**Symposium Report**

**XXIV Congress of the ESCRS, London, 2006**

**Measuring optical and visual quality clarifies the big picture**

**Roi Roibeard O’hEineachain**

in London

Experts in the field of visual research discussed the relationship between optical quality and quality of vision during a symposium at the XXIV Congress of the ESCRS. They also examined the other non-optical factors that can influence visual performance.

Estimations of the optical quality of the eye can be achieved by metrics in both the spatial and frequency domain, but ultimately sensitive subjective testing is necessary to determine an individual’s visual function, said Raymond A Applegate OD, PhD, College of Optometry, University of Houston, Texas.

Metrics of the spatial domain are based on the eye’s point spread function, which can be determined through wavefront sensing and double-pass techniques. Comparison between the eye’s point spread function and that of a diffraction-limited system yields the Strehl ratio, he added.

Measurements in the frequency domain are those that define the modulation transfer function (MTF) of an optical system. The MTF defines how much contrast, as a function of spatial frequency, is transferred by the optical system from the object to the image plane.

It is also possible to plot the modulation transfer function in three dimensions for all possible orientations of the sinusoidal gratings. This forms a volume that can be compared to that of a diffraction-limited optical system.

Dr Applegate noted that when LASIK was first introduced the volume under the MTF was reduced to less than that of a normal eye. It improved with the introduction of wavefront-guided LASIK.

“Since wavefront came in it has become pretty common to get fairly normal MTF after surgery. The goal is to improve it still further.”

Visual acuity has traditionally been measured with high contrast charts. Such testing correlates very poorly with the actual optical quality of the eye in terms of its optical transfer function. However, mesopic low contrast visual acuity does correlate very closely with the optical transfer function.

In a study that compared metrics of optical quality with visual acuity results in a series of subjects with normal eyes, higher order aberrations could account for only four per cent of the variance in photopic high contrast acuity but could account for 37 per cent of the variance in low contrast mesopic acuity.

“In a clinical environment the effect of minor variations in optical quality can be assessed with mesopic low contrast acuity, but not with photopic high contrast acuity,” Dr Applegate added.

**Dynamic aberration**

While most current assessments of the eye currently in use provide a lot of information they are a static measurement. They therefore do not take into account such factors as temporal changes in accommodation, saccadic eye movements, and changes in the tear film, said Robert Iskander PhD, Queensland University of Technology, Australia.

“We postulate that appropriate tools for the analysis of the dynamics of human eye as well as their understanding are needed,” he added.

Some technology for that purpose is already available in the form of the COAS wavefront sensor (WaveFront Sciences, Inc.). The device is a Hartman Shack aberrometer which provides an assessment of the dynamics of total wavefront aberrations. In this way it allows evaluation of spatio-temporal interactions between different aberration components.

“In real time we can actually acquire several or several hundred measurements and what we can do offline after the measurement is to estimate each of the measurements and fit it with a particular set of Zernike polynomials. In turn, we will give us an ensemble of time series which would allow us to assess the dynamics of the total wavefront aberration.”

He noted that each Zernike term will have its own set of fluctuations and variations between measurements. It is therefore necessary when determining an average from the measurements to assess each term individually before discarding a measurement as an outlier.

“No data should be discarded without prior use of statistical tools. The temporal variations in an individual Zernike term or sets of few terms should not be used to decide about changes in refraction. For clinicians, it may be more appropriate to use the concept of dynamically changing refractive power.”

**Adaptive optics**

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“For the first time, we were able to observe in vivo the structure of the cone mosaic and examine its properties. This is important because the photoreceptors set the limit to our visual performance.”

In addition, using off-axis illumination with adaptive optics it is possible to demonstrate the directionality of individual cones. The angle of the cones to the pupil is what gives rise to the Stiles-Crawford effect, the phenomenon whereby light passing near the edge of the pupil is less efficient at evoking sensation than light passing through the centre of the pupil, because of the increased angle of incidence.

“This could have an impact when dealing with defocused images and when you are dealing with highly aberrated eyes.”

Other applications of adaptive optics include the mapping of the cones in terms of their cone type to help uncover the mechanisms of colour vision. The technology can also be used in combination with confocal scanning ophtalmoscopy to determine the correlation between cone spacing and visual acuity.

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“Adaptive optics has had a decisive and influential impact on the evaluation and the
improvement of the human visual system. Yet, vision is a dynamic process that is not only limited by the optical and retinal cellular features but by other factors as well.

**Colour vision and psychophysics**

Ian Murray PhD, University of Manchester UK discussed how in chromatic terms the image projected on the retina is not exactly what an individual perceives. He explained that two phenomena, colour constancy and cone opponency, are mediated by the neural pathways of the optical system and modify image perception in a way that improves object recognition and sharpens colour discrimination.

Colour constancy controls "global" vision, that is, vision involving a broad visual field. It is the process whereby the perceived colour of an object appears to remain unchanged despite the effects of changing lighting conditions. It does not occur in photographic images, which show objects with different hues of colours depending on the light source. It is, however, common to all species with colour vision.

“If you think about it, that's a crucial component of a biologically efficient colour system. Any species with colour vision must have a system which is sophisticated enough to discount luminance.”

Cone opponency is the neural process that controls “local” vision, when the visual field is small. It depends on the spectral mix reflected from an object's surface and causes images to be perceived in a way that is more similar to that of a photographic image.

“Colour opponent theory is supposed to account for how we see local colours. It says there are three post-receptoral channels. The red/green channel is based on antagonism between L and M cones, the blue/yellow channel is based on antagonism between S cones and the L and M cones, and the white/black channel is the achromatic channel.”

The three channels have three corresponding types of retinal ganglion cells. The parasympathetic cells control the achromatic channel, the midget ganglion cells control the red/green channel and the bi-stratified ganglion cells control the blue/yellow channel.

Each type of ganglion cell has a central sensor zone surrounded by an inhibition zone, the parasympathetic cells have red sensors with blue surrounds, the midget ganglion cells have either blue sensors with yellow surrounds or yellow sensors with blue surrounds and the bi-stratified ganglion cells have red sensors with green surrounds. Through these neural mechanisms, colour opponency enables discrimination between over two million colours, Dr Murray added.

**Vision after refractive surgery**

Parameters that influence quality of vision after refractive surgery are anatomical, subjective, and objective in nature, said Prof Thomas Kohnen MD, Johann Wolfgang Goethe University, Frankfurt, Germany.

The anatomical parameters determine the quality of the retinal image and pertain to such features as the curvature of the corneal surface, the cleanness of the optical media and the axial length of the eye.

The subjective parameters concern the patient’s satisfaction with his or her vision. It can be influenced by visual phenomena such as glare, haloes, and loss of contrast sensitivity. Objective parameters involve testing of optical quality in terms of visual acuity, wavefront aberrations, contrast sensitivity, and glare disability.

High contrast visual acuity remains a standard test for visual performance although contrast sensitivity testing at different illumination levels has become more common in refractive practices in recent years.

Wavefront aberrometry can reveal some of the causes of poor visual quality. The first and second order aberrations produce blurring, the higher order aberrations cause deterioration of image quality. Among the higher order aberrations, coma causes phenomena such as ghost images and shadows while spherical aberration produces halos and starbursts.

Questionnaires before and after refractive surgery are a useful means of testing the subjective response to refractive surgery. The types of visual adverse effect reported after refractive surgery tend to vary depending on the type of surgery, he noted.

In eyes that have undergone astigmatic keratotomy or radial keratotomy, glare disability, decreased contrast sensitivity, and image degradations are the most common visual symptoms. LASIK and PRK can produce similar symptoms in addition to diplopia and night vision disturbances. Patients who have undergone lenticular refractive procedures may experience glare and halos under mesopic conditions.

“Quality of vision is an important factor for refractive surgery. Its assessment requires wavefront technology to quantify higher order aberrations and standardisation of visual acuity and contrast sensitivity measurements.”

**Visual quality after cataract surgery**

Oliver Findl MD, Moorfields Eye Hospital, London, UK, noted that the same parameters used in refractive surgery define quality of vision after cataract surgery. He also pointed out that the availability of aspheric IOls has made corneal topography and contrast sensitivity testing more of an issue than was formerly the case.

**Photopic high contrast acuity testing can provide a measure of the ability to see the finest spatial detail under ideal conditions. However, in real-world conditions it is an inaccurate measure of visual performance, he said. Many everyday tasks require object discrimination under mesopic conditions where there is only 50 per cent or less contrast, he added. Therefore the good results reported with conventional IOls in terms of standard Snellen acuity generally represent an overestimation of a patient’s visual function. Conventional IOls add to the corneas positive spherical aberration with a resulting loss in contrast sensitivity, particularly under mesopic conditions, Dr Findl pointed out.**

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Oliver Findl MD

The recent introduction of aspheric IOls has made it possible to reduce patients’ spherical aberrations. Such lenses now exist in several different designs that compensate for varying amounts of corneal spherical aberration. The common feature of these lenses is a prolene anterior surface.

Several studies have demonstrated that aspheric IOls reduce spherical aberration and improve contrast sensitivity. However, the studies also show that there is some variation in the amount of postoperative spherical aberration patients have with any of the aspheric lenses. Some have residual amounts of positive spherical aberration while others have what appears to be a small amount of induced negative spherical aberration.

For this reason, Dr Findl advocated following the practice of George Beiko FRSC (C), Canada. His approach involves using different types of aspheric IOls in different patients depending on their amount of corneal positive spherical aberration. Pre-operative corneal spherical aberration can be measured through corneal topography.

If topography shows that the preoperative corneal spherical aberration is negative, patients should receive standard spherical IOls. If the corneal spherical aberration is only weakly positive (0 to 0.15µm), the Akreos/Sofport AO IO L (Bausch & Lomb) would be a good choice. If spherical aberration is moderately positive (0.16 to 0.33µm), the AcrySof IQ (Alcon) would be a good option. If the spherical aberration is strongly positive, patients would do well with the Tecnis lens (AMO), he advised.

The ultimate measure of quality of vision is its impact on the quality of life of the patient. As with refractive surgery, questionnaires can provide useful information regarding patients’ satisfaction.

One common finding in patients who have undergone cataract surgery is that, while most are satisfied with their vision, there is also a group of patients who are unsatisfied despite good visual acuity, and another group of patients who are happy with their vision despite poor visual acuity.

Possible explanations for dissatisfaction despite good visual acuity include unrealistic expectations, poor contrast sensitivity and higher order aberrations, he said. Those who are satisfied despite poor visual acuity remain something of a mystery but should probably be left as they are, he added.

“Visual acuity does not suffice to describe quality of vision. In quality of vision and quality of life several other parameters are involved. We have to be sure our patients have reasonable expectations by insuring they receive adequate information when we are obtaining informed consent.”