Wavefront Aberration Analysis
& Visual Impact

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Today we'll answer these questions:

- How do higher-order wavefront aberrations (HOAs) affect vision?
- How do we detect them?
- What can be done about them?
- What are the implications for your patients and your practice?

Lower-order & Higher-order wavefront aberrations

WAVEFRONT ABERRATIONS:
Zernike Orders: ONE thru FOUR

- First-Order (PRISM)
  - Lower Order Aberrations (LOA)
- Second-Order (ASTIG & SPHERE)
  - Lower Order Aberrations (LOA)
- Third-Order (TREFOIL & COMA)
  - Higher Order Aberrations (HOA)
- Fourth-Order (2nd ASTIG, QUATREFOIL & SPHERICAL ABERRATION)

Based on ANSI Z80.28

How much ‘negative’ effect do ABERRATIONS have on the ‘average’ person’s VISION?

- Lower Order Aberrations (LOAs) consist primarily of nearsightedness & farsightedness (defocus), as well as astigmatism. These make up about 85 percent of all aberrations in an eye.
- Higher Order Aberrations (HOAs) comprise many varieties of aberrations. Most common are coma, trefoil & spherical aberration, but there are lots(!) more that are only identified by mathematical expressions (Zernike polynomials). All together, these comprise about 15 percent of total aberrations in an eye.
- An eye usually has several different HOAs interacting together. That makes a correlation between a particular HOA & a specific symptom difficult to determine. HOAs are often associated with:
  - double vision, halos, starbursts, & poor night vision.

Second-Order Aberration: Defocus (LOA) (i.e., myopia or hyperopia)

parallel beam = plane wavefront

occupied wavefront = defocused wavefront
Higher-Order Aberrations (HOAs): 3rd through 20th Order

Parallel beam = ideal wavefront
Ideal wavefront = irregular wavefront

Wavefront Aberrations: Zernike “Orders” & Pupil Size

Zernike orders can indicate how much a given aberration will affect vision based on pupil size:
- Lower order aberrations (LOAs) produce significant wavefront errors & negatively impact vision even with smaller pupil sizes.
- Higher order aberrations (HOAs) can produce significant wavefront errors & negatively impact vision mostly with larger pupil sizes. So, HOA’s have a detrimental effect on vision, primarily under low-light conditions (when pupils are BIG!)

Effect of Pupil Size on Image Quality

Step 1: "Reduced image quality created by ocular & optical distortions in the visual system"

- For the average person, "Image Noise" represents approximately 15% of their total refractive error.
- "Image Noise" is dramatically influenced by pupil size (bigger pupil = more "noise").
- When corrected, a reduction in "Image Noise" is perceived as improved ‘visual clarity’ by patients.

Image Noise: The Visual Effects of Higher Order Aberrations

Limited Reflections of Manifest Refraction (MR)

MR: usually done in a room illuminated enough for doctor to see instruments & paperwork (or CPU) needed during an example (logically so!)
- When the MR is done in conditions that FAIL to "maximize" pupil size (i.e., near complete darkness), there will be two consequences:
  1. The influence of HOAs on the prescription are decreased, since smaller pupils "filter out" the aberration’s impact on focus, &...
  2. The depth of focus of the eye is increased (by the smaller pupil aperture), reducing the sensitivity (& reliability) of the results.

The EFFECTS of HOAs won’t always be revealed with a Manifest Refraction (MR)
Good acuity is found in bright light conditions (3mm pupil).

Small pupils increase depth of focus...& can lead to uncertainty of final Manifest Rx.

Limitations of Manifest Refraction (MR)

Limitations of contact lenses in correcting HOAs

- **Rigid Gas Permeable (RGP) CLs** can mask/compensate for many Higher Order Aberrations! This is why people love them!
- **Soft Contact Lenses (SCLs):** can 'help' to a small degree with HOAs but the corneal edema and dryness can cause cancel out the benefits, so it becomes a 'wash'.

Limitations of spectacle lenses in correcting HOAs

**THE TRUTH:**
Spectacles cannot correct Higher-Order Aberrations!
It may be possible to minimize HOAs in one specific “sweet spot” in the lens, but it will be surrounded by excessive aberrations (See Example)

Example of finding CYLINDER POWER (using “Jackson Cross-Cylinder (JCC)” procedure:

**JCC Procedure:** in PRESENCE of HOAs

- The optimum refraction is missed!

**JCC Procedure:** in ABSENCE of HOAs

"Sweet Spot" Improved Vision
Outside "Sweet Spot"

@ "Sweet Spot" in center  Away from center "Sweet Spot"

**So, what CAN we do? Measure & Compensate!**
How do we MEASURE the ABERRATIONS?

A WAVEFRONT ABERROMETER!

How do we MEASURE the ABERRATIONS?

The ABERROMETER...

- Measures “image noise” (HOAs) found in the ocular media
- Measures over 3300 points within 7mm pupil area
- Accurate; data can be used to produce an autorefraction calculation accurate to 0.01D!
  (Example: -1.03 -0.32 X 180)

We can’t “correct” for HOAs (w/glasses), but we can 'compensate' for them!

- Wavefront data from Aberrometer
- Input info to “Software Algorithm”
- Rx created w/0.01D accuracy!
- Ultra-Precise Fabrication
- Step 1
- Manifest Refraction
- Rx
- Step 2
- Step 3
- Step 4
- Step 5

Now run the COMPUTER ALGORITHM: (secret sauce!)

1) It evaluates “wavefront” data
2) It asks for doctor’s Manifest Refraction (MR) results
3) Then it calculates the ideal Compensated Rx to achieve best visual clarity
RESULT? = An Rx accurate to 1/100th of a diopter (SPHERE & CYLINDER) custom tailored to that Pt’s eyes!

We can’t “correct” for HOAs (w/glasses), but we can ‘compensate’ for them! (cont.)

- Because of HOAs, the ideal correction for marginal rays (the ones at the periphery) differs from ideal correction for paraxial rays (ones closer to the center of the visual axis)
- Experiments show pt’s judge the optimum focal point as a place between the marginal & the paraxial ray focus
- The purpose of the wavefront analysis, Manifest Refraction, & CPU algorithm is to find this “ideal focal point!”

We can’t “correct” for HOAs (w/glasses), but we can ‘compensate’ for them! (cont.)

The “magic” is in the ALGORITHM that analyzes all the information & comes up w/super accurate Rx that maximizes retinal image quality by minimizing the amount of blur (“visual noise”) in the vicinity of the retina
We can’t “correct” for HOAs (w/glasses), but we can ‘compensate’ for them! (cont.)

1. The wavefront aberrometry measurements were taken MONOCULARLY; it doesn’t take into account binocularity
2. The DOCTOR does ‘binocular’ balancing, which takes into account how the brain “uses” both eyes
3. The aberrometer cannot eliminate “accommodation” by patients; the DOCTOR uses techniques that CAN!
4. Additionally the DOCTOR:
   - Calculates PRISM needed (if any) & the “base” direction
   - Calculates ADD POWER for multifocal wearing patients

We can’t “correct” for HOAs (w/glasses), but we can ‘compensate’ for them! (cont.)

1) Can compare pt’s HOA results to population “average”
2) Can compare HOA results for 3mm pupil vs. a “maximum” pupil (i.e., day vs. night)

DATA VIEW:
- “WAVEFRONT” maps for each eye
- View TOTAL aberrations or just HOAs
- View aberrations at different PUPIL SIZES
- “Autorefractor” results based on wavefront data

GREAT for showing Pt’s WHY their vision is worse @ night!

NOTE: the “RESIDUAL” category shows 5th thru 20th order of HOAs

We can’t “correct” for HOAs (w/glasses), but we can ‘compensate’ for them! (cont.)

Results when we measure & compensate for HOAs using algorithms & modern spectacle manufacturing technology?

Point Spread Function (PSF) “simulation”
- How ‘dot’ of light focuses on retina after passing thru a “Normal” Rx vs. an “HOA Compensated Rx” (accurate to 1/100th of a DIOPTER)

Results when we measure & compensate for HOAs using algorithms & modern spectacle manufacturing technology?
- Put in the DOCTOR’S manifest refraction (MR)
- Click the “Calculate Rx to 1/100th D” icon
Results when we measure & compensate for HOAs using algorithms & modern spectacle manufacturing technology? (cont.)

• The advent of free-form, or digital surfacing, @ laboratories has made it possible to produce lenses accurate to 1/100th of a diopter (0.01 Diopter)

• 1/100th D (0.01D) Rx's are filled using "ultra-precise" lenses held to tighter quality standards; They can even do PAL's!

That's all great & everything, but…can we even MAKE glasses to 1/100th of a Diopter?!

Implications for your patient's & your practice?

Improved night vision!

Normal Rx

Wavefront Compensated Rx to 1/100th D

Implications for your patient's & your practice?

Improved COLOR perception

CONVENTIONAL Rx    COMPENSATED Rx to 1/100th D

Due to a reduction of chromatic aberrations (i.e., HOAs)

Implications for your patient's & your practice?

Clinical Study: Compensated Rx made to 1/100th D (0.01D)

• 80% have better visual comfort
• 74% see better @ night & in low-contrast situations
• 66% experience clearer, sharper vision
• 60% see colors more intensely

That's all great & everything, but…can we even MAKE glasses to 1/100th of a Diopter?!

Yes!!!

• The advent of free-form, or digital surfacing, @ laboratories has made it possible to produce lenses accurate to 1/100th of a diopter (0.01 D)

• 1/100th D (0.01D) Rx's are filled using "ultra-precise" lenses held to tighter quality standards; They can even do PAL's!
Doctor can now **SEE** why some patients can’t see 20/20, even though everything “looks” good in the eye.

**Implications for your patient’s & your practice?**

- Your clinic stands out as being "special" due to your technology.
- Your clinic produces a ‘unique’ Rx that is unlikely to be filled somewhere else (0.01D!)
- Your patients will experience better vision than they’ve had before.

*They will tell family & friends!*

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