THE ROLE OF OCULAR CONTOUR IN CONTACT LENS DESIGN AND FITTING

Jerome A. Legerton, OD, MS, MBA, FAAO

Moving from Art to Science

- Contact lens fitting has historically been an art. Market forces press for the need to convert it to a technology driven science:
  - Corneal GP fitting involved too many independent parameters of a lens design that were in turn ordered in increments that were smaller than what was known to be clinically significant
  - Most all corneal GP lenses were custom designed and ordered
  - Clinical metrology was not available to individually measure corneal contour
  - Soft lenses have been nearly uni-parameter and without the options for individual fitting of eyes
    - Base curve is used to control fit regardless of the large standard deviation in limbal and scleral geometry

Scleral Lenses Usher in a Need for Science

Clinical Requirements:
- Total corneal clearance
- Spreading lens mass evenly over the sclera near limbus
- Knowledge of limbal and scleral contour

How do we learn about scleral contour?

- Keratometry and topography limited
  - Keratometry measures a radius over a chord of about 2.8 mm
  - Topography measures surface elevation over a chord of about 9.5 mm

- Need: Instrumentation to measure ocular contour out to about 16 mm
  - Visante OCT can do it but cost is outside of average ECP appetite

Roadmap to Understanding Contour and Design Requirements

- Measurement is the first step to modulation
- Discover eye shape
- Simplify design variables
- Create create novel design features and utilize advanced manufacturing to:
  - Avoid lens deformation in soft lenses
  - Avoid lens flexure in scleral and hybrid lenses
  - Create the optimum lens-eye relationship for comfort and vision
  - Create designs that are orientationally stable

Strategy

- Apply modern technology to measure ocular contour
- Method:
  - Fringe topography
  - Adequate sample of eyes
  - Analyze shape circumferentially out to 15.5 mm
Fringe Topography

A new technology for measuring the cornea and scleral surface shape has been developed in the Department of Optometry at the Beuth Hochschule for Applied Sciences at Berlin, Germany. Global Contact No.2/2009(52)

What did we learn about ocular contour?

Precision measurement of ocular sag every 60 microns of chord over 15.5 mm

Contour Data for Mean Eye

Contour Data to Six Standard Deviations

The Enigma of Scleral Contour

Convex Landing Zone Geometry
Contour Based Scleral Lens Design

Ideal geometry with prescribed apical clearance, limbal clearance and axial edge lift

Apical Clearance = 0.080 mm
Limbal Clearance = 0.080 mm
Axial Edge Lift = 0.050 mm
Touch Diameter = 13.0 mm
Posterior OZ = 8.0 mm
Over-All Diameter = 15.5 mm

Prescribed Limbal Clearance

Independent Landing Zone Angle

A single convex radius can be prescribed with selected “curve angles” to produce the desired edge lift as observed by flourescein pattern

Three Moving Parts

- Base Curve Radius:
  - Suggested increments of 0.4 mm from 6.60 to 8.60
- Connecting Zone Depth
  - Modulated in microns in 50 micron steps
- Landing Zone Angle
  - Single convex to eye radius modulated in 1° steps

Key Lens Chords

• J1 = 8.0mm; junction of BCR and connecting zone
• J2 = 10.5mm; junction of connecting zone and landing zone
• “Node” 3 = 13.0mm; location of mid-point of convex to eye landing zone

The Notion of Nodes

<table>
<thead>
<tr>
<th>Node</th>
<th>mm</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>8.0</td>
<td>0.259</td>
</tr>
<tr>
<td>J2</td>
<td>10.5</td>
<td>0.128</td>
</tr>
<tr>
<td>“Node” 3</td>
<td>13.0</td>
<td>0.080</td>
</tr>
</tbody>
</table>

5x Standard Deviation OD
Calculating Sag at 3 “nodes”

- BCR Mean 7.80 mm
- Sag = 1.104 at 8.0 mm
- RZD Mean = 0.850
- Sag at 10.5 = 1.954 mm
  \((1.104 + 0.850)\)
- LZA Mean = 56°
- Sag at 13.0 = 3.029 mm
  \((1.954 + 1.075)\)

Asymmetric Scleral Contour

- Deepest
  - Superior Nasal
- Shallowest
  - Temporal

Note: Inferior Temporal is not equal to superior nasal

Dual Axis Landing Zone

- The Dual Axis feature allows the lens to have a varying sagittal depth in one meridian compared to another while maintaining a spherical base curve.
- As a rule, the vertical meridian of the sclera is deeper than the horizontal. The dual axis feature maintains:
  - more uniform sag circumferentially
  - eliminates flexure
  - provides orientational stability that enables front surface toric or HOA correction

Opportunity

A new scleral lens using the same logic and lexicon as Paragon CRT:
- Base Curve Radius
- Return Zone Depth
- Landing Zone Angle
- Dual Axis:
  - Controls flexure
  - Provides orientation and stability
  - Eliminates mid peripheral bubbles
- Front surface cylinder / decentered multifocal
- A scleral lens with edge lift:
  - Tear exchange
  - Ease of removal

Fitting Scleral Lenses

1. Select parameters from the periphery to the center
   - Landing Zone Angle must demonstrate edge lift and clearance at the 10.5 mm chord (50 microns)
   - Dx set with mean Landing Zone Angle
     - No edge lift = decrease angle
     - Excess edge lift = increase angle

2. Select the RZD to provide total corneal clearance
   - Elevation data from corneal topography can be extrapolated to derive the sag at 10.5 mm
   - Sag of the optic zone at 8 mm derived from look up tables using the base curve radius
   - RZD lifts the optic zone of the lens to cause optic zone junction and lens apex to clear the corneal surface by at least 30 microns
     - OZ touching = RZD too shallow
     - Bubbles under OZ = RZD too deep
Fitting Scleral Lenses

3. Select a base curve radius that flatter than the flat keratometry value
   - Result will be optic zone and apical clearance from the shallowest corneal meridian when the RZD lifts the lens
   - Clearance from steepest meridian will be greater than flat meridian at optic zone junction
   - Exception with ectasia in KC. Fit reference sphere selected by corneal topographer

Final Fit Success Criteria

- Minimal edge lift of 30 to 50 microns
- Clearance at 10.5 mm chord (J-2) of 50 microns
- Clearance through optic zone of at least 80 microns
- Lens movement on push up
- Dual axis to control flexure
- No impingement of conjunctival vessels
- No bubbles over cornea greater than 1 mm

A Word About Diagnostic Lenses

- No scleral lens can be successfully fit empirically without imaging
  - The majority of practitioners do not have anterior segment imaging with precision metrology (OCT)
- Diagnostic lenses are required
  - The greater the number of diagnostic lenses the higher the probability of getting it right the first time
- Re-orders are a lose-lose-lose situation
  - Greater chair time
  - Greater inconvenience for the patient
  - Higher cost for the laboratory

The White Magic: Design + Material + an Efficient Fitting System

EVALUATING THE INITIAL DIAGNOSTIC LENS

NormalEyes 15.5 Look-up Table

Select your starting diagnostic lens using the flat keratometry meridian value:

<table>
<thead>
<tr>
<th>Flat &quot;F&quot; of Regular Cornea</th>
<th>Suggested Base Curve</th>
<th>Suggested Landing Zone Angle</th>
<th>Suggested Corneal Clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.00 to 35.37</td>
<td>0.30</td>
<td>0.30</td>
<td>68.64</td>
</tr>
<tr>
<td>35.37 to 40.57</td>
<td>0.60</td>
<td>0.60</td>
<td>68.64</td>
</tr>
<tr>
<td>40.50 to 45.93</td>
<td>0.80</td>
<td>0.80</td>
<td>68.64</td>
</tr>
<tr>
<td>45.93 to 51.37</td>
<td>1.00</td>
<td>1.00</td>
<td>68.64</td>
</tr>
<tr>
<td>51.37 to 56.80</td>
<td>1.40</td>
<td>1.40</td>
<td>68.64</td>
</tr>
<tr>
<td>56.80 to 62.25</td>
<td>1.50</td>
<td>1.50</td>
<td>68.64</td>
</tr>
<tr>
<td>62.25 to 67.70</td>
<td>2.00</td>
<td>2.00</td>
<td>68.64</td>
</tr>
<tr>
<td>Greater than 67.70</td>
<td>2.50</td>
<td>2.50</td>
<td>68.64</td>
</tr>
</tbody>
</table>

Step 1: Find ideal LZA

Select parameters from the periphery to the center

- Landing Zone Angle must demonstrate edge lift and clearance at the 10.5 mm chord (50 microns)
- Dx set with mean Landing Zone Angle
  - No edge lift = decrease angle
  - Excess edge lift = increase angle
Landing Zone Angle Selection

- The LZA is the only parameter that can produce proper edge lift AND proper clearance at 10.5 mm chord (J2). It does so simultaneously
  - Edge lift control with the LZA
    - *Less* angle is *more* lift and *more* angle is *less* lift
    - A greater LZA reduces edge lift and increases clearance at 10.5 mm (J2)
    - A lesser LZA increases edge lift and reduces clearance at 10.5 mm
  - The lens must have clearance at J2
  - Lack limbal of clearance is seen as a black arc

Effect of LZA Differences

- One degree of LZA change raises and lowers the edge lift and J2 clearance about 50 microns
- The point of maximum touch is at the 13.0 mm chord in a well fit lens.
  - Increasing the LZA moves the edge down and J2 up
  - Decreasing the LZA moves the edge up and J2 down
- The RZD must be adjusted when the LZA is changed to keep the same optic zone clearance from the cornea
  - If the LZA is increased, the RZD must be decreased
  - If the LZA is decreased, the RZD must be increased
  - Consider a 50 µ RZD change for every 1° LZA change
    - Increase LZA then decrease RZD
    - Decrease LZA then increase RZD

Dual Axis Landing Zone

- The modal eye has 300µ of elevation difference at the 13 mm chord from highest to lowest.

- The dual axis feature maintains:
  - more uniform sag circumferentially
  - minimizes flexure
  - provides orientational stability that enables front surface toric or HOA correction

- The Dual Axis feature allows the lens to have a varying sagittal depth in one meridian compared to another while maintaining a spherical base curve

Impact of Each Degree of Change in LZA

<table>
<thead>
<tr>
<th>BCR</th>
<th>Sag 8.0</th>
<th>Sag 10.5-13.0 (Δ Sag)</th>
<th>Sag 13.0 (Δ Sag)</th>
<th>LZA 13.0-16.0 (Δ Sag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.60</td>
<td>1.350</td>
<td>0.650</td>
<td>0.600</td>
<td>48</td>
</tr>
<tr>
<td>6.62</td>
<td>1.352</td>
<td>0.652</td>
<td>0.602</td>
<td>49</td>
</tr>
<tr>
<td>7.50</td>
<td>1.295</td>
<td>0.745</td>
<td>0.700</td>
<td>50</td>
</tr>
<tr>
<td>7.20</td>
<td>1.213</td>
<td>0.860</td>
<td>0.800</td>
<td>51</td>
</tr>
<tr>
<td>7.40</td>
<td>1.174</td>
<td>0.910</td>
<td>0.850</td>
<td>52</td>
</tr>
<tr>
<td>7.60</td>
<td>1.138</td>
<td>0.960</td>
<td>0.900</td>
<td>53</td>
</tr>
<tr>
<td>7.80</td>
<td>1.104</td>
<td>1.010</td>
<td>0.950</td>
<td>54</td>
</tr>
<tr>
<td>8.00</td>
<td>1.072</td>
<td>1.060</td>
<td>1.000</td>
<td>55</td>
</tr>
<tr>
<td>8.20</td>
<td>1.042</td>
<td>1.065</td>
<td>1.050</td>
<td>56</td>
</tr>
<tr>
<td>8.40</td>
<td>1.013</td>
<td>1.100</td>
<td>1.100</td>
<td>57</td>
</tr>
<tr>
<td>8.60</td>
<td>0.987</td>
<td>1.130</td>
<td>1.150</td>
<td>58</td>
</tr>
<tr>
<td>8.80</td>
<td>0.962</td>
<td>1.160</td>
<td>1.200</td>
<td>59</td>
</tr>
<tr>
<td>9.00</td>
<td>0.938</td>
<td>1.190</td>
<td>1.250</td>
<td>60</td>
</tr>
<tr>
<td>9.20</td>
<td>0.915</td>
<td>1.220</td>
<td>1.300</td>
<td>61</td>
</tr>
<tr>
<td>9.40</td>
<td>0.893</td>
<td>1.250</td>
<td>1.350</td>
<td>62</td>
</tr>
<tr>
<td>9.60</td>
<td>0.875</td>
<td>1.280</td>
<td>1.400</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>64</td>
</tr>
</tbody>
</table>

LZA Too Shallow

- Excessive edge lift
- Black ARC touch inside limbus

Evaluating LZA

- LZA Adjusted Higher
  - Still too shallow; See black arc bearing at 10.5 (A) and excessive edge lift (B)
Evaluating LZA

Shallow LZA will immediately show excessive edge lift and dark ring at limbus.

- 54 / 58 LZA is too shallow post compression
  - Note inadequate limbal clearance and apical clearance

Evaluating LZA

- Consider a 1° increase in LZA
- Will lower edge by 40µ and raise lens at 10.5 mm chord by 40µ

Conjunctival “Blanching” Indicates LZA is Too Deep

Ideal LZA

Ideal Fit After Conjunctival Compression
EVALUATING THE RZD SELECTION

Selection of RZD

- Select the RZD to provide total corneal clearance
  - RZD lifts the optic zone of the lens to cause optic zone junction and lens apex to clear the corneal surface by at least 50 microns post compression
  - OZ touching = RZD too shallow
  - Bubbles under OZ = RZD too deep

Fitting Scleral Lenses with Topography

- Close determination of initial BC from Elevation Map (Best Fit Sphere).
- Close determination of initial RZD from sagittal depth analysis at the given junctions

Topography Chord Value – 10.5 mm (J2)

- Sag at the 10.5 mm chord is 1950 microns

Topography Chord Values – 8 mm (J1)

- Sag at the 8 mm chord is 1090 microns
- Estimated RZD = 1950 – 1090 = 860 microns

Calculating the RZD from Topography Sag Data

\[ A = 10.5 \text{ mm (J2)} \]
\[ B = 8.0 \text{ mm (J1)} \]

\[ \text{RZD} = A - B \]
RZD and LZA Too Shallow

- Not enough central clearance
- Insufficient Limbal Clearance

RZD Too Deep and LZA Good

- Excessive central clearance
- Edge lift is good

Ideal Corneal Clearance

- Goal is 80 to 100 µm AFTER conjunctival compression or 200 to 240 µm before compression.
- Cornea is about 550 µm
- Lens is about 240 µm
- This post lens tear film about equal to lens thickness
- Best evaluated with parallel pipette or OCT

Use Parallel Pipette for RZD Evaluation

- Cornea is about 550 µm
- This post lens tear film about equal to lens thickness

Base Curve Calculation

**Selected using**
- Flat meridian keratometry
- Flatter than flat K from lens selection chart
- Reference sphere from corneal topography
- For irregular corneas

**If too steep:**
- Lens will be closer at J1 than at the apex and may facilitate central bubble

**If too flat:**
- Lens will be closer at apex than J1 and may facilitate central touch or arcuate bubble at J1

*Base Curve is not very critical if RZD and LZA are correct*
NormalEyes 15.5 Look-up Table

- Select your starting diagnostic lens using the flat keratometry meridian value:
- Recommended BCR is flatter than Flat K for normal corneas
- Least critical parameter
  - Usually in 0.4 mm steps
  - Can be ordered in 0.1 mm increments

Base Curve Radius Too Flat

- Minimal central clearance (pre compression)
- Accurate bubble at J1

Base Curve Radius Too Steep

- Central bubble capture
- Insufficient limbal clearance

Proper Base Curve Radius/RZD/LZA

- Adequate central clearance
- Acceptable limbal clearance (pre-compression)
- Appropriate edge lift

A Word About Chair Time

- Free to evaluate within seconds of lens application
- Evaluate immediately upon application
- Finesse conjunctival compression: Average known to be 120 microns
- Apply second or third lenses in short serial succession

Get it right the first time by having an adequate diagnostic set and observing a series of lenses if needed

FINAL FIT SUCCESS
Final Fit Success Criteria/post-Compression

• Minimal edge lift of 30 to 50 microns
• Clearance at 10.5 mm chord (J-2) of 50 microns
• Clearance through optic zone of at least 80 microns
• Lens movement on push up
• Dual axis to control flexure; if flexure observed increase thickness
• No impingement of conjunctival vessels
• No bubbles over cornea greater than 1 mm

Ideal Fit After Conjunctval Compression

An Easy-to-Fit Scleral Lens

A rational 3 Zone Lens with Independent Fitting Zones

• Scleral Contour measurement derived ranges and increments
• Diagnostic Sets for all cornea types
• Get it right the first time
• Thinnest scleral lens offered today
• Dual Axis controls flexure and provides orientational stability

Nature Hides on the Side of the Flaw

• The Wild Card
  • Conjunctival compression
  • Conjunctiva thicker closer to the limbus (120 microns)
  • Thinner 1.5 mm from limbus (70 microns)
  • Must compensate in RZD for conjunctival compression

Learnings from Clinical Trials

• Amazing Comfort
• Technique still required to remove lenses
• Don’t use abrasive cleaners
• Can apply lenses with Optifree Express
  • Don’t need non-preserved saline
• Dual Axis nails flexure
• Multifocals provide great vision
• Chair time reduced with 36 lens Dx set for regular cornea
  • 24 additional Dx lenses for ectasia (KC, Pellucid and Post Graft)
  • 12 additional Dx lenses for post surgical

APPLYING OCULAR CONTOUR TO SOFT LENS DESIGN
Soft Lens History and Outcome

- First lens manufacturing circa 1965 – 1970
  - Spin casting
  - Diamond turning on single axis lathes

Both resulted in lenses that were either monocurve or bi-curve as extensions of rigid corneal lens design

- Discovery that base curve radius had to be much flatter than the keratometry values

Use of base curve radius to control sagittal depth

Flaw of Use of Base Curve Radius

- Lens required to “drape” central cornea while requiring either circumferential stretching over sclera or causing scleral indentation
  - Lens Deformation
    - Limits the ability to correct higher order aberrations
    - Limits simultaneous multifocal performance
    - Scleral indentation causes variable lens comfort
      - One size fits all results in variable indentation or compression from eye to eye
      - Has impact on end of the day comfort

Need – Shift Control of Sag to the Periphery of the Lens

Apply same logic and design concepts to soft lenses as used in scleral lens

- Select base curve close to the central keratometry value to avoid draping and random deformation
- Select the overall diameter from the corneal diameter (HVID) to have equivalent extension from limbus on all eyes
- Control the sag by Landing Zone Angles
- Apply convex to the eye geometry in the landing zone