

Fourier analysis- does better data equal better treatment?

Nadja Geipert
in Lisbon

WHILE Zernike polynomials are currently used to calculate most wavefront data in refractive surgery, they are not the only way to do this. Researchers made the case for a newer approach, Fourier wavefront analysis, at a session of the XXIII Congress of the ESCRS.

Douglas Koch MD, professor of ophthalmology at the Cullen Eye Institute, Baylor College of Medicine, Houston, Texas, explained that the Fourier transform fits the Hartmann-Shack lenslet data better than the Zernike 6th and 10th order expansion in highly aberrated and normal eyes.

Dr Koch, along with co-investigators Li Wang MD PhD of Baylor College of Medicine and Dimitri Chernyak PhD of AMO/VISX, wanted to investigate how Fourier transforms and Zernike expansion vary in their accuracy of recalculating Hartmann-Shack lenslet data.

"You can take the lenslet data and do the wavefront calculation for the Fourier transform and the Zernike expansion, go back and predict what those lenslet data are. This would give you a very good idea of what the error of the re-construction is," he explained.

He presented a study that compared Fourier transform's accuracy in reconstructing the Hartmann-Shack data with the Zernike 6th and 10th order expansion's accuracy in different patient groups. They selected a group of ten virgin corneas with a mean spherical equivalent (SE) of -3.28 D, one group of ten post-radial keratotomy corneas with a mean SE of 0.24 D, one group of ten post-myopic-LASIK corneas with a mean SE of -0.14 D, and one group of post-hyperopic-LASIK corneas with a mean SE of 0.21 D.

Higher fidelity with Fourier

To determine the reconstruction error, the team recalculated the Hartmann-Shack lenslet data by doing the wavefront calculation for the two systems and predicting the lenslet data. The comparison revealed that the Fourier approach was significantly better than the 6th and 10th order Zernike in all four groups, except the post-myopic group of the 10th order Zernike. In this group, the fidelity of the wavefront



Douglas Koch

reconstruction was better with Fourier than the Zernike 6th. However, the error increased in all groups as total higher-order RMS values increased.

"None of these are perfect, and they increase as the residual error increases," said Dr Koch.

When comparing the percentage of the total error of the higher order error and the range of the residual gradient in all four groups, Fourier ranged between 18% to 25 %, Zernike 6th ranged between 27% to 39 % and Zernike 10th ranged between



John Vukich

21% to 29 %.

"It is important to remember that 10th order Zernikes are not currently used with Hartmann-Shack devices, and I don't know if that will be feasible," noted Dr Koch.

The potential clinical implications of his findings require further study to determine if the superior accuracy would actually lead to better clinical outcomes, Dr Koch, who collaborated on the study with AMO-VISX Inc, which uses Fourier analysis in its wavefront sensor, added.



Mohamed Shabayek

average peak to valley ratio (P-V) for Zernike was 0.84μ versus 0.78μ for the Fourier. Zernike's average treatment time was 24.3 seconds versus Fourier's treatment time of 23.4 seconds, and the average treatment pulses were 282.5 with Zernike versus 269.6 for Fourier.

"What we're looking at really is a trend. I think, we can deduce from this that there is no meaningful difference in the ability to reproduce these increasingly complex shapes," said Dr Vukich.

Prior research that looked at intended versus achieved shapes for the Zernike 6 through 26 had shown favourable results, according to Dr Vukich. But, as eye surgeons continue to produce increasingly complex Fourier-derived shapes, it has become increasingly relevant whether the surgeon really reproduces the intended shape at the laser level of the application. While scientific modelling research demonstrated that variable spot scanning laser technology is capable of ablating highly complex shapes, it failed to answer the question if the laser can accurately ablate a complex treatment shape onto a human cornea.

Fourier-derived shapes contain an increased density of information and tend to have more topographical features. This begged the question whether the laser ablates a Fourier-derived similarly to a Zernike-derived shape.

"We can analyze the wavefront, we can certainly come up with an intended shape, but there is one more step in this entire process. We need to deliver it to the cornea and we really need to be concerned about the accuracy of that delivery," said Dr Vukich, who also collaborated with AMO/

Fourier ablation algorithms

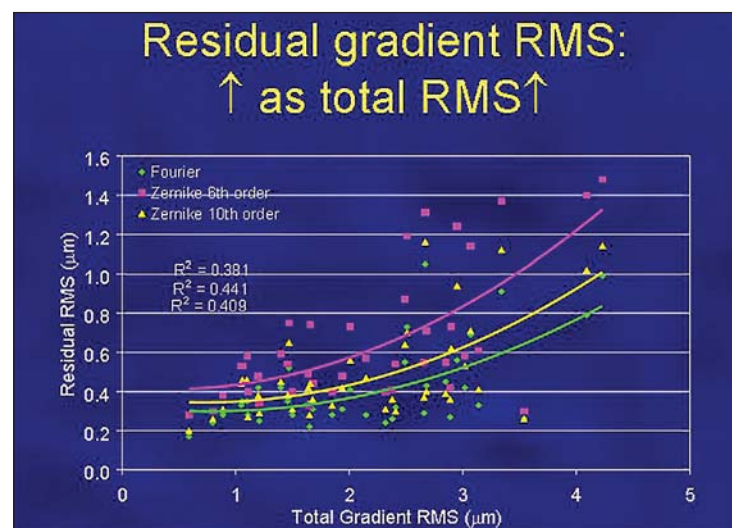
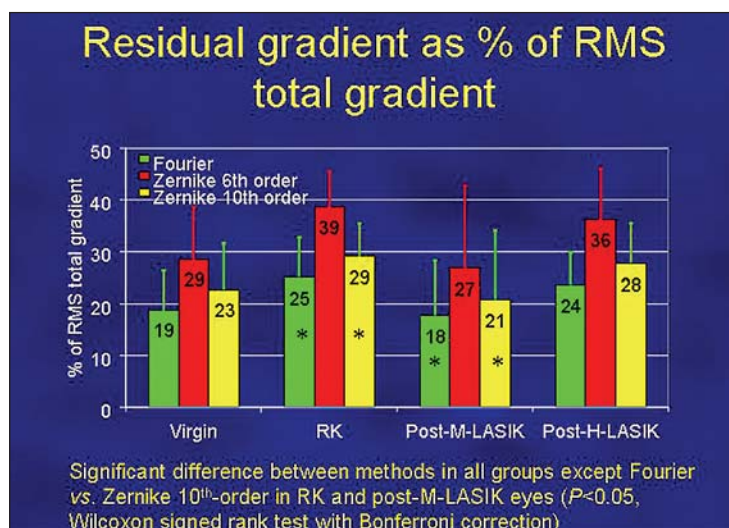
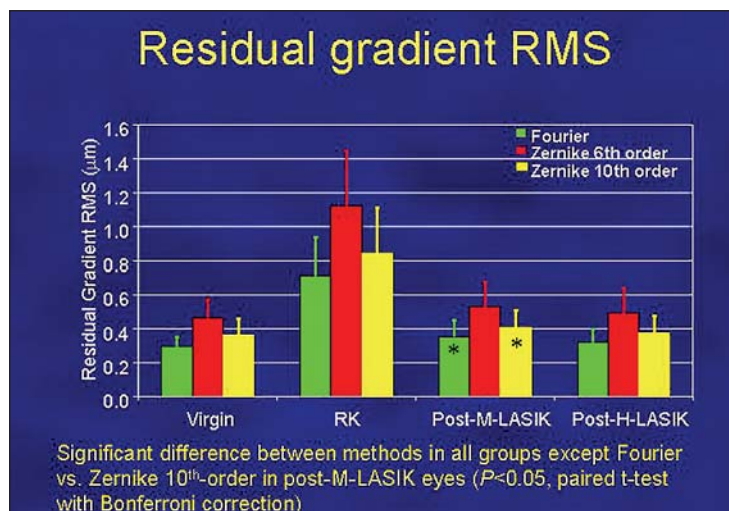
In another study, researchers analysed 50 randomly chosen wavefronts to determine if a laser could ablate a Fourier-derived shape as well as a Zernike-derived shape.

John Vukich MD and colleagues created ablation patterns by using 6th order Zernike reconstruction and then Fourier-based reconstruction. They then recreated their reconstruction shapes with the help of variable spot scanning.

Analysis of intended versus achieved ablation pattern revealed that both Zernike and Fourier ablations effectively replicated the intended shape, said Dr Vukich, an assistant clinical professor at the University of Wisconsin, Madison Medical School in the United States.

"This is certainly very reassuring as we look at therapeutic applications," he added.

However, the Fourier shape actually achieved a slightly higher level of accuracy. The average RMS for the Zernike-based ablations was 0.12μ versus 0.11μ for the Fourier-based ablation. The



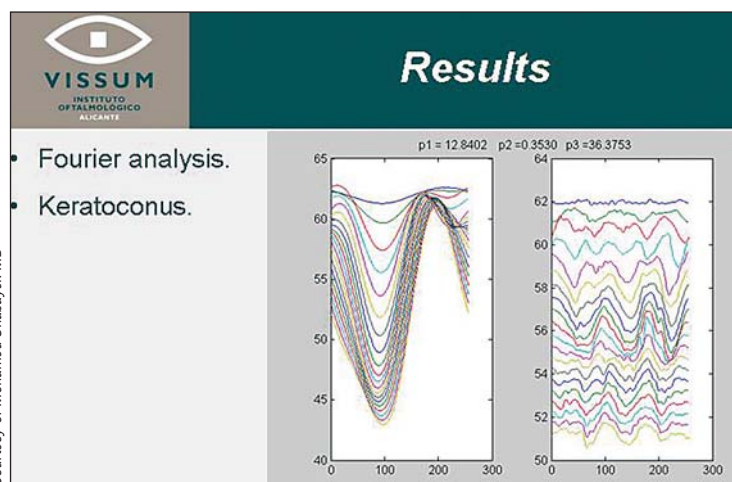
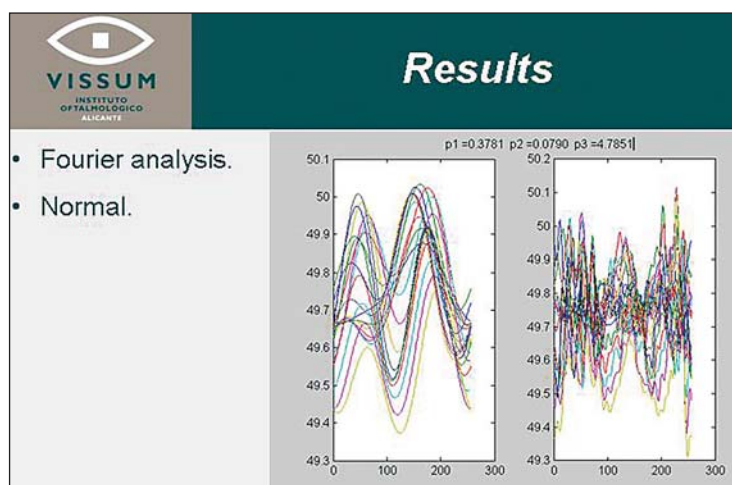
Testing the Theory

- Fourier vs. Zernikes based treatments showed no statistical difference in key parameters

(n=50)	Avg. RMS	Avg. P-V*	Avg. Treatment Time	Avg. Treatment Pulses
Zernike Based Ablation	.12 μ	.84 μ	24.3 sec	282.5
Fourier Based Ablation	.11 μ	.78 μ	23.4 sec	269.6

A comparison of average RMS, Peak to Valley Ratio, treatment time and number of pulses shows that for all categories the Fourier based treatments are actually more precise than Zernike based treatments

Courtesy of John Vukich MD



Courtesy of Mohamed Shabayek MD

VISX.

Fourier useful for keratoconus screening

In a third study, Mohamed Shabayek MD and colleagues studied 70 eyes from 57 patients and divided them into a group of normal, keratoconus and keratoconus suspect eyes to test if Fourier analysis could assist in quantifying regular and irregular components of corneal astigmatism.

The normal group included 20 eyes from 20 volunteers who had no complaints, no clinical signs of keratoconus, no ocular pathology, only minimal refractive error and normal topography. The mean age in this group was 30.1 years. They had a mean sphere of -0.03 D, and

mean cylinder of -0.27 D. The mean uncorrected visual acuity was 1.01.

The second group consisted of 20 eyes from 20 patients who had clinical signs of keratoconus, which were confirmed by topography. In this group, the mean age was 35.1 years. The mean sphere was -3.31 D, ranging from +2.0 D to -10.0 D. The mean cylinder was -4.4 D, ranging from -1.0 to -8.0. The mean best-corrected visual acuity was 0.64.

The keratoconus suspect group consisted of 30 eyes of 17 patients with no clinical signs of keratoconus, but suspicious topography due to irregular astigmatism either asymmetrical or non-orthogonal. The mean sphere was -2.98 D ranging from +2.25 to -10.00 D, and the mean cylinder

was -1.25 D, ranging from -0.00 to -3.75 D. Mean best corrected visual acuity was 0.92.

The research team took three images with well focused and centred videokeratography of all patients. To avoid dry eye, patients had to blink between each image. Software separated the results into a regular component representing regular corneal power and an irregular component, defined by the higher order frequencies, representing irregular corneal power. The third part of the analysis evaluated the relationship between the regular and irregular component.

The values were significantly higher in the keratoconus group compared to the normal and keratoconus suspect eyes. The relationship between the regular and the irregular parts was significantly higher in the keratoconus suspect group than the normal group (p0.02). Fourier analysis of the keratoconus suspect eyes showed that 73% had high "keratoconus" values.

"Fourier analysis could be a useful tool for screening patients seeking refractive surgery by quantifying irregular astigmatism, which is the main characteristic of the disease, and detecting keratoconus earlier," said Mohamed Shabayek MD, from the Institute of Ophthalmology in Alicante, Spain.

Fourier analysis is a mathematical procedure that breaks any function into a sum of sine wave components with different frequencies, amplitudes and phases. Fourier analysis applied to videokeratographic data has been proposed in several studies to quantify corneal irregular astigmatism because it allows the isolation of corneal irregularities.

"Quantifying irregular astigmatism in keratoconus patients provides better understanding of the disease, as well as a better method to follow up these patients," Dr Shabayek said.

As a next step, further follow-up of this group of keratoconus suspect eyes is mandatory to observe if keratoconus clinical signs confirmed with topography will develop with time, he added.

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