Eye Axes and Their Relevance to Alignment of Corneal Refractive Procedures

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In this issue, Reinstein et al. present an article entitled “Coaxially Sighted Corneal Light Reflex Versus Entrance Pupil Center Centration of Moderate to High Hyperopic Corneal Ablations in Eyes With Small and Large Angle Kappa.” A variety of axes and their relationship to the point of fixation have been defined over the years. Some of these definitions are theoretical, whereas others are practical to measure in a clinical environment. In addition, the nomenclature used in these definitions is conflicting. Here, the definitions of these axes and their respective angles will be clarified to mitigate potential controversy on interpreting the results of Reinstein et al.’s research.

In traditional optical systems, the optical elements are typically rotationally symmetric. Each surface has a center of curvature, and in fabricating an optical element, extreme care is taken in ensuring that centers of curvature of the front and back surface lie on the line passing through the geometric center of the element. Said more simply, there is no wedge (till) or decentration between the optical surfaces. Furthermore, when multiple lenses are stacked in a barrel, they are placed so that all of the lenses are aligned with respect to one another. This means the centers of curvature of all of the surfaces fall on a common line known as the Optical Axis.

In the eye, the Optical Axis is a theoretical construct. Figure 1A illustrates the Optical Axis of the eye. To be a true Optical Axis, the surfaces of the cornea and crystalline lens would need to be rotationally symmetric and their centers of curvature would need to lie on a common line. The Optical Axis is therefore perpendicular to each of the surfaces of the eye. Furthermore, in shining a point source into the eye and observing the Purkinje images (back reflections), there would exist a position of the source where the Purkinje images all coincide. The line from the point source through each of the Purkinje images would then define the Optical Axis. In real eyes, the Purkinje images do not align and the surfaces are not rotationally symmetric, so no true Optical Axis of the eye exists. Occasionally, the Optical Axis of the eye is defined as the line that minimizes the deviation of the Purkinje images.

Even with the Optical Axis defined as the best-fit through the Purkinje images, this axis does not coincide with the fovea. In general, the fovea is displaced temporally and slightly inferior to the intersection of the Optical Axis with the retina. Figure 1B shows the location of the fovea, the center of the pupil E, and the nodal points N and N'.

A variety of axes have been defined in relation to the eye. In addition, angles between these axes and the intersections of these axes with the anterior cornea have been defined. There are conflicting definitions in the literature, so here the conflicts will be described for clarification. Figure 1C shows the Visual Axis. If the eye looks at a fixation target, the Visual Axis is defined as the line connecting the fixation point to the front nodal point N, and then continuing from the rear nodal point N' to the fovea. Also shown in Figure 1C is the Coaxially Sighted Corneal Light Reflex (CSCLR) as used by Reinstein et al. The line from the fixation point that is normal to the cornea defines the location of the CSCLR. The CSCLR is found by observing the first Purkinje image from the point of view of the fixation source.

Figure 1D defines two additional eye axes. The pupillary axis is perpendicular to the cornea and passes through the center of the pupil. This axis is found by aligning the first Purkinje image with the center of the pupil. The second axis shown in this figure is the Line of Sight. This axis connects the fixation point to the center of the entrance pupil. The angle between the Pupillary Axis and the Line of Sight has conflicting definitions. For example, Duke-Elder and El Hage and Le Grand define this angle as angle \( \kappa \). Lancaster and Uozato and Guyton\(^\text{d} \) define this angle as \( \lambda \).

To further add to the conflicting definitions, Lancaster defines the angle \( \kappa \) as the angle between the Pupillary Axis and the Visual Axis. It is this latter definition of angle \( \kappa \) that is used in Reinstein et al. Although conflicting definitions of these angles exist, the Reinstein et al. study is actually comparing whether there...
are visual differences following hyperopic treatment between the CSCLR being located near or far from the intersection of the Pupillary Axis with the cornea. Because no significant differences were found, the conclusion of the study is that centering non-wavefront guided hyperopic ablations on the CSCLR provides equivalent results regardless of the relationship between the CSCLR and the Pupillary Axis. Based on this study and as noted by the authors, it is difficult to go beyond this conclusion to state that centering the procedure over the pupil provides different results than when centered on the CSCLR. Comparison of these techniques is still needed to resolve the issue.

In general for an ideal correction, the wavefront over the area of the entrance pupil needs to be corrected. In wavefront-guided procedures, pupil-centered aberrometry is used to measure the wavefront emerging from the eye. The ablation pattern is registered to the measured wavefront and correction delivered. The registration between the measured wavefront and the correction is the important part, regardless of how the wavefront is positioned relative to the various eye axes. In non-wavefront guided procedures, only the spherical-cylindrical component of the wavefront is measured and the centration of this subset of the wavefront is lost. Consequently, there is no way to register the correction to the measured wavefront. In many cases, the mis-registration will be small and the visual errors induced will be nominal. However, refractive surprises may occur if the mis-registration is large.

Finally, Reinstein et al. refer to studies regarding an annular corneal inlay and that centering the inlay on the CSCLR provides improved visual performance (references 18-24). However, care should be taken when trying to extrapolate these results to corneal refractive surgery. For the corneal inlay, the inlay itself becomes the new pupil of the system. Consequently, centering the inlay on the CSCLR also has the effect of shifting the Pupillary Axis to the CSCLR. So, it is unclear whether the visual benefit seen with this device and centering strategy is strictly due to centering on the CSCLR, or whether forcing the CSCLR and the Pupillary Axis to coincide creates the effect. In corneal refractive surgery, the Pupillary Axis remains essentially fixed, so extrapolation between the two procedures is difficult at best.

REFERENCES