Reference Axis Selection: Subcommittee Report of the OSA Working Group to Establish Standards for Measurement and Reporting of Optical Aberrations of the Eye

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ABSTRACT

It is the committee's recommendation that the ophthalmic community use the line of sight as the reference axis for the purposes of calculating and measuring the ocular optical aberrations. [*J Refract Surg* 2000;16:S656-S658]

PURPOSE

Ocular optical aberration measurements from various laboratories or within the same laboratory are not comparable unless they are calculated with respect to the same reference axis and expressed in the same manner. A consistent framework for expressing ocular aberration expression is the topic of another subcommittee. Here we will address the choice of reference axis for the calculation and present methods for aligning the eye to this axis for measurement. We presented this report for discussion and in an effort to build consensus prior to preparing the final report.[1]

BACKGROUND

Unlike a camera, the eye is a decentered optical system with non-rotationally symmetric components (Fig 1). The principle elements of the eye's optical system are the cornea, pupil, and the crystalline lens. Each is decentered and tilted with respect to other components rendering an optical system that is typically dominated by coma at the foveola.[2]

Like a camera, the eye is an imaging device designed to form an in-focus inverted image on a screen. In the case of the eye, the imaging screen is the retina. However, unlike film, the "grain" of the retina is not uniform over its extent. Instead, the grain is finest at the foveola and falls off quickly as the distance from the foveola increases. Consequently, when viewing fine detail, we rotate our eye such that the object of regard falls on the foveola (Fig 2). Thus, with respect to an individual's ability to see fine detail, aberration at the foveola has the greatest impact.

There are two axes of interest which are centered on the foveola—the visual axis and the line of sight. In object space, the visual axis is typically defined as the line connecting the fixation object point to the eye's first nodal point. In image space, the visual

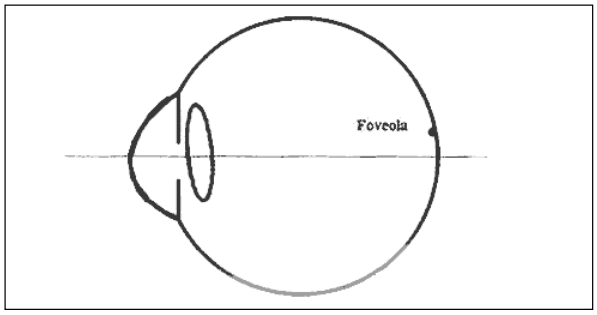

Figure 1. The cornea, pupil, and crystalline lens are decentered and tilted with respect to each other rendering the eye a decentered optical system that is different between individuals and eyes within the same individual. The line is centered with respect to the sclera represented here as being spherical.

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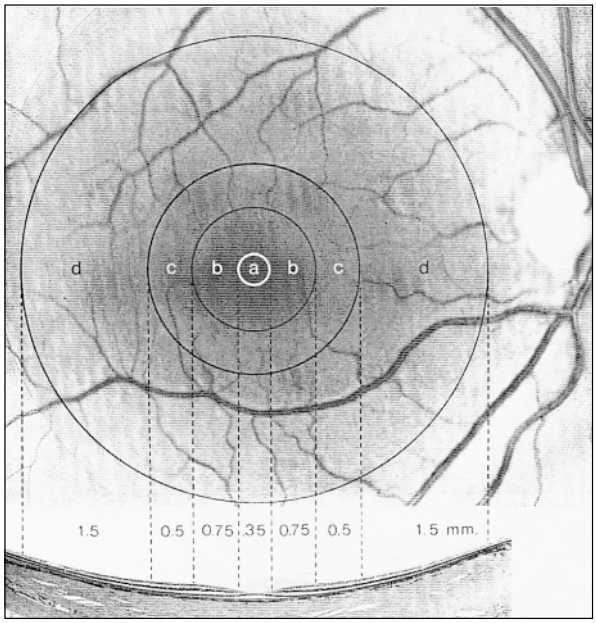

Figure 2. An anatomical view of the macular region as viewed from the front and in cross section (below). a: foveola, b: fovea, c: parafoveal area, d: perifoveal area. (From Histology of the Human Eye by Hogan, Alvarado Weddell, W.B. Sauders Company, 1971, page 491).

axis is the parallel line connecting the second nodal point to the center of the foveola (Fig 3 left). In contrast, the line of sight is defined as the (broken) line passing through the center of the eye's entrance and exit pupils connecting the object of regard to the foveola (Fig 3 right). The line of sight is equivalent to the foveal chief ray. The visual axis and the line of sight are not the same and in some eyes the difference can have a large impact on retinal image quality. For a review of the axes of the eye see the Bradley and Thibos (Presentation 5) at http://www.opt.indiana.edu/lthibos/ABLNTOSA95. (To avoid confusion, it is worth noting that Bennett and Rabbetts in their book Clinical Visual Optics define the visual axis as we have defined the line of sight. The Bennett and Rabbetts definition is counter to the majority of the literature and is not used here.)

The optical industry has a tradition of calculating the optical aberration of systems with respect to the center of the system's exit pupil. In a centered optical system (eg, a camera, or telescope) using the center of the exit pupil as a reference for measurement of on axis aberration is the same as measuring the optical aberration with respect to the chief ray from an axial object point.

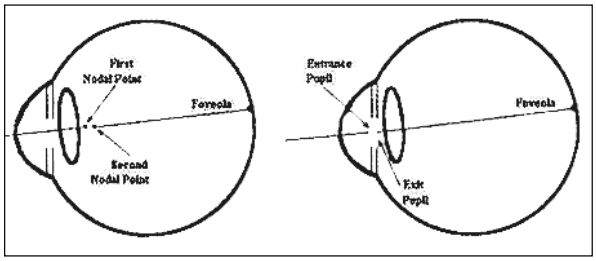

Figure 3. Left panel illustrates the visual axis and panel right illustrates the line of sight.

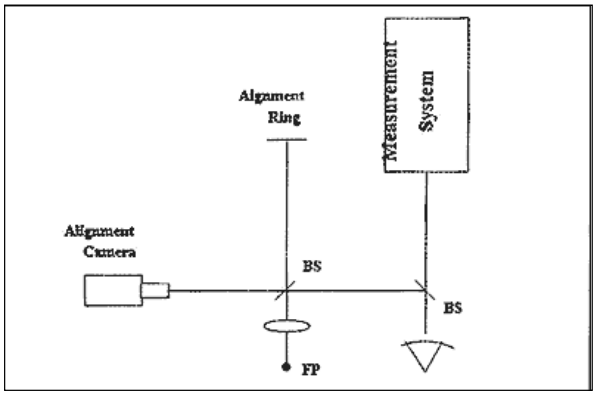

Figure 4. Schematic of a generic objective alignment system designed to place the line of sight on the optical axis of the measurement system. BS: beam splitter, FP: on axis fixation point.

RECOMMENDATION

It is the committee's recommendation that the ophthalmic community remain in optical industry tradition and use the line of sight as the reference axis for the purposes of calculating and measuring the ocular optical aberrations. The rationale is that the line-of-sight is the chief ray for the fixation point and therefore aberrations measured with respect to this axis will have the pupil center as the origin of a Cartesian reference frame.

Methods for Aligning the Eye During Measurement

There are several clever ways to align the line of sight to the optical axis of the measuring instrument. Here we present an example of an objective method and a subjective method to achieve proper alignment.

Objective Method—In the objective alignment method schematically diagramed in Figure 4, the experimenter aligns the subject's eye (which is fixating a small distant target on the optical axis of the measurement system), to the measurement system by centering the subject's pupil (by adjusting a bite bar) on an alignment ring (eg, an adjustable

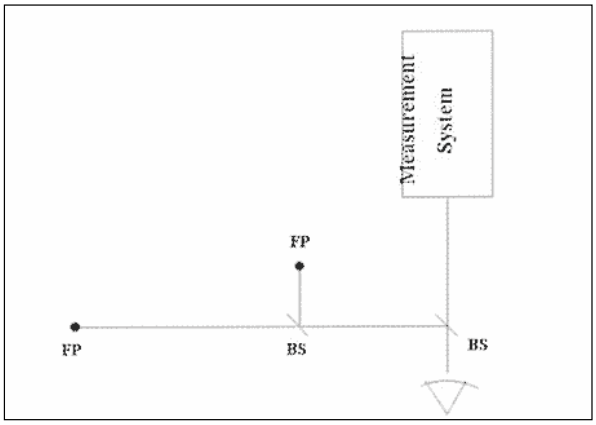

Figure 5. Schematic of a generic subjective alignment system designed to place the line of sight on the optical axis of the measurement system. BS: beam splitter, FP fixation point source.

diameter circle) which is co-axial with the optical axis of the measurement system. This strategy forces the optical axis of the measurement device to pass through the center of the pupil. Since the fixation target is on the optical axis of the measurement device, once the pupil is centered with respect to the alignment ring, the line of sight is co-axial with the optical axis of the measurement system.

Subjective Method—In the subjective alignment method schematically diagramed in Figure 5, the subject adjusts the position of their own pupil (using a bite bar) until two alignment fixation points at different optical distances along and co-axial to the optical axis of the measurement device are superimposed (similar to aligning the sights on rifle to a target). Note that one or both of the alignment targets will be defocused on the retina. Thus the subject's task is to align the centers of the blur circles. Assuming the centers of the blur circles for each fixation point pass through the center of the pupil, this strategy forces the line of sight to be co-axial with the optical axis of the measurement system.

Conversion of Data—If optical aberration measurements are made with respect to some other reference axis, the data can be converted from one reference axis to another (See the tools developed by Susana Marcos at our web site: <http://color.eri.harvard.edu/standardization>. However, since such conversions involve measurement and/or estimation errors for two reference axes (the alignment error of the measurement and the error in estimating the new reference axis), it is preferable to have the measurement axis and the line of sight one and the same.

DISCUSSION

This summary presents the background to and the initial recommendations of the Reference Axis sub-committee of the OSA working group formed to recommend Standards for Expressing the Optical Aberration of the Eye. The committee recommends that the line of sight be used as the reference axis for the calculation of the ocular aberrations and that, when possible, instruments designed to measure the ocular aberrations be aligned to the line of sight.

REFERENCES

1. Thibos LN, Applegate RA, Schwiegerling JT, Webb R, Standards Taskforce Members. Standards for Reporting the Optical Aberrations of Eyes. OSA, TOPS, in press.
2. Howland HC, Howland B. A subjective method for the measurement of monochromatic aberrations of the eye. J Opt Soc Am 1977;67:1508-1518.