Calculation of the thickness of an intraocular lens

Kristian Naeser, M.D., Erik Vincent Naeser, M.D.

ABSTRACT

Lens manufacturers do not usually supply information about the central thickness of an intraocular lens optic. This paper describes a method to calculate the central lens thickness from variables normally supplied by the manufacturer, i.e., the total lens power in situ, the edge thickness, the optic diameter, and some knowledge of the optic architecture. The formulas are universal and valid for any lens, regardless of lens design and material. There is a correlation between calculated values of optic thickness and values supplied by manufacturers. Individually estimated lens thickness may increase the accuracy of intraocular lens power calculation, pseudophakic anterior chamber depth estimation, and pseudophakic axial length calculation.

Key Words: anterior chamber depth, biometry, intraocular lens, intraocular lens power calculation formula, lens thickness, optic

An exact estimate of the central thickness of an intraocular lens (IOL) optic may be useful in intraocular lens power calculation,\(^1\) in the prediction of anterior chamber depth following extracapsular cataract extraction,\(^2\) and in pseudophakic axial length calculation.\(^3\) However, information about the central lens thickness is usually not furnished by the lens manufacturer. While it is usually available upon request, some manufacturers are reluctant to provide this information for proprietary or copyright reasons.\(^4\)

To our knowledge a complete set of formulas to calculate IOL thickness has not been published. We describe a method to calculate the central thickness of an IOL from variables normally supplied by the manufacturers—the total lens power in situ, the edge thickness, the optic diameter, and the radius of the optic surface with constant dioptric power. The accuracy of the derived formulas is discussed.

FORMULAS

The following abbreviations and descriptive terms are used in the formulas:

\[ P: \text{Total power in diopters (D) of the IOL in situ} \]
\[ P1: \text{Power of anterior curvature of the IOL} \]
\[ P2: \text{Power of posterior curvature of the IOL} \]
\[ r1: \text{Radius of anterior curvature of the IOL} \]
\[ r2: \text{Radius of posterior curvature of the IOL} \]
\[ S1: \text{Sagitta of anterior curvature of the IOL} \]
\[ S2: \text{Sagitta of posterior curvature of the IOL} \]
\[ E: \text{Edge thickness of the IOL optic} \]
\[ n1: \text{Refractive index of aqueous} = 1.336 \]
\[ n2: \text{Refractive index of the IOL} \]
\[ D: \text{Diameter (optical) of the IOL} \]
\[ T: \text{Central thickness of the IOL optic} \]

All distances are given in millimeters.

The central IOL thickness is the sum of the edge thickness, the anterior sagitta, and the posterior sagitta (Figure 1),\(^5\) i.e.,

\[ T = E + S1 + S2 \] (1)

The correlation between the sagitta, the radius of the IOL curvature, and the lens diameter may be derived by elementary Pythagorean geometry (Figure 2):\(^4,5\)

\[ S = r - \sqrt{r^2 - \frac{4}{n2}D^2} \] (2)

By convention, incident light travels from left to right and anterior convex curvatures are denoted by a plus sign, while anterior concave surfaces are given by a minus sign. However, lens thickness cannot be negative. We solve this problem by inserting formula (2) in formula (1) and giving variable signs:

\[ T = E \pm (|r1| - \sqrt{|r1|^2 - \frac{4}{n2}D^2}) \pm (|r2| - \sqrt{|r2|^2 - \frac{4}{n2}D^2}) \] (3)

A plus value is chosen if the dioptric power equivalent to the radius, shown in brackets, is positive; a minus value is chosen if the dioptric value is negative.

Example 1: In the case of a reversed meniscus lens the power of the anterior curvature is negative, while the power of the
The total lens thickness (T) is the sum of the anterior sagitta (S₁), the edge thickness (E), and the posterior sagitta (S₂).

\[ T = E + (S₁ - \sqrt{r₁² - \frac{1}{4}D²}) + (S₂ - \sqrt{r₂² - \frac{1}{4}D²}) \]  

Correlations between total lens power in situ and the radii of the IOL curvatures can be established. For any given lens the powers of the two curvatures are defined as:

\[ P₁ = (n² - 1.336) \times 1000/r₁ \]  
\[ P₂ = (1.336 - n₂) \times 1000/r₂ \]  

The total power of a thick lens in situ is defined as:

\[ P = P₁ + P₂ - P₁ \times P₂ \times T/(n² \times 1000) \]  

For low-power lenses the expression may be reduced with negligible loss of accuracy to:

\[ P = P₁ + P₂ \]  

Most IOLs are designed with one curvature of constant radius (and therefore constant power), while all variation in power is reflected in changes in the radius of the second curvature. A few biconvex lenses have identical power in the two curvatures:

I. Let us consider a lens with a variable anterior curvature (r₁) and a constant posterior curvature (r₂). Using formulas (5) and (8), the variable power is expressed as:

\[ P₁ = P₁ - (1.336 - n₂) \times 1000/r₂ \]  

The variable curvature is expressed as:

\[ r₁ = (n₂ - 1.336) \times 1000/(P₁ - (1.336 - n₂) \times 1000/r₂) \]  

II. In a biconvex lens with identical powers, P₁ = P₂ = \( \sqrt{P} \), while |r₁| = |r₂|. The central IOL thickness is calculated as:

\[ T = E + 2\times(|n² - 1.336| \times 1000/(\sqrt{P}) - \sqrt{(n² - 1.336) \times 1000/(\sqrt{P})² - \frac{1}{4}D²}) \]  

Example 2: In Table I, formula (11) is used to calculate the central thickness of IOLs with different designs. The calculated values are compared to magnitudes over lens thickness supplied by the manufacturers. The difference in these magnitudes amount to no more than 0.02 mm.

**DISCUSSION**

The only approximation in the derivation of formulas (11) and (12) is the exclusion of the expression “P₁\*P₂\*T/(n²\*1000)” from formula (7). Including the expression in the analysis would complicate the following calculations and require more advanced mathematical models, e.g., iterative analysis. The expression may safely be omitted as its numerical value in these thin and low powered IOLs is insignificant: For the 20 D biconvex IOL mentioned in Table I “P₁\*P₂\*T/(n²\*1000)” amounts to 0.058 D. The formulas are exact for plano-convex lenses. Furthermore, there is an amount of tolerance in the industrial process of IOLs. The American National Standard for IOLs recommends that the dioptic strength of an IOL be within ±0.5 D of the labeled value, the edge thickness be within ±20% or ±0.05 mm of the design nominal, and the diameter of the optical component be within ±5% of the designed magnitude.

Table I demonstrates that central IOL thickness may be calculated within 0.02 mm of labeled value from the following variables: total lens power in situ, edge thickness, and posterior sagitta.
Table 1. Comparison of the calculated values of central IOL thickness and the values supplied by the manufacturers for three IOLs.

<table>
<thead>
<tr>
<th>Intraocular Lens Design</th>
<th>Central Optic Thickness for Dioptic Power</th>
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</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Biconvex</td>
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<td>Manufacturer’s value</td>
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<td>Calculated value</td>
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<tr>
<td>Meniscus</td>
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<tr>
<td>Calculated value</td>
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<tr>
<td>Planoconvex</td>
<td></td>
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<tr>
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<td>0.65</td>
</tr>
<tr>
<td>Calculated value</td>
<td>0.64</td>
</tr>
</tbody>
</table>

* Constant posterior curvature of the power 6 D, edge thickness of 0.2 mm.
† Constant posterior curvature of the power −7 D, edge thickness of 0.25 mm.
‡ Edge thickness of 0.2 mm.

ness, optic diameter, and a knowledge of the lens design. Among these variables the total lens power is always known because it is the basic variable in IOL implantation. The edge thickness is usually supplied by the manufacturer in commercial drawings; the edge thickness is usually close to 0.2 mm as this will accommodate the lens haptic in its contemporary designs. Information about the lens optic diameter is always given. The clinician should be aware that the diameter of the optic in some lenses includes a portion of “optically inert” material. This is the case in some laser ridge and disc lenses in which a small peripheral ring of the optic has a plano configuration and only the central portion has a curvature and therefore a power. It is essential to make a distinction between the crude optic diameter and the diameter containing the curvature; the term “D” in the formulas refers to the latter value (Figure 2). This distinction is normally retrievable from commercial sales material. The lens design, i.e., information about the distribution of lens power in one or two variable curvatures, is usually clearly illustrated.

The described formulas may be used to optimize formulas for IOL power calculation, to predict pseudophakic anterior chamber depth, and to calculate axial length in pseudophakic eyes. The early theoretical IOL power calculation formulas did not calculate refraction separately from the anterior and posterior IOL surfaces. Individual estimation of IOL thickness can be used in third generation power calculation formulas by calculating vergence or principal planes within the IOL. An even more significant factor in predicting pseudophakic refraction is an exact estimate of postoperative anterior chamber depth. The thickness of the biconvex lens described in Table 1 varies from 0.64 mm to 1.78 mm for an 11 and a 35 D IOL, respectively. This power-dependent variation in IOL thickness has an influence on the anterior chamber depth. In 1990, we described a method for predicting pseudophakic anterior chamber depth using an individual estimate of lens thickness. As Holladay and Prager have demonstrated it is essential to consider the IOL thickness in calculating axial length in pseudophakic eyes.

In summary, it is possible to perform an exact calculation of IOL thickness from easily available variables. This information may increase the accuracy of IOL power calculation. However, the proof of this improvement in IOL power calculation awaits clinical trials.

REFERENCES