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Research Article

# Achromatic Ophthalmic Telescope to Restore Vision in Age-Related Macular Degeneration Patients

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## Abstract

Purpose To develop a new optical solution based on a variable achromatic telescope (AOT) that allows retinal relocation to restore the loss of central vision in Age-Related Macular Degeneration (ARMS) patients.

**Methods:** Zemax optical modelling software was used to design an AOT that allows retinal relocation by light steering based on the control of the off-axis decentration of the AOT lenses: The performance of the optical solution was tested and evaluated in an ARMD theoretical eye model by optical simulation.

**Results:** The calibration process of the AOT allowed obtaining a general equation for AOT involving the size of the damage area at the retina, the required off-axis telescope displacement and the focal length of the employed lenses. The peripheral retinal image quality was evaluated for different AOT configurations.

**Conclusions:** This work presents an ophthalmic solution based on an achromatic optical telescope with capabilities to restore the loss of central vision due to retinal damage in ARMD patients. On the other hand, the methodology provides a new subjective method to evaluate the restored visual acuity at the peripheral retina.

***Keywords:*** *Achromatic Ophthalmic; Macular Degeneration Patients*

## Introduction

Age-related macular degeneration (ARMD) is a progressive degenerative retinal disease that causes macular dystrophy, subretinal neovascularization and changes in the retinal pigment epithelium [1]. ARMD is the world's third leading cause of blindness in older adults after glaucoma and cataract [2]. From an epidemiological point of view, the prevalence of ARMD disease increases since the age of 50 reaching the peak around the age of 80 [3].

The global prevalence of ARMD patients projected for 2020 was 196 million, and expected to increase up to 288 million in 2040 [4]. Without an early diagnosis that ensures successful treatment [5] or in advanced stages, ARMD patients evolve to foveal degeneration, where the visual acuity is highest. This dystrophy causes loss of central vision [3] and visual impairment [6].

Patients with macular function loss can benefit from vision rehabilitation by incorporating optical prisms to low and distance vision glasses to produce image relocation toward the peripheral retina [7-9].

The real prismatic effect of the light that after passing through the ocular media overcomes the damaged area and optimizes the visual acuity can not be accuracy achieved with the current ophthalmic solutions. On the other hand, modifying the prismatic power after adding the prisms into wearable eyeglasses is not possible and this limitation can become critical due to bad vergence adaptation inducing negative effects in fixation disparity [10]. In this sense, the accurate calculation of the prismatic effect and achieved optical quality of the relocated retinal image in ARMD are still challenge topics.

This work presents an achromatic ophthalmic telescope (AOT) based on the Galilei configuration which allows micrometric control of the prismatic effect induced by relative lateral displacement of the lenses allowing accurate retinal relocation and image formation out of the damaged area. The proposed eye model allows incorporating the patient biometry for a better calculation of the required configuration and initial prismatic effect. This first approach can be optimized by subjective testing of the visual acuity with the patient wearing the AOT in a similar way to subjective refraction in optometry practice. The application of the AOT in low vision could provide a new way of subjective evaluation of vision and optical quality improvement at the periphery of ARMD patients.

## Methods

### ARMD Eye Model and retinal illumination

Zemax (Zemax, OpticStudio®) optical system design software was chosen to design the AOT and to develop an ARMD eye model for testing and calibration. The Liou and Brennan´s eye model [11] provides anatomically accurate retinal analysis and image formation in an unaccommodated emmetropic eyes. This eye model has been used in this study and incorporated in non-sequential mode of Zemax software. NSM allows ray tracing in any order, analyzing straylight and modelling of sources and detectors. In this sense, the retinal surface was replaced by a detector of 80 radial by 80 angular zones. The radius of curvature was chosen to be the same that the inner sclera. The scotoma (damaged area) was generated by coupling an absorbing surface of PMMA material to the central part of the detector. The retinal illumination was based on white light source diode projecting a uniform disk on the retina of 10º of visual field. Fig. 1 shows the retinal disk projection in an ARMD-free eye model (Figure 1a) and different degrees of severity of the scotoma in ARMD affected eyes, corresponding to 1º (Figure 1b), 2º (Figure 1c) and 5º of damaged visual fields. The pupil size of the eye model was fixed in 6 mm in this study.

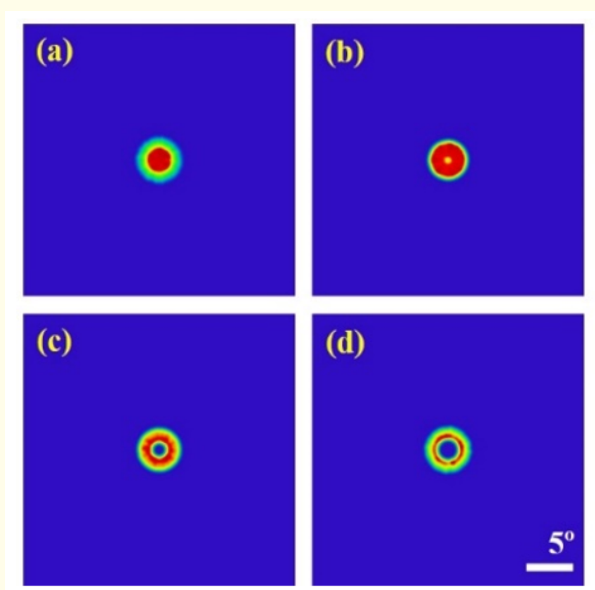


***Figure 1:*** *Retinal projection of a uniform disk covering the 10º central visual field for non-damaged retina (a) and for 1º (b), 2º (c) and 5º (d) of damaged visual fields, respectively.*

### Telescope design and ocular point spread function

Laser beam expanders traditionally consist of Galilean telescopes which are formed by a positive and a negative lens separated by the sum of their focal lengths. Briefly, the higher the difference between the focal lengths the higher the magnification of the output beam.

In this work, a Galilei telescope with angular magnification equal to unity is proposed to overcome the damaged retinal area. The concept is based on the prismatic effect that is induced when the optical axis of the lenses are not aligned in a lateral plane.

The proposed AOT is based in a couple of achromatic doublet (ACD) lenses with opposite focal lengths. In this work we have evaluated the performance of the AOT for different configurations corresponding to three couples of opposite focal lengths using Zemax lens catalog from Thorlabs Company (Thorlabs, Inc.). The lenses used in each configuration are summarized in table 1.

| Configuration | Lens Model | Focal Length |
|---|---|---|
| *Conf. #1* Lens 1 | AC-254-050-A | $f_1$= + 50 mm |
| *Conf. #1* Lens 2 | ACN-254-050-A | $f_2$= - 50 mm |
| *Conf. #2* Lens 1 | AC-254-075-A | $f_1$= + 75 mm |
| *Conf. #2* Lens 2 | ACN-254-075-A | $f_2$= - 75 mm |
| Conf. *#3* Lens 1 | AC-254-100-A | $f_1$= + 100 mm |
| *Conf .#3* Lens 2 | ACN-254-100-A | $f_2$= - 100 mm |

***Table 1:*** *ACD lenses used in the telescope evaluation.*

To evaluate the optical performance in terms of retinal image quality of the described configurations, the extended illumination source is replaced by a small-diameter collimated laser beam (2 mm diameter, λ=535 nm). Figure 2 shows an example of the operating principle of the AOT. When the AOT is off (i.e. no lateral displacement, Δy=0 mm), it can be observed how the collimated beam is focused at the intersection of the optical axis and retinal plane of the ARMD eye model. When a relative lateral displacement is set at the AOT (AOT on) the induced prismatic effect causes retinal relocation of the collimated beam after passing through the ocular media. In this work, the second surface of the second lens is fixed at the corneal vertex distance of 12 mm.

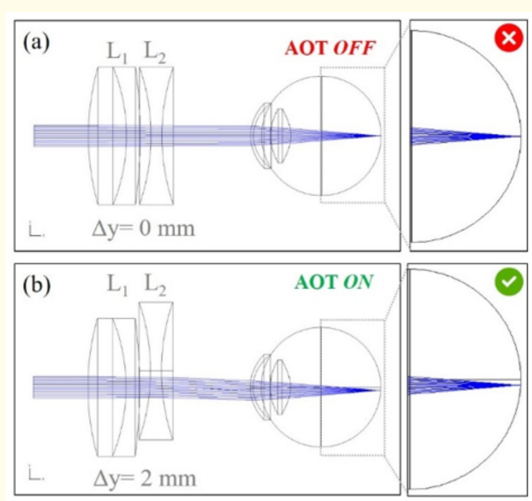


***Figure 2:*** *Example of the AOT operation.*

Figure 3 shows the eye model point spread functions (PSFs) for the three different AOT configurations and the corresponding radial averaged MTFs, from the real (blue lines) and the diffraction-limited (black lines) MTFs the Strehl ratio (SR) is computed. Briefly, a system can be near-diffraction-limited (aberration free) considered RS ≥ 0.80. The obtained SR values were SR = 0.999, 0.995 and 0.993, respectively, therefore the off-operation of the three configurations of the AOTs provides aberration-free image retinal formation what is a good starting point from the calibration process without spurious aberrations entering the eye.

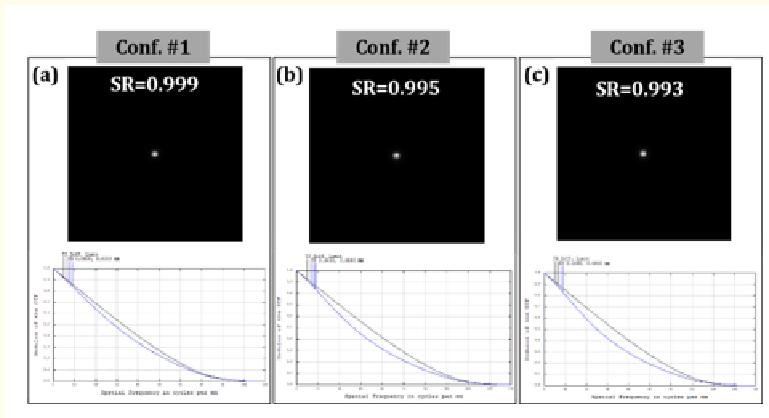


***Figure 3:*** *Ocular PSFs for the different configurations for the AOT (off operation) (upper panels). The bottom panels compare the real aberrated (blue lines) and diffraction-limited MTFs (black lines).*

## Results

Retinal relocation eccentricity and relative displacement of the AOT

The ideal goal of the AOT is to provide the minimum retinal relocation with maximum visual acuity. Figure 4 compares the retinal eccentricity or relocation as a function of the relative displacement of the lenses for the three different configurations of the AOT. For this purpose the retinal illumination used was the punctual source showed In figure 3.

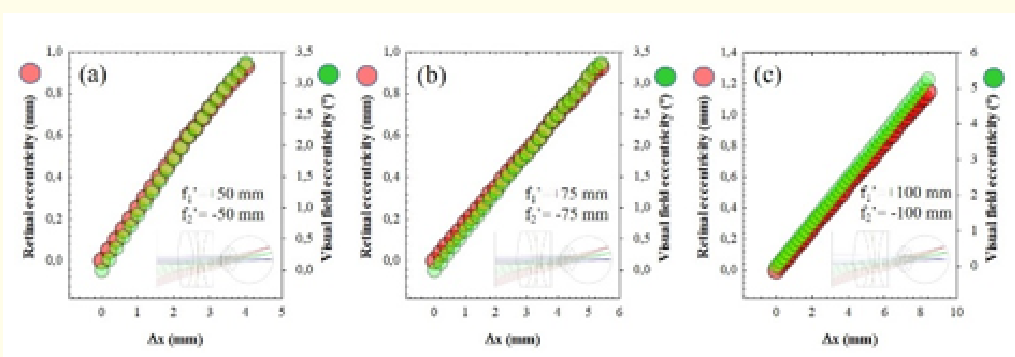


***Figure 4:*** *Ocular PSFs for the different configurations for the AOT (off operation) (upper panels). The bottom panels compare the real aberrated (blue lines) and diffraction-limited MTFs (black lines).*

The reached visual field was calculated considering the equivalence of 1º for every 280 µm of longitudinal eccentricity [12]. From the simulated results, the relationship between laterial displacement of the lenses Δx, and visual field eccentricity VFE, is given by eq. (1):

VFE= K * Δx (1)

with K=f (FL) being a factor depending on the FL:

$$\boldsymbol{K = f\,(FL) = a * F_L^2 + b * F_L + c} \qquad (2)$$

Where a= -0.0002, b= 0.0413 and c= -1.607. Depending on the visual demands of the ARMD patient a balance between AOT parameters must be agreed: The longer the absolute value of the focal length (FL) of the pairs of lenses the smoother the retinal relocation, but the longer the required relative displacement. On the other hand, the shorter the focal length, the higher the weight and dimensions of the AOT.

Retinal imaging as a function the AOT configuration The previous section showed a calibration process of the AOT as a function of the FL of the telescope lenses using punctual source retinal illumination. This section evaluates the performance of the AOT projecting an extended source based on a uniform disk (described in Methods) corresponding to 10º of visual field onto a total retinal field of 30º. The retina was modelled with a central circular-like escotoma of 5º of diameter. The upper row (Figure 5a, Figure 5b and Figure 5c) shows retinal images with retinal relocation achieved by lateral displacement of Δx=1.90 mm, 2.70 mm and 4.20 mm corresponding to the three AOT configurations, respectively. It is clearly visible that the prismatic effect partially overcomes the central escotoma, which can be absolutely overpassed by incorporating the parameters calculated from Figure 4 that correspond to Δx = 3.80 mm, 5.40 mm and 8.40 mm for a damaged retinal area of 5º of diameter, respectively.

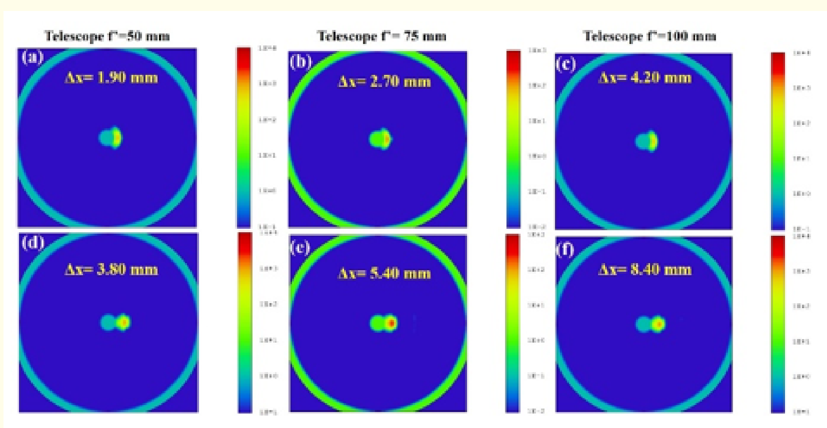


***Figure 5:*** *Fundus images corresponding to a retinal field of 30º delimited by the pheriperal rings. The central part of the images shows the dimensions of the escotoma of 5º of diameter. The upper panels shows an example of partial correction, which is corrected in those images shown in the bottom panels after incorporating the parameters calculated from Figure 4.*

### Vision simulation and retinal optical quality after retinal relocation

The prismatic effect based on the AOT relative displacement, this off-axis configuration induces significant optical aberrations that degrade the retinal image quality, the higher the damaged area, the higher the aberrations that compromises the AOT. On the other hand retinal eccentricity beyong the central 3 degrees has a significant lower population of cones and consequently poor visual acuity, therefore the final visual acuity depends on the damaged area, induced aberrations and the patient itself. In this sense, Figure 6 shows the ocular PSFs of the AOT off 8 (Figure 5a) and those corresponding to the eccentricities reached in Figures 5 (d-f) with the different configurations of the AOT using punctual source illumination. A visual inspection reveals a greater spreading in the PSF in the AOT configurations that require longer lenses decentration. For visual perception, Figures 6 (f-h) show the convolution of the Snellen E optotype of the Figure 6c with the corresponding PSFs, the costs of reaching the prismatic effect by lens decentration are optical aberrations (mainly defocus, astigmatism and coma) which degrade the optical quality and image contrast as shown in the vertical pixel intensity profiles (Figures. 6i-l). The convoluted images shown in Figures 6 (j-l) present a Michelson Contrast of 0.63, 0.58 and 0.42. To overcome the same damaged area (retinal eccentricity), the longer the FL at the configuration of the AOT the worse the image degradation. Although the final visual acuity will depend on both the delivered optical degradation at the given periphery and the retinal response of the patient, for the sense of completeness Fig. 7 shows the total aberration computed by the Root Mean Square (RMS) value induced by lens decentration at the AOT represented in Figure 4.

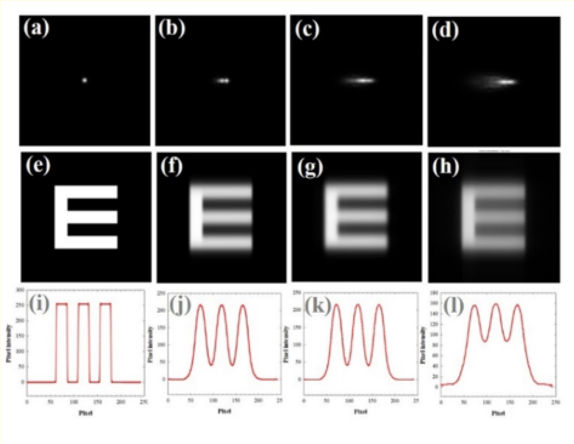


***Figure 6:*** *Upper row: PSF of the AOT off and corresponding PSFs of the images of Fig. 5 (d, c, f), respectively. Mid row: convolution of the Snellen E optotype (Fig.6e) with the PSFs of the upper row. Bottom row: pixel-intensity vertical profiles computed from the images of the mid-row.*

The RMS values of total aberration that degrades the image of Figure 6 (i) into images of Figures 6 (f-h) by means of the PSFs shown in Figures 6(b-d) are 0.26, 0.32 and 0.45 µm, respectively. This results shown that the worst performance corresponds to the AOT configurations with longer FL as require greater lens decentration at the AOT (Figure 7).

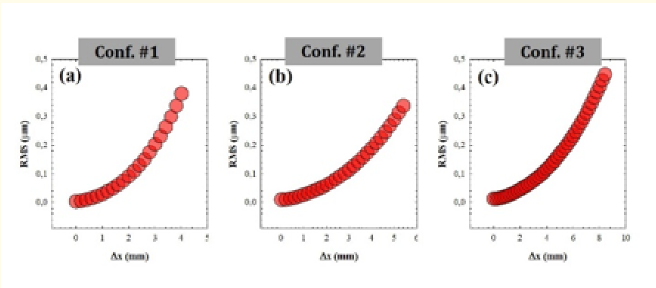


***Figure 7:*** *RMS values as a function of the lateral displacement of the AOT, Δx, for each telescope configuration.*

## Discussion and Conclusions

This work presents a new ophthalmic approach to overcome loss of vision due to retinal damage in ARMD patients. The instrument is based on a simple optical telescope with Galilean configuration and uses the beam steering control for retinal relocation by relative decentration of the telescope lenses as operation principle.

The study first presents the design of the telescope composed of pairs of achromatic doublets with opposite FL and a theoretical eye ARMD model with a scotoma located at the central retina. Zemax software was used for optical design and the performance evaluation of the proposed ophthalmic solution under different configurations.

This cost-effective optical solution overpasses the chromatic dispersion induced by optical prisms added to eyeglasses prescribed for low vision and ARMD patients [7-9].

Results revealed the capability of the AOT for retinal relocation through the eye with micrometric control. The ARMD model allows incorporate the patient biometry for a more accurate initial calculation of the AOT parameters.

The different configurations were classified as a function of the lenses FL, from them a calibration process allowed obtaining a general equation of the AOT to overcome the scotoma relating the damaged area, the relative AOT displacement and the chosen FL.

The costs of induce prismatic effects by lens decentration at the telescope were mainly optical aberrations: defocus, astigmatism and coma. The final achieve visual acuity will depend on the required peripheral relocation as a function of the retinal damage, the induced optical aberration by the AOT and the retinal response itself.

In this sense, the initial configuration of the AOT based on patient campimetry and biometric data allows real-time modifications in the way of subjective evaluation of peripheral visual acuity evaluation, which may differ from theoretical calculations due to the particular visual perception of the patient.

Initial considerations must include a balance between FL and severity of the damaged area, as the longer the FL the lighter the volume and weight of the AOT but worse the optical quality.

To conclude, this work presents an optical solution that restores loss of central vision due to retinal damage in ARMD patients and provides a new subjective method to evaluate the restored visual acuity at the peripheral retina.

Future improvements of the proposed AOT include the pre-compensation of the optical aberrations that would improve the optical quality of vision at the peripheral relocation.

## Disclosures

Author declare no conflicts of interest.

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