SCLERAL CONTACT LENS TILT MEASUREMENT FOR HIGHER ORDER ABERRATIONS CORRECTION

XIFENG XIAO, PHD, DANIEL NEAL, PHD

WAVEFRONT DYNAMICS INC.

Background and Purpose

Scleral contact lenses are generally designed to vault over the cornea and, by definition, to rest on the sclera.

Thus, there is no reference between the scleral lens and the cornea in terms of centration or tilt.

The sclera has variations in shape in the nasal and temporal directions, so the lens is likely to be moderately or significantly tilted relative to the line of sight [1,2].

For effective wavefront higher order correction, it is essential the wavefront correction be placed in the correct location [3].

The sag of scleral lenses is fairly large (5-6 mm), which can lead to a significant error unless the tilt is measured and taken into account.

TYPICAL EXAMPLES

When a contact lens experiences tilt, the edge identified lens center and fiducials identified center are different. Both right and left lenses tend to tilt on temporal directions.

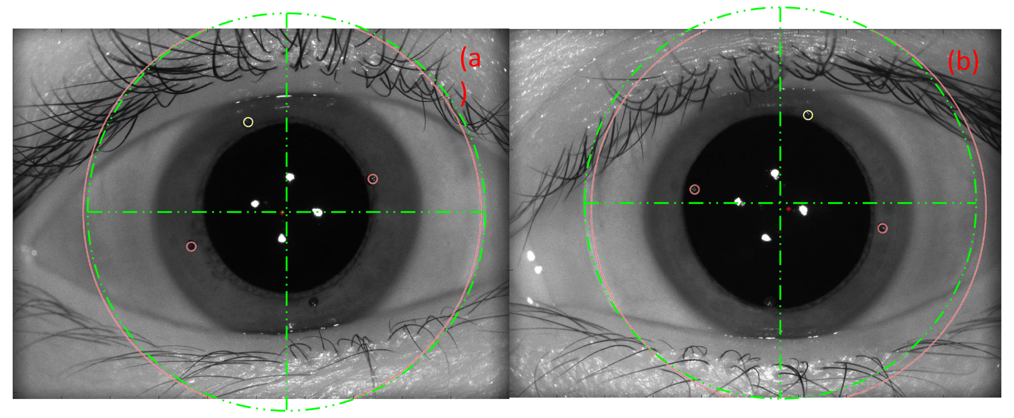


Figure 1. Demonstration of edge identified lens (Green) and fiducials identified lens (red) for right eye (a) and left eye (b).

Two methods were used to measure the centration and tilt of the scleral contact lens: A) fiducial marks were placed near the center, and B) measurements with a telecentric topographer were used in conjunction with the CL edge.

Method A

Use designed fiducial marks

- Apply the predesigned fiducial marks (two or more) to the Sph/Cyl lens. In our design, 3 marks are 4mm away from the center and placed at 0, 90, and 180 degrees, respectively;
- Use their geometrical relationship and calculate the center (X_C, Y_C). For example, if (X_{M1}, Y_{M1}) and (X_{M2}, Y_{M2}) are on diagonal direction,

$$(X_C, Y_C) = [(X_{M1} + X_{M2})/2, (Y_{M1} + Y_{M2})/2] \quad (1)$$

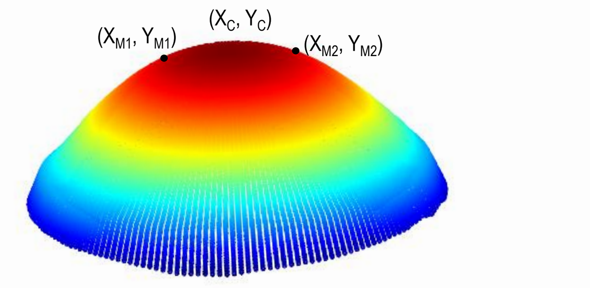


Figure 2. Contact lens profile with two (or more) designed fiducial marks (X_{M1}, Y_{M1}) and (X_{M2}, Y_{M2}) that are used to calculate center (X_C, Y_C)

Pros and Cons:

- Reliable fiducial recognition algorithm, Calculation is straightforward;
- The procedure of adding fiducials on the Sph/Cyl lens is required.

Method B

Use the measured corneal vertex (X_V, Y_V) and lens edge information

- Extract contact lens size, sag S_0, optical zone's radius of curvature R, from Sph/Cyl lens points files;
- Obtain corneal vertex position (X_V, Y_V) and edge identified lens center ($X_{C'}$, $Y_{C'}$) from the aberrometer measurements.

$$(X_{C'}, Y_{C'}) = [(X_{E1} + X_{E2})/2, (Y_{E1} + Y_{E2})/2]; \quad (2)$$

where (X_{E1}, Y_{E1}) and (X_{E2}, Y_{E2}) are two points at lens diagonal direction.

- Implement the calculation to find tilt angle θ with x and y components $\theta = (\theta_X, \theta_Y)$:

$$\tan(\theta_X) = (X_V - X_{C'})/R; \quad \tan(\theta_Y) = (Y_V - Y_{C'})/R. \quad (3)$$

and real contact lens center (X_C, Y_C):

$$X_C = X_{C'} + S_0\sin(\theta_X); \quad Y_C = Y_{C'} + S_0\sin(\theta_Y). \quad (4)$$

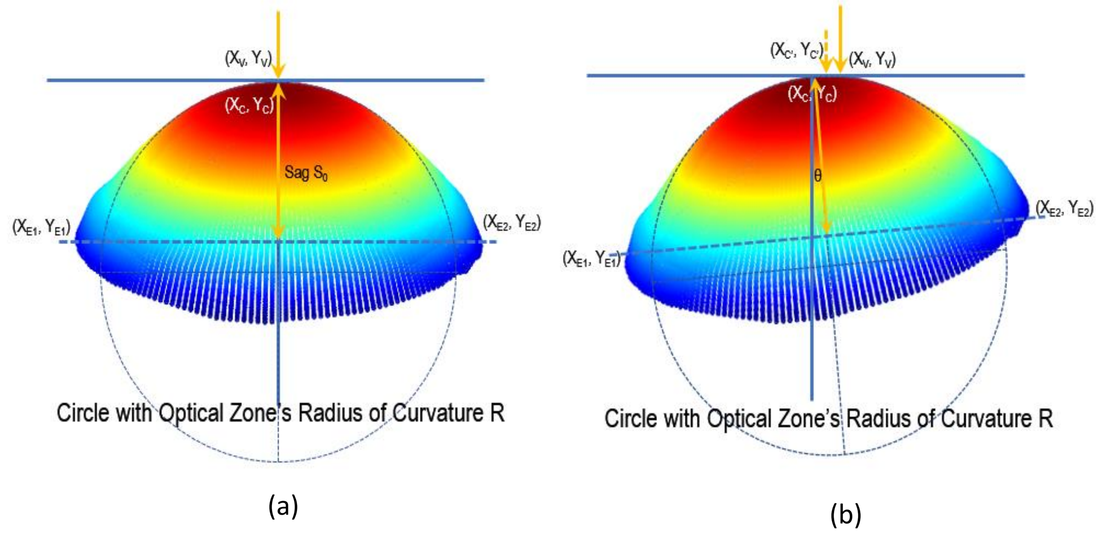


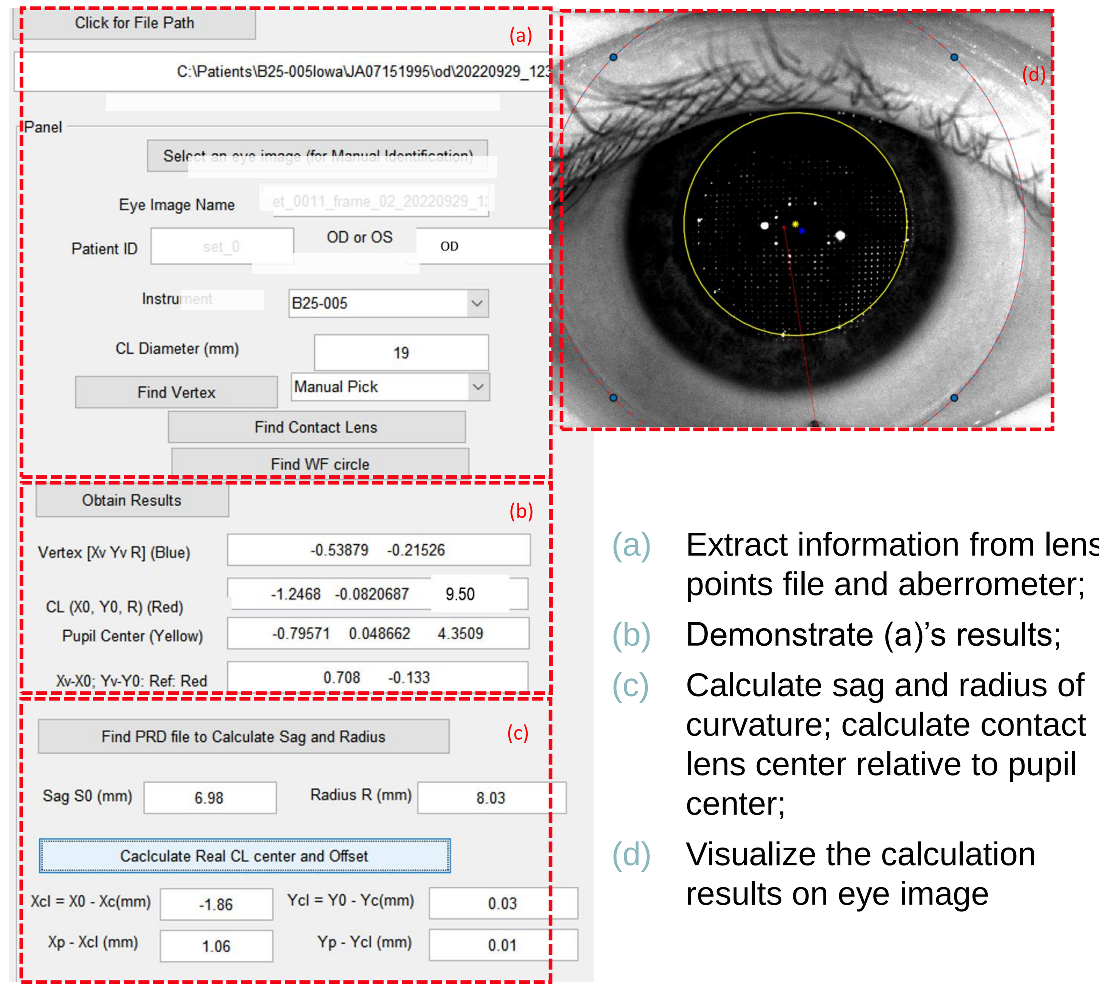
Figure 3. Parameters that are used in Method B for calculating the decentration of contact lens and (a) scenario with no tilt and (b) scenario with tilt.

Pros and Cons:

- For habitual scleral lens wearers, they can skip the step that Method A required – can directly make a wavefront guided lens without an extra diagnostic lens.
- The algorithm development and the calculation are relatively complex;
- Contact lens edge recognition is challenging, and wide field of view camera is required.

Method A & B

Functional (Algorithm Supported) GUI



(a) Extract information from lens points file and aberrometer;
(b) Demonstrate (a)'s results;
(c) Calculate sag and radius of curvature; calculate contact lens center relative to pupil center;
(d) Visualize the calculation results on eye image

Results and Discussions A

IMAGE QUALITY COMPARISON

Polychromatic Point Spread Function (PSF)

Pupil function P(x, y) with wavefront aberration $W(x, y, \lambda)$ is defined as [4]:

$$P(x,y,\lambda) = \begin{cases} 10^{-0.08(x^2+y^2)} e^{-i\frac{2\pi}{\lambda}W(x,y,\lambda)}, & \text{in the pupil} \\ 0, & \text{outside the pupil} \end{cases} \quad (5)$$

Optical Transfer Function OTF(f_x, f_y, λ) is the scaled autocorrelation function of the pupil function

$$OTF(f_x, f_y, \lambda) = \frac{P(x,y,\lambda) \otimes P(x,y,\lambda)}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} |P(x,y,\lambda)|^2 dxdy} \quad (6)$$

PSF at λ is the multiplication of Gaussian-weighted wavelength Gauss(λ) with the Fourier Transform of OTF

$$PSF(\xi_x, \xi_y, \lambda) = \text{Gauss}(\lambda) \cdot FT[OTF(f_x, f_y, \lambda)] \quad (7)$$

Polychromatic PSF is the normalized sum of PSF(ξ_x, ξ_y, λ)

$$PSF(\xi_x, \xi_y) = \frac{\sum_{\lambda=400nm}^{700nm} PSF(\xi_x, \xi_y, \lambda)}{\sum_{\lambda=400nm}^{700nm} Gauss(\lambda)} \quad (8)$$

Results and Discussions B

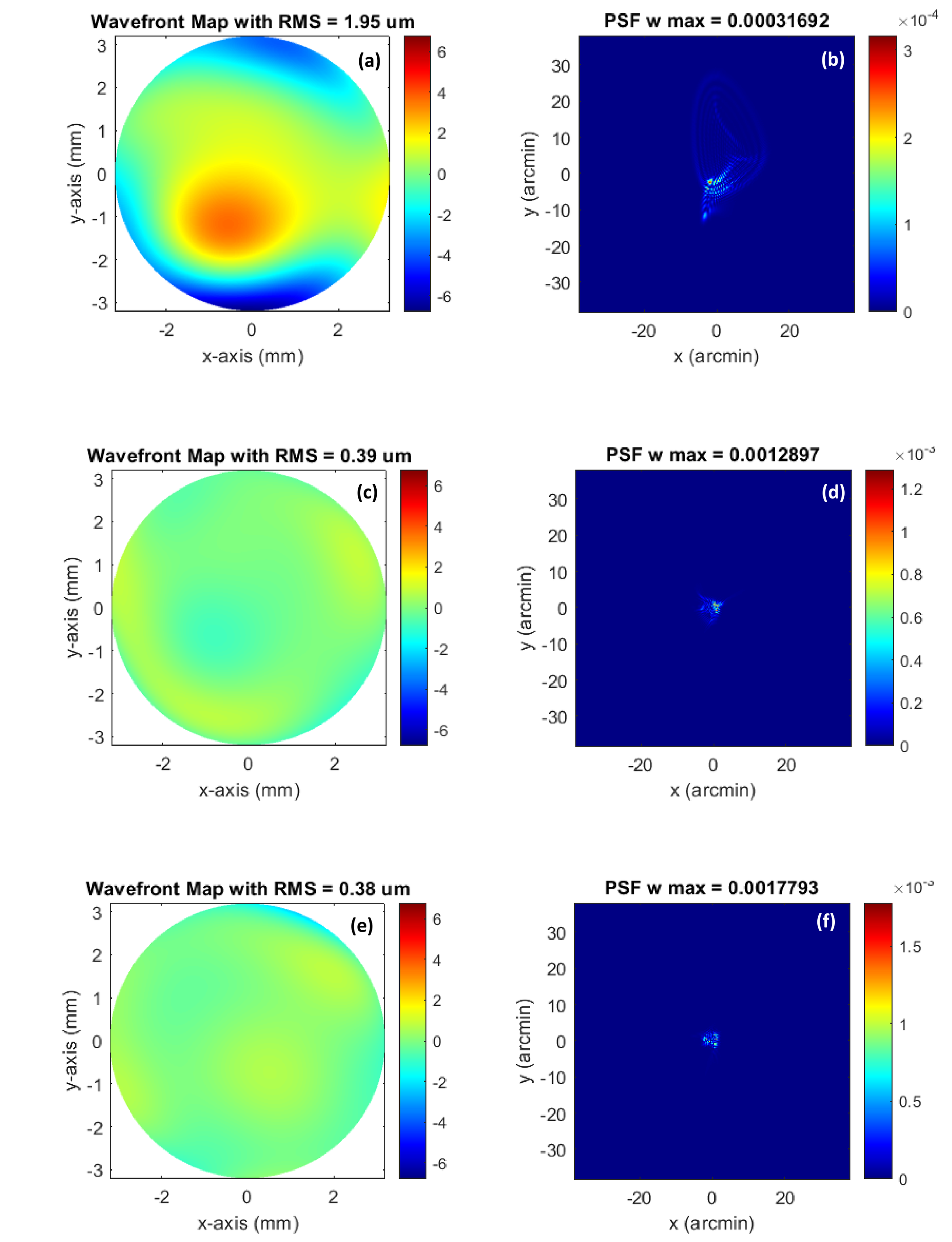


Figure 4. Residual wavefront aberration W(x, y, λ=555nm) with (a) Sph/Cyl lens, (c) WFG lens designed by method A, and (e) WFG lens designed by method B on. (b), (d) and (f) are their corresponding polychromatic PSF (Equation 8).

- Residual aberrations with WFG lenses designed by both methods A and B are 80% less.
- The corresponding maximum PSFs are 4-5 times larger than that of Sph/Cyl only lens.

VISUAL ACUITY COMPARISON

Polychromatic PSF Convolution with E () 20/20

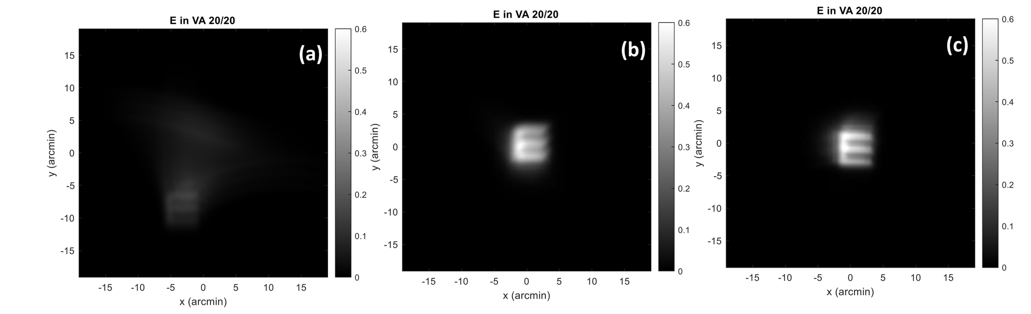


Figure 5. Letter E on acuity chart 20/20 through Sph/Cyl only lens (a); WFG lens designed via Method A (b) and Method B (c). Same colorbar amplitude is applied for the best comparison purpose.

- WFG lenses designed by both methods demonstrate clear VA 20/20 while Sph/Cyl lens had difficulty in reaching 20/20.
- Aberrations with Sph/Cyl lens spread the energy out wider, lower contrast and resolution.

Results and Discussions C

ROOT MEAN SQUARE (RMS) STATISTICS

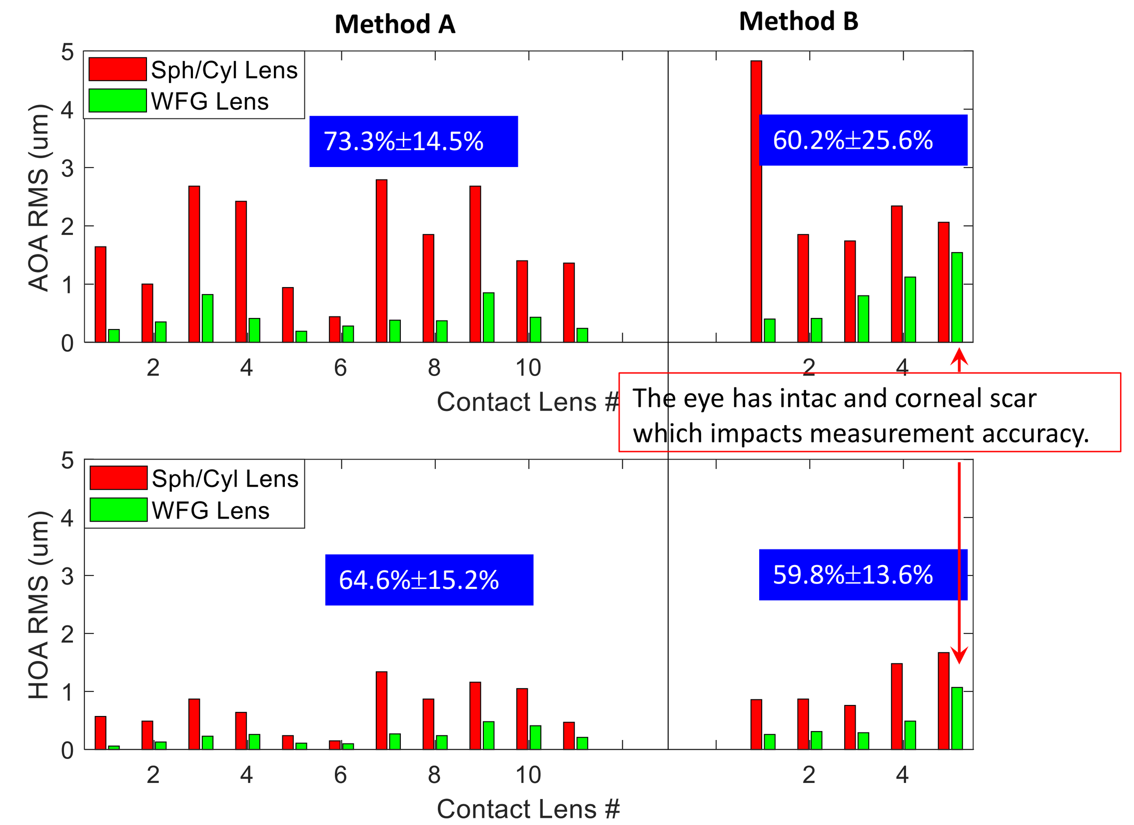


Figure 6. RMS for All Order Aberration (AOA) (top) and High Order Aberration (HOA) (bottom) for 11 WFG lenses designed by Method A (left) and 5 WFG lenses designed by Method B (right).

- Considering the 5th eye has wavefront measurement accuracy caused by others, WFG lenses designed by both methods have comparable RMS reduction on both AOA and HOA.

Conclusions

- Both methods for calculating lens centration, rotation and tilt were shown to be equivalent. No difference between the wavefront guided correction of lenses made with the two methods.
- By measuring the tilt with the telecentric topographer, it is not necessary to make a special Sph/Cyl lens with fiducial marks in most cases. For a patient that already wears scleral lenses, this means that the HOA lens can be made in a single iteration.

References

1. *S. J. Vincent, M. J. Collins, "A topographical method to quantity scleral contact lens decentration," Contact Lens and Anterior Eye, 42(4) 462-466 (2019).*
2. *D. Fadel, "The influence of limbal and scleral shape on scleral lens design," Contact Lens and Anterior Eye, 41, 321-328 (2018)..*
3. *L. Wang, D. D. Koch, "Effects of decentration of wavefront-corrected intraocular lenses on the higher-order aberration of the eye," Arch. Ophthalmol., 123, 1226-1230 (2005).*
4. *G. Dai, Wavefront Optics: for vision correction, Chapter 8, SPIE Press, 2008.*