Prospects for practical higher order aberration correction

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Purpose

About 14% of the population has elevated higher order aberrations (HOA) which result in some loss of visual quality [1]. About 1% suffers from keratoconus, pellucid marginal degeneration, corneal transplant, post-op ectasia or other condition that significantly degrades their vision [2]. Typically, these individuals are not eligible for LASIK and existing modalities (GP lenses, etc.) may not sufficiently restore normal vision. Thus, a measurement driven custom wavefront correction is needed [3]. Many of these patients are fitted with scleral contact lenses. However, these lenses often do not restore vision to normal levels due to incomplete index matching, corneal back surface and lens.

Previous studies have demonstrated the correction of wavefront error with scleral lenses and have shown the effectiveness of this treatment [4,5].

The purpose of this work is to evaluate practical ways to ameliorate barriers to adoption of Higher Order Aberration (HOA) correcting contact lenses (CL).

HOA contact lenses are not new, and several researchers have demonstrated effective HOA correction is possible. Clinicians have expressed reluctance in adoption, citing concerns such as effectiveness, feasibility, equipment, patient variables and cost.

Perceptions of HOA contact lens practicality – social media posts

Questions extracted from various social media posts

- Are aberrations stable over time?
- Can we measure the eye with large aberrations?
- How do we get consistent, accurate measurement?
- Can we measure through a scleral lens?
- Are contact lenses stable in position and rotation?
- Can we make contact lenses consistently and accurately with the desired correction?
- What patients should we select for HOA correction?
- How does pupil size and shift affect aberration correction?
- Does the wavefront correction add steps to the process?
- Does it work?

Scleral lenses alone do not always improve the net aberration

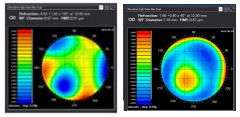

Figure 1. Aberrations of a KCN eye a) bare eye and b) eye with scleral lens

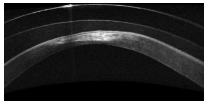

Figure 2. OCT image of a keratoconus eye with scleral lens

But they always invert the pattern

Both front and back surfaces of the cornea are affected by keratoconus. The scleral lens regularizes the front surface, but the net optical path may not be that much smoother.

Methods

Through social media posts, on-line chat rooms, and focus groups of CL practitioners, perceived HOA process issues were identified. Concerns were categorized as: measurement accuracy, workflow, patient factors, and outcomes. We evaluated and optimized factors affecting these concerns. A clinical study using these methods looked at chair time and visual outcomes.

40 consecutive eyes from 20 patients , 54% male, 46% female ages 23-76, were fitted with rotationally stable impression-based scleral contact lenses [6]. A dynamic, high resolution aberrometer measurement was made at each patient visit. The design integrated low order aberrations (LOA)and HOA into the optical zone.

DYNAMIC ABERROMETER

A high resolution, dynamic wavefront aberrometer system was developed to provide accurate measurements of highly aberrated eyes [7]. In a feasibility clinical study, this instrument was used to guide the treatment of patients with aberrated corneas. The instrument was used to evaluate the aberrations, provide parameters for the design of the scleral lens, evaluate the fit of the lens, and then a second lens was designed to correct the wavefront aberrations based on measurements through the first lens. For those patients that already were fit with a scleral lens, their existing lens was used as the predicate.

Results and Discussion

Measurement accuracy: Measurement accuracy was facilitated by using a high resolution lenslet system, sequential data capture over time through blinks to account for tear film variability, accommodative control in the system to prevent instrument myopia, a high-resolution camera to identify ocular features, and topography for patch centration.

Workflow With objective fitting techniques, only 3 office visits were needed: 1) base lens fitting visits 2) dispensing of LOA and HOA measurement visit 3) dispensing of HOA lens (reduced from 5 to 3 visits). LOA and HOA were corrected simultaneously reducing lens remakes from 4 to 2.

Patient Factors HOAs are stable over multiple timescales. Dilating the pupil assures the treatment area is bigger than the natural pupil.

Outcomes The HORMS reduced from an average of 0.9 to 0.35 um in one iteration, which was a 62%+/-13% improvement. All eyes had reduced HOA, no eye lost any lines of acuity.

Figure 3. Multi-function aberrometer/topographer

- Dynamic wavefront aberrometry, iris image, pupil, corneal topography, keratometry and refraction
- Contact lens fitting
- Subjective refinement with integrated eyechart
- Live wavefront and refractive displays

Results and Discussions A

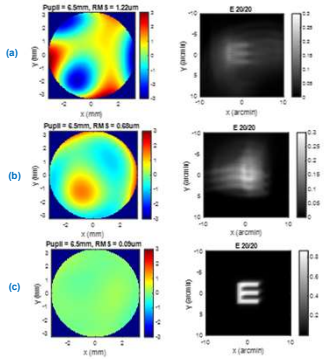

Figure 4. WFG lens reduction in aberrations. a) bare eye, b) traditional scleral, c) WF corrected

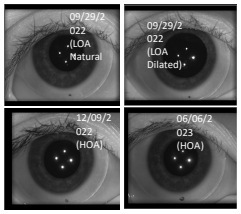

Figure 5. Long term HOA lens stability on the eye

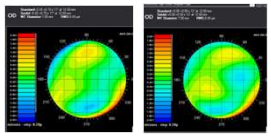

Figure 6. Long term HOA lens stability on eye a) initial, b) after 6 months of wear

Results and Discussions B

Workflow

Visit 1

- Evaluate LOA scleral lens fit
- Screen for HOA correction
- Dilate eye
  - Measure aberration through LOA lens
- Order HOA lens
- Dispense LOA lens

Visit 2

- Evaluate HOA lens performance
- Dispense

Clinical study

The severity ratio for each eye is calculated by dividing the Sph/Cyl corrected HORMS value by the age/pupil normal higher order RMS for that eye. The severity ratio can be used as a guide to predetermine which patients will benefit significantly from HOA correction. In this study 50% of the patients were at least 2X the normal range.

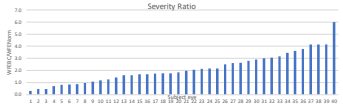

Figure 7. Severity Ratio for the study patients.

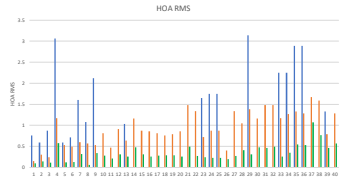

Figure 8. HOA RMS for bare eye, scleral lenses and WFG lenses

Figure 9. HOA RMS results for bare eye, scleral lenses and WFG lenses

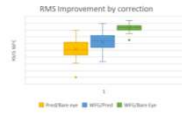

Figure 10. Reduction in HOA RMS. scleral/bare eye, WFG/scleral and WFG/bare eye

Results and Discussions C

These scleral lenses are extremely stable on the eye, so the correction works very well in nearly all cases. WFG correction brought the subject to normal aberration levels in most cases.

The WFG refraction also improved the refraction compared to the standard scleral lens since the low orders are included in the WFG correction.

On average scleral lenses reduced the bare eye higher order aberrations (6 mm pupil) from 1.70±0.87 μm RMS to 0.94±0.33 μm RMS (reduction of 52%±16%). The wavefront correction reduced the aberrations to 0.34±0.19 μm RMS (83%±6% reduction). This resulted in a 62%±13% improvement over the basic scleral lens. All patients preferred the wavefront guided lens.

Lens	Percent improvement
Sph/Cyl scleral lens compared to bare eye	52±16%
WFG lens compared to bare eye	83±6%
WFG lens compared to sph/cyl scleral	62±13%

Table 2 – The RMS comparison of bare eyes, Sph/Cyl lenses and WFG lenses

Conclusions

While there are barriers to HOA correction with contact lenses, these barriers can be identified and resolved. For the current 40 eye study all patients experienced a reduction in HORMS with a single iteration. This provides practical HOA treatment for aberrated eyes for keratoconus and other conditions.

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