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Intraocular Lens Tilt, the Pupil, and Simple Eye Models

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Modern instrumentation measures parameters that can be used for a simple eye model, where on average the cornea, the pupil, and the lens, are approximately aligned along an optical axis. The instruments themselves make measurements along an approximate visual axis, which can lead to descriptions of an intraocular lens (IOL) being tilted by 5°, rather than the eye being rotated (angle alpha). One fundamental limitation is that corneal keratometry and topography do not appear to be routinely evaluated along the optical axis, potentially leading to a displaced corneal surface in the model. Also, the pupil location has complexities that affect its evaluation, with the iris moving forwards as a person ages, and then backwards following cataract surgery. The magnitudes of these changes are evaluated for cataract patients..

Keywords: *Intraocular lens tilt; Angle alpha; Angle kappa; Pupil diameter*

Introduction

Eye models often assume circular symmetry when fundamental properties are being evaluated, yet it is also known that the foveola is not on the optical axis, leading to an average rotation of the eye away from the nose of 5° (angle alpha). Intraocular lenses (IOLs) simplify an eye model because the refractive index of the lens material is constant, rather than having a gradient refractive index like the crystalline lens, and also it is possible for their optical design to be known because they are manmade lenses (though manufacturers are not often forthcoming with the design details). Ophthalmic measurement equipment has progressed rapidly in recent years, and a general concept has been implemented where there is an underlying assumption that the cornea, the pupil, and the lens lie generally along a single optical axis. However, the eye is usually oriented to have retroreflection at the cornea, at the same time as the eye is sighting along the instrument axis [1]. This leads to the iris and the internal lens appearing tilted when looking at the eye along the instrument axis, even if there was perfect symmetry.

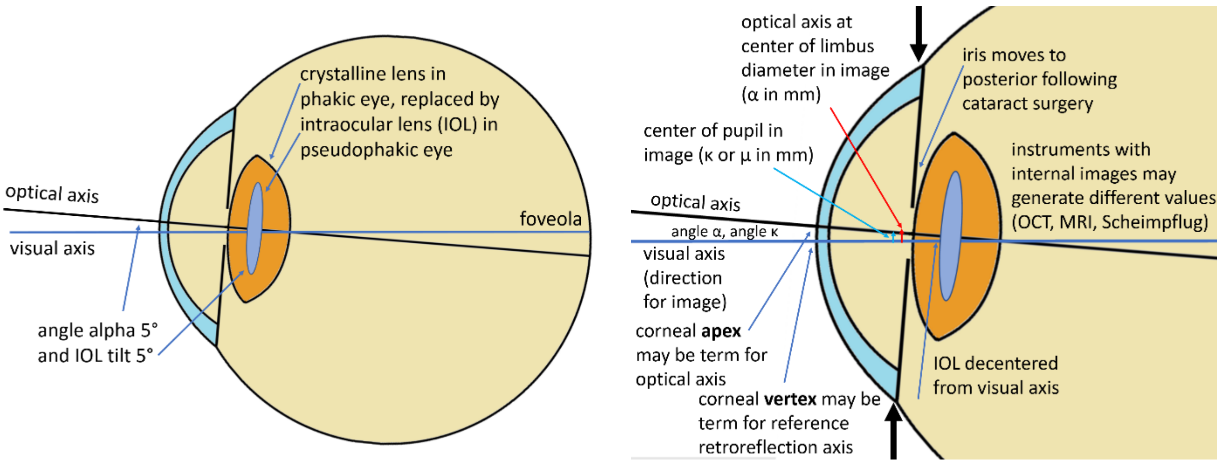

Figure 1. Simplified model of average eye. Angles may be in degrees or mm. Right eye from above.

This description for the eye is not always summarized very clearly, and it also has a fundamental discrepancy because corneal keratometry and topography measurements are made along the instrument axis rather than the optical axis. Published parameters were used to evaluate this broad topic, and OCT images were used to evaluate the pupil.

Methods

Publications were reviewed that had parameters like IOL tilt, IOL decentration, angle alpha, angle kappa, and chord mu. OCT images for preop and postop cataract patients covering the full axial length range [2] were also re-evaluated, and the apparent magnification of the pupil was estimated for each eye using the paraxial equation: Pupil Magnification = nfluid / (nfluid -zp*Kadj/1000) [3], with nfluid = 1.336, Kadj the best estimate for corneal power, and zp the axial depth of the limiting iris diameter, with the depth increasing following cataract surgery.

Results

Angle alpha is the most straightforward parameter, with several sources giving an average angle of about 5° rotating about a vertical axis outwards from the visual axis to the optical axis for both the actual angle in object space [3], and the tilt of both the iris and an IOL [4] (Fig. 1). This is consistent with the eye being primarily a centred optical system, with the eye rotated because the foveola is not on the optical axis. The corneal information is less straightforward, with one definition for the “apex” being the location with the smallest radius of curvature [3], and one definition for the “vertex” being the location of the coaxially sighted corneal light reflex (CSCLR) [5]. These appear to be for the two axes of interest, yet corneal data are not recorded along what is thought to be the axis of symmetry.

Rather than measuring angles, equipment measurements are often based on an additional assumption about eye symmetry. The white region outside clear cornea (the limbus) can be easily identified in an image of the eye, and the centre of this is assumed to be the optical axis at the depth of that image plane. The pupil centre can also be found in the same manner. Lateral distances can be calculated in mm from the retroreflection reference point, though these might be labelled as angles (α, κ), with the pupil centre sometimes called chord mu (μ) rather than kappa. It is valuable to have the parameters readily available, and the pupil information is perhaps the most complex. The pupil centre can vary with illumination changes, but also the iris is pushed forwards with age as the crystalline lens grows, and then drops back following cataract surgery, leading to the variations in Fig 2 for cataract patients.

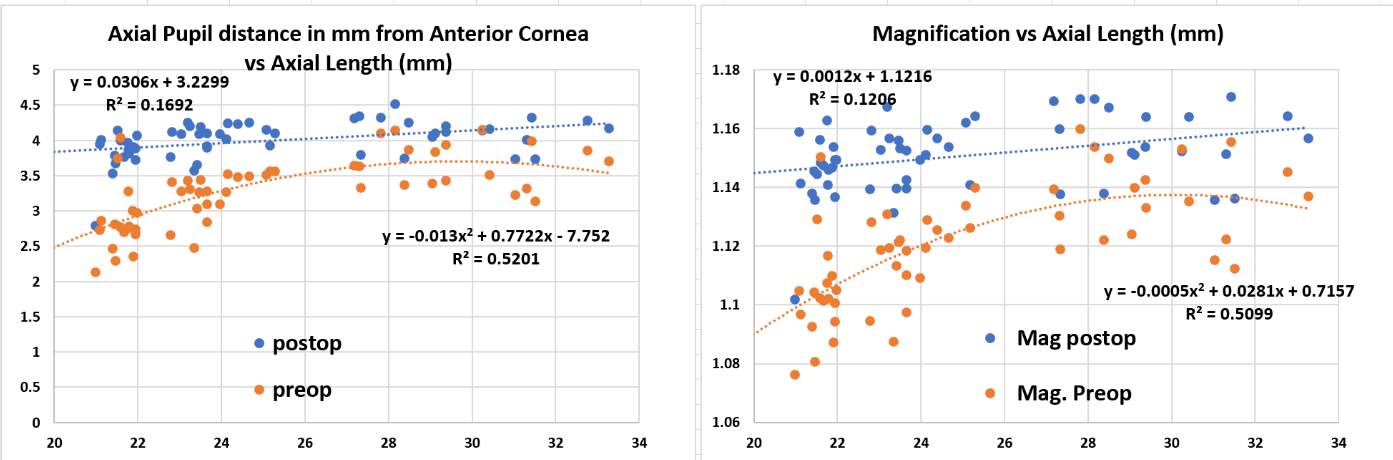

Figure 2. (left) Axial distance from corneal vertex to physical pupil. (right) Estimate of magnification of physical pupil in an image. Most eyes are in the 2nd grouping of axial lengths.

The pupil is often assumed to be decentred on average, yet mean angle Kappa values for younger phakic eyes of 3.9° [3] and 5.8° [5] suggest that the pupil is also generally centred on the optical axis. With chord mu (or kappa), instruments that use a visual image give the distance of the *apparent* pupil centre from the reference of about 0.3 mm, yet instruments with internal information, such as Scheimpflug and OCT, might give a value for the *actual* internal pupil of about 0.2 mm [6]. Mean kappa and alpha values elsewhere for phakic eyes of 0.35 mm [5] and 0.44 mm [7] hint at a decentred pupil because the values are not identical, but it is possible that effects due to magnification of the pupil are not specifically addressed. IOL decentration values are also given by some instruments, but typically as decentrations compared to the visual axis for a rotated eye, rather than from the optical axis.

Conclusions

There are many publications that provide values for rotations, tilts, and decentrations using different methods, both for the phakic eye and the pseudophakic eye, but rarely with enough information for a complete understanding. Taken together, the concept that both types of eye are on average generally symmetrical about an optical axis, including a generally centred pupil, seems reasonable. This implies that an IOL is typically centred by the capsular bag (and if certain styles of IOL are slightly more variable in centration than others then measurements should show it). It would be useful if publications gave information relative to both the axes of interest. A "tilted and decentred IOL" sounds like a problem, but it seems likely that the average IOL is centred on the optical axis. The most important retinal location is the foveal centre, and that could be described using a field angle, relative to the optical axis. There are substantial variations in the parameters about the mean, and there are particular concerns about the centration of corneal procedures, and the centration of IOLs that are not monofocal. Improvements in characterizing the pupil location would be beneficial, as would additional information about the centration of corneal data (with the words *vertex* and *apex* being too similar for the description of two different points on the cornea).

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References

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Two Figures added for the VPO presentation that were not in the original submission.

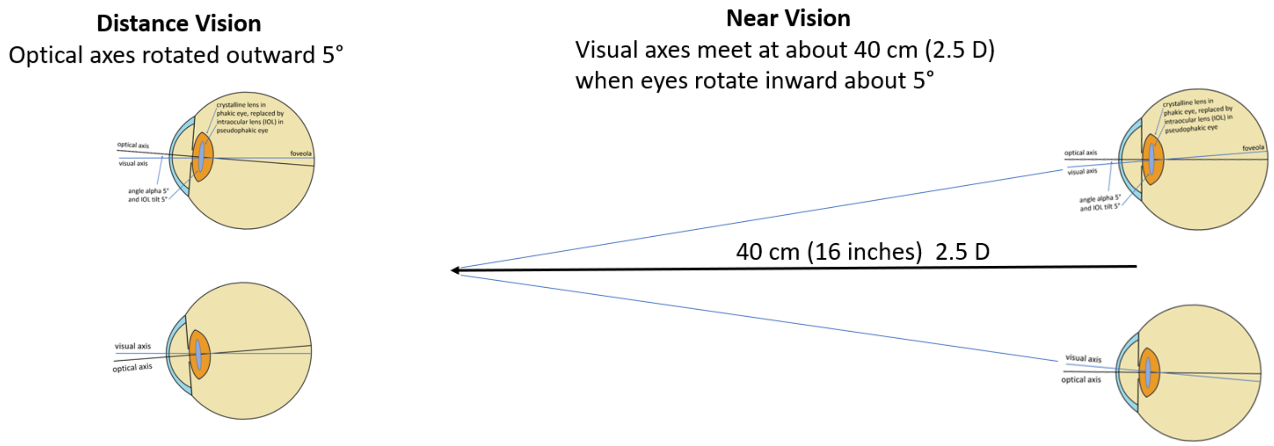

Figure 3. When the visual axes are oriented towards infinity, the optical axes are rotated outwards horizontally by 5°. When the optical axes are oriented towards infinity, the visual axes meet at approximately 40 cm (2.5 D).

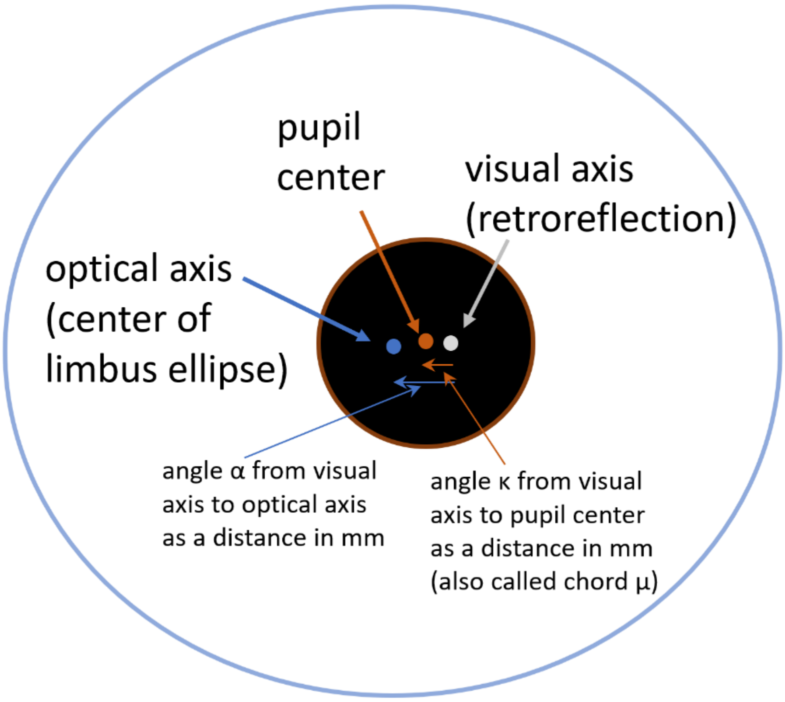

Figure 4. Instrument manufacturers seem to have introduced parameters based on a single image of the eye from the front, but without a clear primary reference or justification. Chang et al [1] discussed the topic later, and described the "subject-fixated coaxially sighted corneal light reflex" that is used to represent the visual axis. Other instruments provide parameters with similar names, but perhaps with different definitions.