Wavefront experts discuss the practical clinical applications of this diagnostic tool, as well as the science behind its theories.

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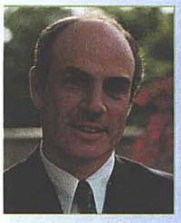

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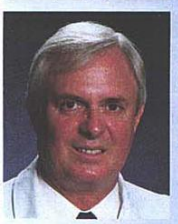

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EW DIALOGUE

The future of wavefront refraction as a diagnostic tool

Definitions and concepts

Marguerite B. McDonald, MD: Let's start by defining wavefront refractions.

Jack T. Holladay, MD: Wavefront refraction is what I like to call spatial refraction, or knowing the refraction at every point on the cornea. For clinicians, it is important to understand that with wavefront, we can look at the refraction of the whole eye just like we look at a cornea's refractive topography map.

Stephen D. Klyce, PhD: In the past, we've measured the aberrations of the corneal surface using corneal topography devices and now we can measure the topography of the whole eye.

Holladay: Wavefront is just like a drop of water. You drop a pebble in the water and a circular ring goes out. Wavefront is exactly like that except rather than a drop in the water, you usually have a vibrating filament.

So, you have spheres originating from a point of light that get larger and larger as they propagate through space.

Klyce: Another way people have described wavefronts is the optical path of light rays through a lens system. If the optical path lengths are uniform over the pupil of the eye, then there would be no aberration of the wavefront, and we get into the possibility of supernormal vision.

Noel A. Alpins, MD: I like to explain the wavefront refraction as a refractive map relating only to the optical component of the eye's refraction. In general terms, a refaction relates to a wavefront refractive map in a similar way that keratometry relates to a topographic map.

Ronald R. Krueger, MD: Keratometry was traditionally used to understand the cornea's curvature. Corneal topography came along and gave us a whole new dimension. I believe that wavefront refraction will give us another dimension of what can be determined with subjective or objective refraction.

McDonald: What methods and technologies are being investigated for generating wavefront refractions?

Keith P. Thompson, MD: Well, our system has been around for a while. We call it the spatially resolved refractometer and we published it in *Applied Optics* in 1982. We bring in one channel of light and align that on the center of the pupil or the optical axis. We simply measure the refraction completely through the eye's optical system, spatially resolved at that one particular point. That's zeroed out by the patient by aligning a test dot in cross hairs, then we measure the angle at the point that is necessary to bring it to the fovea, and then we take 30, 40, 50 measurement points. It takes 3 or 4 minutes per test.

Krueger: There are a number of technologies being investigated. Hartmann-Shack uses a single, very thin laser beam going into the eye and reflecting off the retina. The rays that are reflected back out of the eye, go through the entire optics of the eye and define the wavefront pattern. You can characterize a Hartmann-Shack technique as an outgoing wavefront pattern.

The Tscherning aberrometer presents an entire grid of laser spots, which go in, bend through the various optical elements, and ultimately are imaged on the retina. Then, through a very small aperture, you can capture that retinal image and define it. It can be characterized as more of an "ingoing optics" pattern of the wavefront.

Tracey is also ingoing optics, but rather than projecting an entire grid of laser spots, it's projecting individual laser spots at different orientations and angles of entry in very rapid succession, such that you can get almost an entire pattern within milliseconds. The relationships of those spots as they are projected and captured on the retina are put together to build the wavefront pattern.

I know that Tscherning is the type Wavelight, Schwind, and Technomed have been working with. Hartmann-Shack is the style that Autonomous, Visx, and Bausch & Lomb have been working with, and Tracey is a separate entity.

McDonald: What are the pluses and minuses of each?

Thompson: Our technique takes 3 to 4 minutes and it's patient-dependent; you get the patient involved. All the autorefractometer problems — being totally objective and bypassing the patient — are avoided.

Krueger: With the Tscherning aberrometer, looking at my own eye, I can see the grid pattern on my retina; I can see how distorted it is. And if I accommodate, I can watch the grid pattern of laser spots change to define the level of accommodation and how it's changing the optics of my eye.

I think that the Hartmann-Shack also works well, as the patient can fixate on the incoming laser beam, which reflects off the fovea to define the wavefront pattern as it's coming out of the eye.

Wavefront refractions without customized lasers

McDonald: Without a customized ablation laser, how valuable are these refractions? Will they really be a diagnostic tool for refractive surgeons?

Thompson: I think that's a really the big issue. We've had autorefractors for 2 or 3 decades, perhaps longer. How many of us prescribe or make refractive surgical decisions based on our autorefractometers? Very few. Because we have to get the patient involved in the process.

So, I think the answer is going to be determined by our clinical experience. In other words, how do these devices help us make better therapeutic decisions? And we honestly don't know the answer yet.

John F. Doane, MD: Am I ready to throw away subjective, manual, manifest, or autorefraction? Absolutely not. As far as the utility of wavefront refractions, right now, they give us more knowledge. As with anything, more knowledge is more power.

Klyce: What's missing from refractions is all the information about the eye's irregular astigmatisms. It is this kind of spatial refractometry that will give us a feeling for the amount and extent of irregular astigmatism in the whole eye, not just on the corneal surface. This, I think, should feed into the decisions that refractive surgeons make in terms of treatment.

Krueger: Absolutely, subjective refraction or even retinoscopy in an irregular cornea doesn't always give

us the best spherocylindrical refraction. Because the irregularity limits the best-corrected visual acuity, all bets are off on the true magnitudes and orientation of sphere and cylinder. Wavefront refraction actually breaks down all the components of the irregularity to give you the true refractive error as well as the higher order refractive aberrations. As an example, conventional laser retreatment on an eye that doesn't refract to 20/20 may be way off target, and would be tested with wavefront refraction first.

Thompson: Certainly, if the eye has lots of aberrations, you don't have to go any further down the neurological pathway to find the problem.

McDonald: Even without a customizing laser, this is just good feedback. We can use these standalone diagnostic tools to tell us whether we're getting better or worse as we modify algorithms and change our surgical techniques.

Alpins: Wavefront refraction is more like an autorefractor measurement in that it really takes no account of the patient's conscious control of preferred astigmatism magnitude and orientation. It doesn't deal at all with the non-optical components of astigmatism.

Holladay: I look at the wavefront from a diagnostic measurement, in terms of giving me information about how I've done. There is nothing comparable to that now. I think using this for our measurements has raised the bar for us to really evaluate our outcomes objectively.

Alpins: I consider it a very useful tool for charting refractive anomalies within the eye, such as might be contained within the crystalline lens. It's useful for the determination of the most effective aspheric profile necessary in the refractive treatment of any eye to avoid an excessively oblate cornea.

Doane: I think we have to understand what the patient's corneal, retinal, and occipital acuity is going to be.

I think we have to go back to the very basics of vision and understand where we're going to apply what we know to achieve 20/10. From what I've seen from the Visx 20/10 system, if there is an opacity in the system in the crystalline lens or the cornea, wavefront doesn't get us away from doing a standard exam using a retinoscope or a direct ophthalmoscope, and you still have to go back to your basic slitlamp examination to find out at what level the pathology exists.

Holladay: If your spatial topographic map of the cornea and your spatial refractive map aren't identical, those aberrations are not in the front surface — they're almost always lenticular. It will be helpful for isolating those.

Also, I don't think the goal should be 20/10. I don't want to be perfect at infinity, because I know it will reduce my depth of field and, at 45, you're better off having a little spherical aberration.

Thompson: I think these devices are going to give us a way to provide objective optical performance. That's something we really don't have clinically. And we need a metric.

We all know visual acuity is a very poor benchmark. A lot of patients have good Snellen acuity and poor-quality vision. These devices can give us visual performance, and if we set a metric and make it as a function of pupil size (once you get the data extracted, these devices will be able to do that), I think it's going to be a very useful clinical benchmark.

Usage as a primary diagnostic tool

McDonald: What kind of data have already been published or presented from the podium?

Krueger: I have a paper in press now that maps the spherocylindrical refraction and the refractive aberrations of my own eye, which is an emmetropic 20/15 eye with no correction. Even with my excellent vision, I can tell from that wavefront refraction that I have about a +0.5 D sphere/–0.5 D cylinder refraction. When I dilate my pupil, I notice that my vision is not quite as good. And it's because the higher-order aberrations (such as coma in my eye) are more manifested within the dilated pupil.

Alpins: I think there are a couple of things the general ophthalmologist needs to understand about how wavefront differs from conventional refraction. One is that it's not really a vergence of those rays coming out as much as a separation.

And second, that wavefront is still missing the non-optical component of astigmatism, where the conscious state controls how much magnitude and axis of astigmatism there is. Wavefront deals only with the purely optical components within the eyes, leaving out the perceptual level.

McDonald: Will wavefront refractions replace auto, manifest, and cycloplegic refractions, just as videokeratoscopy replaced keratometry?

Alpins: I believe the answer is definitely no, because for a start, keratometry is a very useful tool in analysis; it's so convenient and quick. You can have a keratometer on every refracting lane, but this isn't really a practical, economic reality with topography.

The same can be said for the availability of manifest refractions in each lane — autorefractors or wavefront refractors aren't going to be available in every room.

Holladay: Would you agree, Dr. Alpins, that it replaced the retinoscope? It didn't replace refraction.

Alpins: Certainly very few ophthalmologists would prescribe spectacles off an autorefractor printout. This makes you seriously consider whether you would permanently dispense a laser-delivered prescription onto a cornea from an automated wavefront refraction, without reference to the manifest refraction.

Krueger: I think it's going to mean different things to different people. I've got a keratometer in every lane, but I never use it. I just go right to the corneal topography and I look at the maps. That's how I interpret my patients before and after refractive surgery.

Holladay: You're never going to replace the patient with anything that's objective right now. We won't be sophisticated enough to make a model that represents all of that, because the brain is so sophisticated.

The brain has to be studied as much as the optics and it must include the perception, because otherwise you're missing the whole point of what that computer is using.

Thompson: With most wavefront instruments, you put a bright light source into the eye, try to bring it to a point on the retina, and collect the light emerging from the pupil. Not only do you not have the cortex involved, you don't have the patient's preference of the location of the retinal plane.

Krueger: I think that's a good point. There may be some limitations, because you don't get immediate patient feedback. Perhaps the wavefront will help us to develop a relationship so we can begin to understand how much is contributed by optics, and how much is contributed by the brain's interpretation.

McDonald: We will probably determine in the future whether, in certain populations, there is a significant component to the refraction that is contributed by the cerebral cortex and whether this is affected by age or other factors.

Doane: With the Visx 20/10 system, when it's closed-loop, you actually can get a subjective response from the patient. This is a massive step forward, when we can harness information on the first-order sphere, and order-regular astigmatism and the third through the 10th orders to reduce or correct coma and spherical aberrations and irregular astigmatism.

McDonald: With the Autonomous system, you dilate and fog them by slowly bringing the target into focus from "infinity." And they do have to tell you when it's clear, after which you generate the wavefront. So it is 99% objective.

Pending commercial availability

McDonald: Let's talk about the different devices and when they are going to be commercially available.

Holladay: My recommendation is that you don't want to buy one until you know what the association is with the laser. You have to be careful, because links with these refractometers and topography units are going to be made with lasers, so you want to wait until they've worked all that out.

Krueger: They might be even paired up as a diagnostic system. I believe Orbscan is looking into adding wavefront.

Thompson: And Nidek, for example, has a built-in Placido disk topographer with its wavefront sensor.

McDonald: Does everyone think the purchase of wavefront diagnostic technology might give the surgeon a marketing advantage?

Alpins: Any new piece of technology, if marketed well to the public, will attract their attention, but they usually have to understand the benefits and what they're going to provide. So, there are probably cheaper ways to impress your patients than to spend all the money on one of these.

Holladay: I'm suggesting wavefront is like topography was 15 years ago. When we were developing those, they did all kinds of measurements. We broke ground, but couldn't do anything about it until lasers came along. My only caution to the clinician is that there is no doubt that within the next 2 or 3 years, you're going to need to get one. It's not going to bring in any new patients. While you're going to pick up some things, you're not going to pick up anything that you can't see with a good retinoscope.

Krueger: Well, I know years ago before corneal topography really got popularized, a lot of people were questioning, "Gee, is this really necessary in a refractive surgery practice?" I think we're going to find that wavefront is imperative for our understanding and successful practice of refractive surgery.