

JRS Standard for Reporting Astigmatism Outcomes of Refractive Surgery

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Standardization of reporting outcomes has been aspired to since the inception of laser refractive surgery and a standard format was initially proposed by Waring in 1992,¹ formalized in a joint effort by the editorial staffs of the *Journal of Refractive Surgery* and the *Journal of Cataract and Refractive Surgery* in the familiar set of six Standard Graphs summarizing efficacy, predictability, safety, refractive astigmatism, and stability.^{2,3} More recently, this set of six graphs has undergone some finetuning⁴⁻⁷ and the two Journals, joined also by *Cornea*, reiterated the requirement for these graphs to be included when applicable for any manuscript submitted to these Journals. This has enabled refractive surgery outcomes to be presented in a succinct, one-page format, while also providing a comprehensive analysis that can be easily compared between (and within) studies. Now, with astigmatism management becoming such a critical component in all refractive surgical procedures, additional modification to the Standard Graphs seems appropriate to further serve the needs of our authors and readers.

REPORTING ASTIGMATISM

The current set of six graphs includes a histogram of simply the magnitude of the manifest refractive astigmatism before and after a procedure. This histo-

gram provides the reader with a basic understanding of the astigmatic change and it can be immediately appreciated whether an astigmatic correction was, on the whole, successful or not. However, given the vectorial nature of astigmatism, there is clearly a significant amount of further information regarding the efficacy of a treatment for astigmatism that could be provided. How best to do this has been tackled by different authors; the diversity of opinion in how best to represent the effectiveness of the treatment of astigmatism is exemplified by a special issue⁸ of the *Journal of Cataract and Refractive Surgery* in which six different methods were compared by analyzing the same data set.⁹⁻¹⁴ Given the complexity of analyzing astigmatism to this level of detail, there are inevitable differences between these approaches (although the underlying double-angle vectorial principles are the same in all cases) and it has so far not been possible to come to an absolute agreement on a standard despite significant efforts between editorial boards and external experts.

Our goal at the *Journal of Refractive Surgery* is to implement a minimum standard required for all articles reporting outcomes of astigmatic treatments that comprises a graphical display that is simple and easily understandable without requiring expert mathematical knowledge of vector analysis, but gives an overall basic understanding of the effectiveness of an astigmatic treatment. We also provide a framework for more detailed reporting of astigmatism treatments and a freely downloadable spreadsheet that can be used by authors to easily display their astigmatic data for publication.

DEFINING ASTIGMATISM TERMINOLOGY

Before discussing the Journal's new standard for the graphical display for astigmatism, we believe it necessary to revisit a potentially contentious topic in this area—that of the terminology used to describe the analysis of astigmatism. In 2006, an attempt to address the question of a minimum standard format for reporting astigmatic outcomes was proposed by the Astigmatism

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TABLE 1
Terminology for Reporting Astigmatism

Alpins Method ^{9,17,18}	ANSI ¹⁵	Reason
Target induced astigmatism vector (TIA)	Intended refractive correction (IRC)	TIA is easily understood as the astigmatic correction that was attempted. On the other hand, the term 'intended refractive correction' could also be interpreted as inclusive of sphere (eg, as spherical equivalent).
Surgically induced astigmatism vector (SIA)	Surgically induced refractive correction (SIRC)	SIRC does not specifically apply to astigmatism (it can be misinterpreted as inclusive of sphere), whereas SIA can only be interpreted as the astigmatism achieved by the surgery. Also, SIA is a term that can be applied to either manifest refractive or corneal analysis, whereas SIRC would be inappropriate for corneal analysis alone.
Magnitude of error	Error of magnitude	This describes the arithmetic difference between the SIA and TIA (ie. the magnitude of the error). The term 'error of magnitude' implies that the error is related to the magnitude of the treatment, which is not necessarily the case.
Angle of error	Error of angle	This describes the angle between the axis of the SIA and the axis of the TIA (ie, it is the angle of the error between these two vectors). It is not an error of an angle because by definition there are no angles in astigmatism (only axes); an angle does not specify a position in space, whereas an axis specifies the actual orientation.
Difference vector (DV)	Error vector	This is literally defined as the vectorial "difference" between the TIA and SIA vectors; this difference may not represent an "error" in the surgery or treatment because other factors could be in play causing such a "difference" to occur. In addition, the Alpins Method has precedence with no added benefit to changing the terminology.
Correction index	Correction ratio	This is defined as the SIA divided by the TIA. Although this could be described as either a ratio or an index, the Alpins Method has precedence with no added benefit to changing the terminology.
Index of success	Error ratio	This is defined as the DV divided by the TIA and provides the surgeon with a measure of the "success" in correcting the astigmatism rather than introducing the negative connotation of "error." In addition, the Alpins Method has precedence with no added benefit to changing the terminology.

ANSI = American National Standards Institute

Project Group of the American National Standards Institute (ANSI), and their report was published in this Journal,¹⁵ albeit without peer-review on the basis that the article was a completed formal document from ANSI and that the content was the final report from the project's group.¹⁶ The majority of the astigmatism analysis methods included in the ANSI article were directly adapted from the methods developed and originally published by Alpins in 1993,^{9,17,18} in many instances with simple renaming of the original terminology. Although this was highlighted at the time in correspondence to the Editor,¹⁹ the altered terminology has been used subsequently in many publications reporting astigmatism.²⁰

Our position at the Journal is that all future reports of astigmatism should adhere to the original terminology as described by Alpins.^{9,17,18} There are three reasons for this, and the guiding principle is clarity in communication above all else. The Alpins terminology has been in use for more than 20 years and had been in use for 13 years prior to the ANSI article,¹⁵ and so had already become widely used in the field within hundreds of publications. Because there is no added clarity in using the new terminology, there is no benefit to alternative strategies for describing the same thing; different terminology can only cause unnecessary con-

fusion to readers. We further agree with the basic principle of acknowledging primary source material, as has been recently highlighted by Dupps.²¹ It is common for authors to be more aware of recent publications, so there is always a risk that a primary source can get lost during the evolutionary citation process if some authors start referencing the more recent publication only. It is an easy mistake to make; we have been guilty of doing exactly this, for example when we cited the ANSI article¹⁵ in our editorial on updating the Standard Graphs in 2009.⁴ Finally, and most important, our analysis finds the terminology in the original Alpins articles^{9,17,18} to be superior by taking into account the strict mathematical and semantic context for the specific task of describing astigmatic vector changes in the ophthalmological domain. For clarity and reference, we have set out in **Table 1** the original Alpins Method terms alongside the ANSI altered terms together with the reasoning behind the preference of adhering to the original terminology.

We hope that the reader will agree with this impartial and objective determination of the relative merits of adhering to the original terminology described for this method of astigmatic analysis by Alpins.^{9,17,18} We will endeavor to keep our reviewer base aware of this situation.

JRS STANDARD GRAPHS FOR REPORTING ASTIGMATISM

The refractive astigmatism histogram gives us an overall idea of the effectiveness of the magnitude of the astigmatic correction in the case where the method is relatively successful; what is needed now is a way of showing why an astigmatic correction was not 100% successful. This can be because of an error related to the magnitude of the treatment, an error related to the axis of the treatment, or a combination of the two. Specifically, we would want to be able to answer the following questions:

1. Did the attempted astigmatic treatment magnitude undercorrect or overcorrect?
2. Did the under/overcorrection depend on the magnitude of treatment?
3. Was there a consistent rotational error? (ie, was the applied treatment axis consistently clockwise or counterclockwise to the intended treatment axis?)
4. Was the treatment having a varying effect depending on the orientation of the treated astigmatism? (ie, was there a difference between the treatment being applied to with-the-rule, against-the-rule, or oblique astigmatism? Or was unexpected induced astigmatism always at a particular axis?)

With four variables to evaluate, it is impossible to design a single graphical plot that summarizes them all. Therefore, we need to use a series of graphs. Because our aim is simplicity and accessibility, the simplest solution would be to use graphs that directly answer each of these questions in turn, which the Alps Method already provides.^{9,17,18}

This leads us to choosing the following two graphs (**Figures 1G-1H**), which would be based on the subset of astigmatic treatments (ie, excluding spherical treatments):

1. A scatter plot of target induced astigmatism vector (TIA) vs. surgically induced astigmatism vector (SIA): this plot answers questions 1 and 2, and is immediately recognizable to everyone because it is essentially the same type as the attempted vs. achieved spherical equivalent refraction scatter plot of the Standard Graphs. This makes it an excellent graph to include as part of a minimum standard because it incorporates a lot of information in a single easily understandable format.
2. A histogram of the angle of error: this plot answers question 3 directly, and is simple to understand in terms of how far away from the intended axis the treatment was performed.

One of the barriers to reporting astigmatism is the complexity of the mathematics of double-angle vector analysis. These two graphs have the advantage of being the simplest to understand (understanding the mathematics is not required) while providing the most directly relevant information. These two graphs (along with the refractive astigmatism histogram already in the Standard Graphs) would then form the required minimum standard for reporting astigmatism. This leaves question 4 unanswered, but this is likely to be the rarest type of astigmatic error and so would usually be addressed by authors submitting articles where a more comprehensive astigmatic analysis is clearly warranted.

THE NINE STANDARD GRAPHS

By including these two extra astigmatism graphs, we now have eight graphs to fit onto one page. This naturally lends itself to having a ninth graph to make a 3×3 grid. The rows also naturally fall into three categories—visual acuity, spherical equivalent refraction, and refractive astigmatism—with a space in the visual acuity row. Therefore, it seems a good opportunity to add a histogram of the Snellen lines difference between the postoperative uncorrected distance visual acuity (UDVA) and preoperative corrected distance visual acuity (CDVA). This parameter represents the true aim of refractive surgery, particularly from a patient's point of view: to achieve visual acuity as good as or better than that preoperatively with correction. This method of analyzing UDVA normalizes the data to the CDVA so that studies can be directly compared without the distribution of CDVA confusing the issue when comparing UDVA only. Also, this provides the refractive surgery community with a modern goal to aim for now that 20/20 rates are so high. The only issue with this graph is that it is not comparatively relevant for procedures such as cataract surgery where the preoperative CDVA is low due to the cataract, in which case this graph may be omitted.

To make it easier for authors, we have expanded our free downloadable spreadsheet to include the three additional graphs (www.standardgraphsforrefractive-surgery.com). Once the vector analysis has been done, this spreadsheet can be used to graphically display the data in the format described here.

FURTHER REPORTING FOR ASTIGMATISM

For articles where astigmatism correction is a significant part of the study, or where there is an interesting result relating to astigmatism, further analysis can of course be included in the article. As described earlier, there is a wide range of methods for analyzing and reporting astigmatism, so we are not defining a

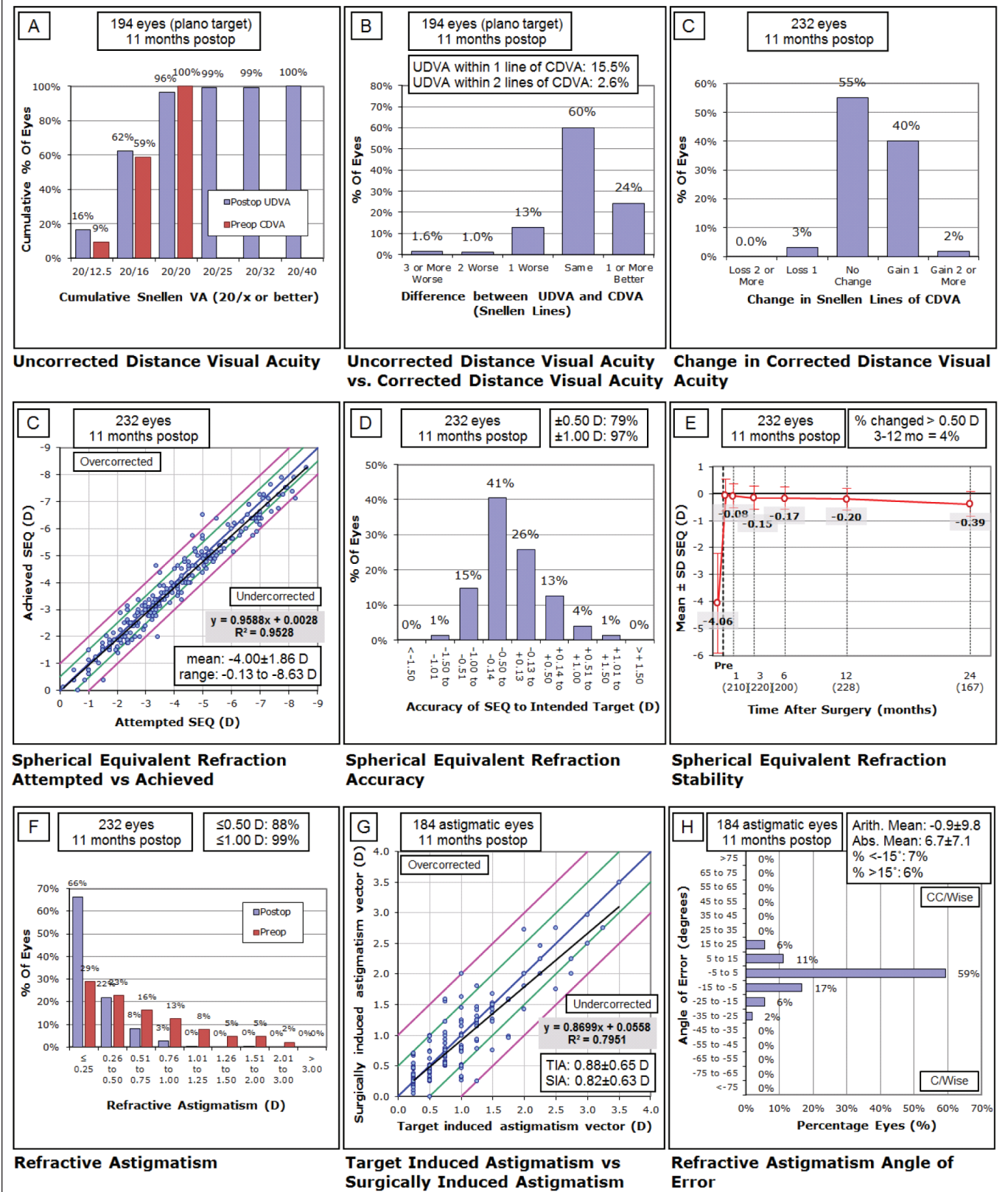


Figure 1. Standard graphs for reporting refractive surgery outcomes (2014). UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; SEQ = spherical equivalent refraction.

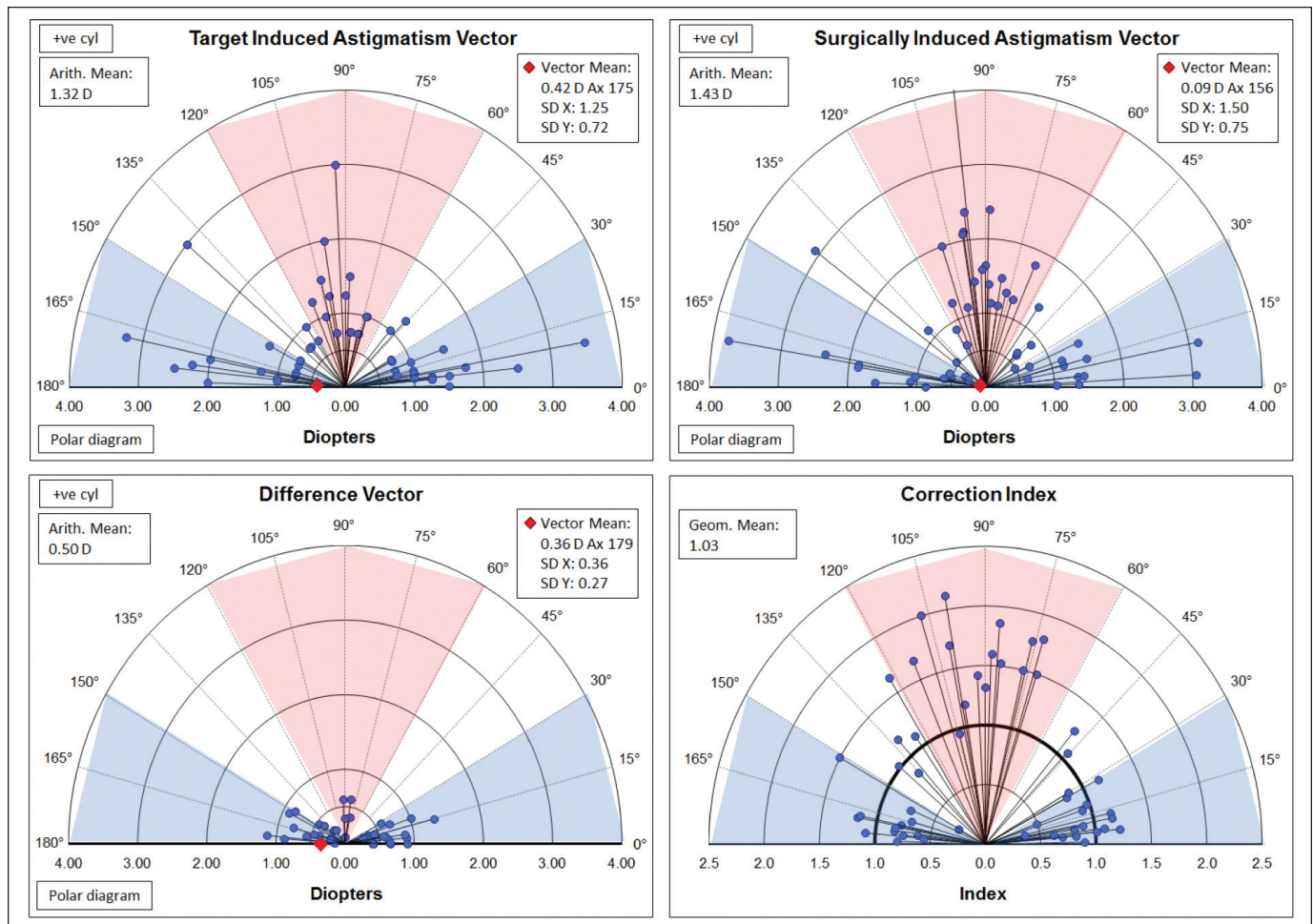


Figure 2. Standard graphs for reporting outcomes for astigmatism correction, based on the Alpins Method. Single-angle polar plots for the target induced astigmatism vector (TIA), surgically induced astigmatism vector (SIA), difference vector (DV), and correction index (CI). The vector means are plotted as a red diamond (calculated in double-angle vector space) and the standard deviations for the X and Y directions are displayed in the call-out box.

compulsory set of graphs to include for publications in the Journal. However, our opinion is that the Alpins Method provides a comprehensive display that answers all of the questions related to astigmatism correction. For the next level of astigmatism reporting, we would suggest including the following additional graphs (**Figure 2**):

1. TIA: this graph shows the distribution of the astigmatism treatment that was performed, in particular the distribution of axis (the distribution of magnitude has already been included in the scatter plot).
2. SIA: this graph shows the surgically induced astigmatism, and acts as a comparison to the TIA.
3. Difference vector: this graph shows the remaining astigmatism (adjusted for the target if non-zero) and provides a summary of the astigmatic error taking into account both magnitude and axis.
4. Correction index (calculated as SIA/TIA, plotted

at the axis of the TIA): this graph shows the under/overcorrection by refraction, but also answers question 4 above: whether there is any difference in correction between with-the-rule, against-the-rule, or oblique orientations.

The Journal would prefer authors to use single-angle polar plots rather than double-angle plots for these graphs because (1) single-angle polar plots do not require any further learning or understanding than what is taught to all ophthalmologists/optometrists, (2) data plotted on a single-angle plot are directly transferrable to the clinical situation of a topography, treatment, or eye, and (3) single-angle plots require less space on the page. This is according to the goal of simplicity and accessibility to the majority of the readership, especially because this allows quick interpretation for most readers. It must be emphasized that the use of single-angle polar plots is for graphical display purposes only

and should not be misinterpreted as having performed vector calculations in a 0° to 180° space—the calculations must of course always be performed after doubling the angle to transform the astigmatism data into vectors in 360° Cartesian coordinates so that standard vector mathematics can be used (as has been described in all of the method articles described earlier). The one disadvantage of single-angle polar plots is that the standard deviation ellipse cannot be displayed. To resolve this issue, we propose that the X and Y standard deviation values be included in a box on the single-angle polar plots as in **Figure 2**.

The other advantage of double-angle plots is that data points at 0° and 180° are visually grouped together, whereas they are on opposite sides of a single-angle polar plot. However, ophthalmologists are used to viewing single-angle polar plots and immediately recognize that points near 0° are similar to points near 180°. To help with this issue, we propose adding a shaded region to highlight the areas of common orientation.

Further plots (including double-angle plots) may be included in articles at the discretion of the author and/or the reviewers and editors if it is believed that they can provide useful information that has not already been covered by the Standard Graphs. This will certainly be the case in studies that focus more closely on the analysis of astigmatism. For example, including a similar analysis based on corneal topographic or keratometric astigmatism may be required or even more complex astigmatic analysis could be included such as the new CorT parameter as described by Alpíns et al.²² Other examples include the analysis of incisional surgery, in which case the SIA and flattening effect of the incisions should be calculated and displayed,^{17,23} or in a toric intraocular lens analysis where a distinction should be made between the SIA of the toric implant and the SIA of the surgical penetrating ocular incision to avoid confusion.

CONCLUSION

Our goal was to expand the Standard Graphs to include more detail relating to the correction of astigmatism, to provide the maximum directly relevant information in a format that is accessible for the majority of readers. We believe that we have achieved this goal by including the TIA vs. SIA scatter plot and angle of error histogram because these are the most immediately understandable astigmatic displays for the non-vector analysis initiated and they answer three of the four basic questions about astigmatism correction. Because astigmatism analysis is multi-dimensional, it is not possible to capture the nuances in a single graphical display. Alpíns seems to have provided the simplest approach whereby each graph is used to answer each

question sequentially, enabling the cause of an inaccurate astigmatic correction to be understood as the combination of these.

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