.04 to 13.12 ± 2.89 D). The older group contained 16 subjects with a mean age of 43.5 ± 0.5 years, and the mean AApinhole was 4.72 D (from 6.24 ± 1.83 to 10.96 ± 3.49 D). There was no significant difference between the two groups (3.56 vs. 4.72 D, respectively, P = 0.065, Mann-Whitney U test).

Visual Field

Visual field constriction within the central 30° was not seen in any subject. Mean VF test time was prolonged with the pinhole glasses from 359 ± 34 to 420 ± 30 s (P < 0.001). Mean VFI, MD, and PSD while wearing pinhole glasses also changed significantly. Among these values, the MD value showed the largest change (decreased by 783%), and VFI showed the smallest change (decreased by 1%). All subjects showed similar patterns of VF change; test time increased, MD values decreased, PSD values increased, and VFI values changed minimally (Table 2). Therefore, VF while wearing pinhole glasses featured a generally reduced sensitivity. It was more prominent in the peripheral fields than in the central field (Fig. 4).

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Contrast Sensitivity

The decrease of CS was statistically significant at all spatial frequencies (A, B, C, and D) while wearing pinhole glasses (Table 3; Fig. 5). The higher the frequency, the greater the decrease in CS while wearing pinhole glasses (Table 3).

Stereopsis

Mean stereopsis with and without pinhole glasses was 44.6 ± 12 and 90 ± 57 seconds of arc, respectively. Therefore, stereopsis decreased significantly with pinhole glasses ($P < 0.001$). No subject had better stereopsis while wearing pinhole glasses. Only eight of 48 (17%) subjects maintained the same stereopsis values; the other 40 subjects (83%) had deteriorated stereopsis values.

Table 2. Change of Parameters of Visual Field Tests Before and After Wearing the Pinhole Glasses

<table>
<thead>
<tr>
<th>Without Pinhole Glasses</th>
<th>With Pinhole Glasses</th>
<th>Percentage Change</th>
<th>$P$ Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test time, s</td>
<td>359 ± 34</td>
<td>420 ± 30</td>
<td>+17</td>
</tr>
<tr>
<td>VFI, %</td>
<td>99.4 ± 0.7</td>
<td>98.4 ± 1.3</td>
<td>-1</td>
</tr>
<tr>
<td>MD, dB</td>
<td>-0.48 ± 1.57</td>
<td>-4.22 ± 1.66</td>
<td>-783</td>
</tr>
<tr>
<td>PSD, dB</td>
<td>1.89 ± 1.52</td>
<td>2.26 ± 0.71</td>
<td>+20</td>
</tr>
</tbody>
</table>

*+, increase; −, decrease. †$P$ value by paired $t$ test.

Correlation Between Pupil Size and Visual Acuity Change

We determined the correlation between pupil size and the difference of distance visual acuity ($\text{UDVA} - \text{PinholeDVA}$). Mesopic pupil size and visual acuity improvement with pinhole glasses showed a significant positive correlation ($R = 0.724, P < 0.001$). After excluding 10 participants who had 20/20 UDVA at baseline and 20/20 with pinhole glasses, the correlation between pupil size and visual acuity change became more positive ($R = 0.868, P < 0.001$). Pinhole pupil size and visual acuity improvement with pinhole glasses also showed a significant positive correlation ($R = 0.700, P < 0.001$), but photopic pupil size did not show any correlation with the change in distance visual acuity while wearing pinhole glasses ($R = 0.211, P = 0.218$) (Fig. 6).

Discussion

In the current study, we determined the influence of pinhole glasses on eye function. The pinhole glasses improved uncorrected distance and near visual acuity, increased DOF and pseudocommodative power, and enlarged pupil size; however, CS, stereopsis, and VF indicators including MD, PSD, VFI, and test time deteriorated. To our knowledge, this is the first report regarding the visual functional changes that occur while wearing pinhole glasses.

We think that visual acuity with pinhole glasses improved due to the original pinhole effects. Small pinhole aperture

FIGURE 4. Visual field tests without (A) and with (B) pinhole glasses. Mean deviation decreased significantly from $-0.73$ to $-4.86$ dB, and PSD increased from 1.20 to 2.14 dB. Visual field index changed from 100% to 99%. Abnormalities of retinal sensitivity were observed at the peripheral field area. MD, mean deviation; PSD, pattern standard deviation; VFI, visual field index.

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narrow the envelope of the incident rays, so the size of the retinal blur circle becomes proportionally smaller. Therefore, the entire retinal image becomes sharper.\textsuperscript{9,10} In addition, small apertures block aberrant rays emanating from the periphery,\textsuperscript{11-15} decreasing retinal blur circles. Unfortunately, small aperture size is not without limitations. Very small aperture size can induce diffraction and visual acuity decrease. One report showed that aperture size smaller than 0.75 mm causes considerable diffraction blurring, while aperture size larger than 2.0 mm causes no diffraction-related problems.\textsuperscript{16} Therefore, it is important to set the appropriate aperture size to simultaneously achieve ideal pinhole effects and avoid diffraction blurring. In this study, we used pinhole glasses with 0.9-mm pinholes (definitely smaller than the average 3.6-mm photopic pupil), which resulted in improvement of visual acuity.

Our study demonstrated an increase in DOF (1.30 D) when subjects wore pinhole glasses. There are several factors that may influence the DOF, including the visual target, luminance, contrast, spatial frequency, visual acuity, and pupil size. Among these, decreased aperture size and decreased luminance from wearing pinhole glasses have been shown to result in an increased DOF.\textsuperscript{21,22}

Pinhole glasses changed accommodative amplitude from 8.35 to 12.34 D. That is, the pseudoaccommodative power induced by pinhole glasses was 3.99 D. This effect may be explained by the small aperture of the pinhole glasses requiring less accommodative power for the same stimulus. As a result, subjects can generate the maximal amplitude of accommodation for a particular stimulus.\textsuperscript{23} These effects of pinhole glasses can support presbyopia, and this concept led to the development of a small-aperture corneal inlay.\textsuperscript{5-7}

Image quality increased by a pinhole can be diminished when the level of illumination reaching the retina is attenuated.\textsuperscript{24} In this situation, pinhole glasses with a series of equally sized, regularly placed pinholes are better than a single pinhole occluder. Multiple pinholes increase the incident light rays and can improve luminance. Nevertheless, the area of the opaque portion of the glasses is still larger than that of the perforated portion. Therefore, pinhole glasses with 125 0.9-mm pinholes reduce the brightness and enlarge mean pupil size from 3.6 to 6.0 mm, which is very close to mesopic pupil size. The impacts of decreased luminance were well demonstrated in test results for VF, CS, and stereopsis. For this reason, visual quality was markedly decreased if subjects used the pinhole glasses under dim illumination, and particular attention is needed when wearing the pinhole glasses under this condition. Considering this aspect, we strictly maintained the room illumination constant during the ocular examinations.

Visual field index, MD, and PSD of the VF test deteriorated with pinhole glasses. Among these changes, the MD change was the largest. It decreased from −0.48 to −4.22 dB, or 783%. This change is explained by reduced luminance because decrease of MD is similarly shown in central cataract patients. A decibel is 0.1 logarithmic unit, so a change of 3.74 dB represents a 2.4-fold decrease of stimulus attenuation. However, luminance attenuation was not even for the whole field. Rather, it was more prominent on peripheral fields (Fig. 4). Therefore, mean VFI, which is independent of cataracts and puts weight on central field over peripheral fields,\textsuperscript{25} decreased by just 1% (Table 2). This result can be explained as follows. Rays of light traverse the multiple pinholes from various directions. The rays pass through cleanly when they are released perpendicularly to the pinhole aperture. However, when the rays pass through from the periphery, they may slant and encounter interference at the aperture or be blocked by the side of the pinhole. The more peripheral the rays, the fewer incident rays pass through (Fig. 7). Finally, decreased sensitivity was more prominent at peripheral fields than at the central field. Although the VF had a generally reduced sensitivity with pinhole glasses, VF constriction within the central 30° was not shown in any subject.

Contrast sensitivity while wearing pinhole glasses decreased significantly at all four spatial frequencies. The decrease was more marked with increasing frequency. Similar results have been observed in previous studies.\textsuperscript{6,7} Decrease of luminance was related to deterioration of CS.\textsuperscript{26,27} Pupil or pinhole size has a large effect on the optical transfer function of the eye, and if the pupil or pinhole size is fixed, transfer rate decreases more as frequency increases.\textsuperscript{28,29} Accordingly, in our study, decrease of luminance by pinhole glasses caused general reduction of CS. Since the small aperture of the pinhole played the role of a low-pass filter, decrease of CS was more definite at high spatial frequency. Stereopsis also decreased with pinhole glasses. This result is explained by the fact that luminance affects stereopsis and is directly proportionate.\textsuperscript{30,31}

Improvement in UDVA while wearing pinhole glasses was markedly related to pupil size. The larger the pinhole pupil size or mesopic pupil size, the greater the improvement in visual acuity. As mentioned earlier, mean pupil size with pinhole glasses was similar to mesopic pupil size; therefore, mesopic rather than photopic pupil size might show a positive relationship. We propose the following reasons for this finding. First, a large mesopic pupil size permits a large amount of incident rays. Therefore, luminance behind the pinhole glasses increases. Second, a large pupil reduces diffraction blurring.
Third, a large mesopic pupil can include multiple pinholes, making it easier to find a hole centered on the pupil. Therefore, the manufacturing features of pinhole glasses must be considered in the interpretation of our results. These features include total number of pinholes, size of pinhole apertures, and separation interval between multiple pinholes. Patient characteristics, including vertex distance and the mesopic pupil size, should also be considered because if vertex distance increases, awareness of the multiple pinholes increases. In situations with an enlarged pupil, the eye would then perceive multiple apertures.

Our study has some limitations. All participants underwent the same ophthalmic examination while wearing pinhole glasses 1 week later. Therefore, some of the differences between the two conditions could be attributed to the fact that subjects were always tested in the same, rather than random, order. However, examinations comprised tests with no learning effect except for the VF test. Moreover, results related to the VF test while wearing pinhole glasses worsened despite any learning effect. Therefore, the examination order related to pinhole glasses would not affect the validity of the results. Another limitation is that objective DOF should be evaluated under the condition of accommodation paralysis using cycloplegics. However, other studies have shown that the results from DOF studies with and without cycloplegia are similar, and the eye accommodates the minimum amount to place the target within its depth of field to see the object clearly, independent of the viewing distance. It can be inferred that evaluation of DOF without cycloplegics would be less affected by accommodation, and thus the results obtained here would be acceptable for measuring DOF.

In conclusion, pinhole glasses have some advantages, including improvement of visual acuity for patients with a UCVA < 20/20, DOF, and amplitude of accommodation; however, they also have disadvantages including general reduction of VF sensitivity, deteriorated contrast sensitivity, and reduction of stereopsis. Therefore, particular attention is needed when wearing the pinhole glasses while driving, playing sports, or working with instruments. Furthermore, pinhole glasses are more beneficial for subjects with larger mesopic pupil size.

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References


