Today we’ll answer these questions

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

Wavefront Aberration Analysis & Visual Impact

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Low-order & Higher-order wavefront aberrations

WAVEFRONT ABERRATIONS:
Zernike Orders: ONE thru FOUR

- First Order (PRISM)
- Second Order (ASTIG & SPHERE)
- Third Order (TREFOIL & COMA)
- 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 and farsightedness (defocus), as well as astigmatism. They make up about 85 percent of all aberrations in an eye.
- Higher Order Aberrations (HOAs) comprise many varieties of aberrations. Some of the most common are coma, trefoil and spherical aberration, but there are lots(!) more that are only identified by mathematical expressions (Zernike polynomials). All together, these comprise about 15 percent of the 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. But HOAs are often associated with:
  - double vision, ghosts, halos, starbursts, loss of contrast & poor night vision.

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

parallel beam
plane wavefront
ideal wavefront
defocused wavefront
Higher-Order Aberrations (HOAs): 3rd through 20th Order

parallel beam = ideal wavefront
plane 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) can produce significant wavefront errors & negatively impact vision even at smaller pupil sizes
  – Higher order aberrations (HOAs) can produce significant wavefront errors & negatively impact vision with larger pupil sizes

• Therefore, higher order aberrations begin to have detrimental effect on vision, primarily under low-light conditions (i.e., when pupils are BIG!

Effect of Pupil Size on Image Quality

1 mm 2 mm 3 mm 4 mm

5 mm 6 mm 7 mm

Image Noise: The Visual Effects of Higher Order Aberrations (HOA)

“Reduced image quality created by ocular & optical distortions present within the vision correction system”
• For the average person, image ‘noise’ represents approximately 15% the 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

Limitations of Manifest Refraction (MR)

The EFFECTS of HOAs won’t always be revealed with a manifest refraction (MR)

• Manifest Refraction (MR) is usually done in a room illuminated enough for the doctor to see the 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 important consequences:
  1. The influence of HOAs on the prescription are decreased, since the smaller pupil “filters out” the aberration’s impact on focus, and...
  2. The depth of focus of the eye is increased (by the smaller pupil aperture), reducing the sensitivity (and to some extent, reliability) of the results
**Limitations of Manifest Refraction (MR)**

- Small pupils increase depth of focus.
- Leads to uncertainty in final of Manifest Rx

Contrast & "sharpness" are decreased significantly in poor light conditions (7mm pupil)

Good acuity is found in bright light conditions (3mm pupil)

**Limitations of Manifest Refraction (MR)**

HOAs can shift the prescription – based on pupil size

Demonstration of how vertical COMA & SPHERICAL ABERRATIONS (both HOAs) can SHIFT the point of “best focus” (based on pupil size)

**Limitations of cabinet refraction (MR)**

MR is done in steps of 0.25 D, which is sufficient for small pupils...

But, this may mean the dioptic end-point of sharpest vision may not be found for all patients.

Usual correction

But THIS is the ideal correction

Usual correction

More SPH & Less CYL?

+2.83 - 0.38 x 180

Less SPH & More CYL?

+2.75 - 0.50 x 180

Best Rx IS actually HERE

+3.00 - 0.25 x 180

**Example of Jackson Cross-Cylinder (JCC) procedure:**

In absence & presence of high-order aberrations (HOAs)

**Limitations of contact lenses in correcting HOAs**

- **Rigid Gas Permeable (RGP) CLs** can mask or compensate for many Higher Order Aberrations! This is why people who are wearing them LOVE THEM for the quality of vision they get! (And why they struggle to switch to Soft CLs or glasses.)

- **Soft Contact Lenses (SCLs)** can 'help' to a small degree with HOAs but the corneal edema and dryness they can cause cancel out the benefits, so it becomes a 'wash'

**Limitations of spectacles lenses in correcting HOAs**

Here is THE TRUTH: Spectacles cannot correct higher-order aberrations

It may be possible to eliminate HOAs of an eye for one specific "sweet spot" in the lens. However, this region will then be effectively surrounded by a ring of excessive aberrations (SEE EXAMPLE)

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 to 0.01D!
  (Example: -1.03 -0.32 X 180)

If we can’t “correct” for HOAs, can we ‘compensate’ for them?

1) Evaluates the "wavefront" data

2) Asks for the doctor’s Manifest Refraction (MR) results

4) Algorithm then calculates what the ideal, compensated Rx should be to achieve best visual results based on doctor’s findings and wavefront results

EXAM

COMPUTER ALGORITHM: (secret sauce!)

- Aberrometer (wavefront) measurement through BIG pupil (to detect aberrations of the eye)
- Manifest Refraction (MR)

RESULTS? = An Rx accurate to 1/100th of a diopter (SPHERE & CYLINDER)

If we can’t “correct” for HOAs, can we ‘compensate’ for them? (cont.)

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

If we can’t “correct” for HOAs, can we ‘compensate’ for them? (cont.)

- The “magic” is in the ALGORITHM that analyzes all the information gathered & comes up with a super accurate Rx that will maximize retinal image quality by minimizing the amount of blur (“visual noise”) in the vicinity of the retina
If we can’t “correct” for HOAs, can we ‘compensate’ for them? (cont.)

1. The wavefront aberrometry measurements were taken MONOCULARLY (the DOCTOR can do ‘binocular’ comparisons!)
2. The aberrometer cannot “binocular balance” patients; the DOCTOR CAN!
3. The aberrometer cannot eliminate “accommodation” by patients; the DOCTOR has techniques that CAN!
4. This is why the DOCTOR is of great importance:
   • Binocular Balancing of patient
   • Minimizes Accommodation by patient
   • Calculates Prism needed (if any) & Base direction
   • Calculates ADD POWER for multifocal wearing patients

If we can’t “correct” for HOAs, can we ‘compensate’ for them? (cont.)

SO HERE IS WHAT IT ALL LOOKS LIKE:

1. “WAVEFRONT” maps for each eye
2. View TOTAL aberrations or just HOAs
3. View aberrations at different PUPIL SIZES
4. Get “autorefractor” results based on wavefront data

What are the results when we measure & compensate for HOAs using well-developed algorithms & modern spectacle manufacturing technology? (cont.)

1. Compare patient’s HOA results to population “averages”
2. Compare HOA results for 3mm pupil vs. a “maximum” pupil (i.e., day vs. night)
   • This is GREAT for showing Pt’s how their vision worsens when they drive at night!

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

What are the results when we measure & compensate for HOAs using well-developed algorithms & modern spectacle manufacturing technology?

- Put in the DOCTOR’S manifest refraction (MR)
- Click the “Calculate Rx to 1/100th D” icon

What are the results when we measure & compensate for HOAs using well-developed algorithms & modern spectacle manufacturing technology? (cont.)

- What a ‘dot’ of light would look like on the retina after passing through a “Normal” Rx compared to an Rx calculated to minimize the effects of the HOAs present (e.g., an “Rx to 1/100th of a DIOPTER”)

Point Spread Function (PSF) “simulation”
What are the results when we measure & compensate for HOAs using well-developed algorithms & modern spectacle manufacturing technology?

- **YES!!!**
- The advent of free-form, or digital surfacing, at the laboratory level has made it possible to produce lenses to an accuracy of 1/100th of a diopter (0.01 D).
- These 1/100th D (0.01D) prescriptions are filled using "ultra-precise" spectacle lenses; Held to tighter quality standards; Work great with “Free-Form” PALs.

That’s all great & everything, but...can we even MAKE glasses to 1/100th of a D?!

Implications for your patient’s & your practice?

- **Improved night vision**
- **Improved color perception**
- Due to a reduction of chromatic aberrations (i.e., HOAs)

Implications for your patient’s & your practice?

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

Clinical Study: Compensated Rx made to 1/100th D (0.01D)
**Implications for your patient’s & your practice?**

- Doctor can now SEE why some patients struggle to see 20/20 even though everything "looks" good and healthy in the eye.

- Can better explain to PATIENT what is going on with their vision.

**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 patient will experience better vision than they’ve had before – They will tell family & friends!

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

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