from the editor

How should we analyze astigmatic data?

Where Is the Controversy?

Meaningful analysis of astigmatic data is essential to understanding the results of refractive and cataract surgical procedures. Certain elements of astigmatic analysis are simple and straightforward, but other aspects can be extraordinarily complex.

Many authors have described methods of analyzing astigmatic data. This raises the question: What are the minimal requirements for accurately reporting astigmatic data? To answer this question, we must consider the goals of this analysis. First and foremost, we are concerned with patients' outcomes. To this end, we are interested in such basic elements as uncorrected visual acuity (UCVA), loss of best spectacle-corrected visual acuity, and arithmetic analysis of astigmatic data, as will be described.

A simple analysis, however, is not sufficient. As clinicians and scientists, we have to understand these results in much greater detail to continually improve patient outcomes. The initial step in more sophisticated analysis is calculating the surgically induced change in astigmatism. As Naeser proves in the lead article of a special section in this issue, there is one and only one solution for calculating the surgically induced change in astigmatism, although multiple routes can be chosen to derive this value.

Several investigators have developed elaborate methods of further describing and characterizing astigmatic change. Since there are marked differences among these approaches, we think it is important to view them side by side. As a result, we invited 6 authors or groups of authors to perform a common task: analyze the same set of refractive data. Each author was provided a data set from my practice of 100 eyes that had had laser in situ keratomileusis (LASIK) for correction of myopia with astigmatism. Authors were provided preoperative and postoperative values for manifest refraction and keratometry. (In a few instances in which postoperative keratometric data were not available, corneal curvature values from computerized videokeratography were supplied.) We asked each contributor to demonstrate his method of analyzing spherical and astigmatic changes induced by the LASIK procedure. The result is a series of remarkable contributions.

Reader's Guide

To assist the reader in navigating these articles, I have provided a brief description of each contributor's methodology. In addition, I have used the term ***snapshot*** to refer the reader to a key figure in the article that illustrates many of each contributor's key points.

Six Approaches

Alpins uses vector analysis to generate various indices to more fully describe astigmatic outcomes. Many of these indices, such as *difference vector* (DV), *index of success* (IOS), and *coefficient of adjustment* (CA), provide remarkably useful and intuitive means of understanding the effects of the surgery. ***Snapshot:*** Figures 1 and 2 provide a comprehensive overview of the surgically induced astigmatic change in a single patient.

In a manner analogous to Alpins, Kaye and Patterson use vector analysis to generate indices (3 in their approach) to enhance our understanding of astigmatic results. One of these, the *global index correction* (GIC), is an intriguing way of characterizing the overall visual effect of both the spherical and astigmatic components. ***Snapshot:*** Figure 2 is a concise illustration of Kaye and Patterson's analytic approach.

Holladay, Moran, and Kezirian review fundamental concepts such as vertexing and selection of appropriate values for corneal index of refraction. In their analytic approach, cylinder magnitude and axis are converted to x and y Cartesian values and are displayed using doubled-angle plots. They calculate the *defocus equivalent* (DE) as an index that reflects the impact of residual spherical and cylindrical error on UCVA. ***Snapshot:*** Their article is heavily illustrated, but a representative graph is Figure 8A, which shows the doubled-angle plot of preoperataive and postoperative refractive astigmatism with ellipses that represent the standard deviations of the *x* and *y* Cartesian values.

Thibos takes another approach to analyzing astigmatic data. He separates the refractive data into 3 power vectors: spherical equivalent and 2 Jackson crossed cylinders separated by 45 degrees. With these, he demonstrates analysis of the data with useful graphic depictions. Thibos also calculates the *blur strength*, which is another type of index that can be used to characterize the effect on vision of the spherical and astigmatic components of the residual refractive error. ***Snapshot:*** Figure 3 shows the reduction in astigmatism by a graphical display of the J_0 and J_{45} power vectors preoperatively and postoperatively.

Naeser and Hjortdal use polar analysis and, in a method that is analogous to Thibos' approach, characterize any astigmatic value by 2 polar values that are separated by 45 degrees. ***Snapshot:*** Figures 2 and 4 demonstrate their application of bivariate analysis and elegantly display the preoperative and postoperative polar values, the surgically induced change, and the statistical relationships among them.

In a subsequent manuscript, Naeser and Hjortdal extend their methodology to trivariate analysis, which provides a 3-dimensional depiction that displays both polar values and the spherical equivalent. Trivariate analysis is also used by Harris, although he displays different parameters.

Harris provides a complex analysis using linear optics, ray transference, and matrices. His methods are clearly beyond the scope of the average reader of the journal, but they challenge current theories and may contribute to "raising the bar" for the type of analysis that will be required as we progress to wavefront-guided correction of vision. ***Snapshot:*** Figure 2 shows stereopair scatterplots of various parameters with ellipsoids defining 95% confidence intervals.

Required Elements of Astigmatic Analysis

What then should be the minimal standards for reporting astigmatic data? We have addressed this issue previously,[1] and the fundamental conclusion is the same, but the papers on this issue offer many options for expanding the interpretation of the astigmatic data. I would suggest that the elements of astigmatic analysis include:

Arithmetic Analysis

1. Mean preoperative and postoperative astigmatism and arithmetic difference, with standard deviations and ranges.
2. A tabular display of the number and percentage of eyes in various astigmatic categories is also helpful; for example, note the number of eyes with ≥0.5 diopter (D), 0.51 to 1.0 D, 1.1 to 2.0 D, etc., perhaps adjusting these intervals as mandated by the data and the surgical goal.

Surgically Induced Astigmatism

Surgically induced astigmatism can be calculated by vector or polar analysis, with each providing an identical value, as noted above. However, this figure alone is often of little or no value in interpreting astigmatic results. It is here that more elaborate descriptions of astigmatic change become meaningful.

Expanded Analysis

Authors are strongly encouraged to include more sophisticated forms of astigmatic analysis, as demonstrated by the articles in this issue. Elements of this analysis could include the following: (1) Global indices: Further studies are required to determine which of these most closely predicts visual performance. Options would include the DE (Holladay, Moran, and Kezirian), blur strength (Thibos), or the GIC (Kaye and Patterson). (2) Indices describing specific aspects of astigmatic change: These would include those described by Alpins and by Kaye and Patterson. (3) Advanced statistical analysis, such as bivariate analysis (Holladay and coauthors and Naeser and Hjortdal) and trivariate analysis (Naeser and Hjortdal and Harris) or more complex analyses, such as linear optics (Harris).

Despite our desire to have "standards" for methods of analysis, the usefulness of these more advanced methods will have to be evaluated and refined as they are applied in subsequent studies. With time, the minimal requirements might be expanded to include elements of the descriptions provided in the articles in this issue. Until then, we encourage authors to test these various approaches and use them in their own articles to enhance their characterization of astigmatic change.

Future Trends

The methods described by these authors have been applied to analyze a basic form of astigmatism: that characterized by either refraction or by keratometric measurement of 4 points on the corneal surface. Many of the authors' approaches can be modified and expanded to characterize change in corneal topographic and wavefront data. However, corneal topographic and wavefront data will also require different approaches (eg, calculation of root mean square values for wavefront aberrations). We look forward to receiving articles from authors regarding the more sophisticated approaches that will be required for analysis of these more complex data.

The journal is extremely grateful to the authors of these articles. Their creativity, insights, and hard work have tremendously broadened our understanding of this complex area.

Douglas D. Koch, MD

Reference

1. Koch DD, Kohnen T, Obstbaum SA, Rosen ES. Format for reporting refractive surgical data. J Cataract Refract Surg 1998; 24:285−287