CORNEAL TOPOGRAPHIC MODIFICATION OF OCULAR WAVEFRONT-GUIDED TREATMENT

Stephen D Klyce, PhD
LSU Eye Center, New Orleans, LA
IF YOU REALLY WANT
TO CORRECT HIGHER ORDER ABERRATIONS
DON'T APPROXIMATE, INCORPORATE THE CORNEAL TOPOGRAPHY

Stephen D Klyce, PhD
LSU Eye Center, New Orleans, LA
Disclosure

Dr Klyce has been a consultant to NIDEK, Inc.
ADVANCES IN LASER CORRECTIONS FOR MYOPIA

1993: < 5 mm OZ with oblate central zone

2004: > 7 mm OZ + central prolate Spherical Aberration compensation
2005: -2.00 D CUSTOMIZED Tx looks like untreated cornea.
OD: 20/15 Normal

OS: 20/40 PKP w/glare
APPROACH TO CUSTOMIZATION

1) Measure ocular wavefront
2) Fit with the Zernike polynomial series
3) Calculate required corneal shape change and the ablation pattern
4) Ablate corneal stroma
Optical data is calculated at different planes.

Corneal topography

Diopters

Wavefront

Point Spread Function

Alienation

aberrated wavefront

ideal wavefront
WAVEFRONT DEVICES

**Hartmann-shack**
Alcon/Summit/Autonomous CCMD/Ladar Wave
Zeiss Humphrey (non-Ladar Wave)
Topcon + topo
Visx 20/10 Wavescan
Bausch & Lomb Zyoptics
Aesculap Meditec WOSCA

**Tscherning**
Wavelight Wavefront Analyzer
Schwind Wavefront Analyzer
Tracey retinal ray tracing

**Refractometry**
Emory Spatially Resolved Refractometer (manual)
NIDEK OPD Scan (skiascopy; automatic + topo)
OPD Scan - NIDEK Scanning Slit Aberrometer with Corneal Topographer

Courtesy of Yosuke Ozawa, NIDEK
“OPD INTERNAL”
THE INTERNAL ABERRATIONS MAP

OPD Refraction (D)  
Whole Eye  

Refractive Power (D)  
Corneal Topography  

OPD internal (D)  
Internal Aberrations
1) Measure ocular wavefront

- Spatial resolution issues

- Couple wavefront data with higher resolution corneal topography data
1) Measure ocular wavefront
2) Fit with the Zernike polynomial series
3) Calculate required corneal shape change and the ablation pattern
4) Ablate corneal stroma
ADEQUACY OF ZERNIKE FITS

Axial Diopters

N.B.: The Zernike polynomial is a smoothing function.

Elevation Fit Error

Fit Errors
RMS: 4.35 um
MAX: 79.99 um

SIM K's
56.84 D @ 76°
51.62 D @ 166°
ADEQUACY OF ZERNIKE FITS

Number of Zernike terms

Mean RMS error (µm)

NRM
LASIK
PRK
RK
CYL
CLW
KCS
KC1
KC2
KC3
PMD
PKP
1) Measure ocular wavefront
2) Fit with the Zernike polynomial series
3) Calculate required corneal shape change and the ablation pattern
4) Ablate corneal stroma
THE PERFECT WAVEFRONT CORRECTION

- Local corneal curvature must be considered
- Reflection from the surface
- Angle of incidence
- Assess result with CT wave analysis and elevation maps
“MUNNERLYN FORMULA”

\[ t_0 \cdot S \frac{t_0}{D} (n^2 - 1) \]

- \( t_0 \): Microns of central stroma removed
- \( S \): Optical zone diameter
- \( D \): Power of lens removed
- \( n \): Refractive index of cornea, 1.377

“MUNNERLYN FORMULA”

EXACT EXPRESSION

\[
\sqrt{\frac{R_1 (n^2 - 1)}{D}} \times \frac{R_2}{4}
\]

Additional parameters:

- \( R_1 \): Pre-op radius of curvature
- \( R_2 \): Post-op radius of curvature

THE PERFECT WAVEFRONT CORRECTION

- Local corneal curvature must be considered

Amount of tissue removed for a given correction is dependent on corneal curvature.
Amount of tissue removed for a given correction is dependent on local corneal slope.
RADIAL COMPENSATION OF BEAM ENERGY - SLOPE
RADIAL COMPENSATION OF BEAM ENERGY - SLOPE
RADIAL COMPENSATION OF BEAM ENERGY - SLOPE
Amount of tissue removed for a given correction is dependent on local corneal slope and the character of the corneal surface. Surface moisture produces: mirror reflection vs diffuse reflection.
PATIENT:  
CLINIC:  

LSU Eye Center B  
SS#:  

EXAM: 574-3 = B -- EYE:  OD  9/03/92 -- 0:31  

SMOOTH = 1  

C = A - B  
(Difference)  

Diopters  

Hit ESCape key to exit to System Menu.
REFLECTION OF LASER ENERGY

Shiny

Dull
Surface moisture illuminated with 193 nm UV acts as a chromophore with a large instantaneous increase in refractive index to increase reflected energy by 40%.
1) Measure ocular wavefront
2) Fit with the Zernike polynomial series
3) Calculate required corneal shape change and the ablation pattern
4) Ablate corneal stroma
IS THE PERFECT WAVEFRONT GUIDED TREATMENT POSSIBLE?

Must incorporate the precise corneal shape into algorithms to compensate for topography variations, radial compensation effects. Must continue to adjust algorithms for biomechanical and healing effects.
IS THE PERFECT WAVEFRONT GUIDED TREATMENT POSSIBLE?

Possible solutions:
- Use accurate devices
IS THE PERFECT WAVEFRONT GUIDED TREATMENT POSSIBLE?

Possible solutions:
- Use accurate devices

Mean Height Difference: -1.32 +/- 4.79 microns.
IS THE PERFECT WAVEFRONT GUIDED TREATMENT POSSIBLE?

Possible solutions:
Compare difference in pre- and post-op topographies
IS THE PERFECT WAVEFRONT GUIDED TREATMENT POSSIBLE?

Possible solutions:
Compare difference in pre- and post-op topographies.

Height Change

Cylinder change: 0.43 D (Induced: 0.57 D @ 15)
Mean Height Difference: -22.12 +/- 27.92 microns.
CONCLUSIONS

1) “The cornea is not a piece of plastic”
   - C. Roberts

2) The cornea is also not flat and is __ H₂O

3) To improve wavefront guided laser vision corrections geometric, biologic, and physical properties of the cornea need careful consideration

4) Accurate corneal topographic data is essential to achieve optimum results
THANK YOU!
1) Measure ocular wavefront
2) Fit with the Zernike polynomial series
3) Calculate required corneal shape change and the ablation pattern
4) Ablate corneal stroma
RADIAL COMPENSATION OF BEAM ENERGY - SLOPE
Fit with the Zernike polynomial series

Zernike doesn't work for highly aberrated eyes

Use the actual data or Fourier
ERROR IN TISSUE REMOVAL

Intended correction (D)

Approximation

Exact solution

6 mm OZ; 43 D pre-op

Stroma removed (µm)
plane wavefront

ideal wavefront

defocused wavefront
plane wavefront

ideal wavefront

aberrated wavefront
THE PERFECT WAVEFRONT CORRECTION

- Local corneal curvature must be considered
- Reflection from the surface
- Angle of incidence
- Assess result with CT wave analysis and elevation maps
CENTRAL ISLAND HYPOTHESES

- Plume vortex
- Delivery system optics
- Excimer laser stability
- Novel wound healing
- Acoustic shock
- Nonuniform stromal hydration
THE PERFECT WAVEFRONT CORRECTION

- Local corneal curvature must be considered
- Reflection from the surface
- Angle of incidence
- Assess result with CT wave analysis and elevation maps
Amount of tissue removed for a given correction is dependent on local corneal slope and surface character.

Surface moisture produces: mirror reflection vs diffuse reflection.
Disclosure

Dr Klyce has been a consultant to NIDEK, Inc.

Collaborators

P Artal
MB McDonald
S Pieger

EJ Sarver
MK Smolek
J Tabernero
\[ PSF = \left| FT(P) \right|^2 \]

\[ P(x, y) = e^{-i \frac{2\pi}{\lambda} W(x, y)} \]
1) corneal topography contains the necessary shape information to allow the ablation beam to be adjusted to uniquely correct for the energy loss in individual eyes due to changing angle of incidence of the ablating beam;

2) that subtracting pre- and post-surgical corneal elevations reveals the achieved ablation;

3) subtracting the achieved from the planned ablation yields the error. Together, these are a powerful addition to current systems.