GEOMETRICAL OPTICS OF INTRA-OCULAR LENSES

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A large variety of intra-ocular lenses (IOL) are available nowadays. This does not facilitate the clinician's task to choose the most appropriate IOL for his patient. In this paper we would like to determine the optical parameters which can play a role in the final visual outcome of patients equipped with an IOL and to propose a useful check list based on the optical properties of IOLs.

The parameters of the intra ocular lenses most often proposed by the manufacturer are: the overall diameter, the diameter of the optical part, the bio-material used for manufacturing the optic part and the haptic part, the IOL shape and the vaulting between optic and haptic.

Additionally, since there is a clinical evidence that small corneal incisions induce less astigmatism, there is a tendency to prefer foldable and thin bio-materials in daily live practice.

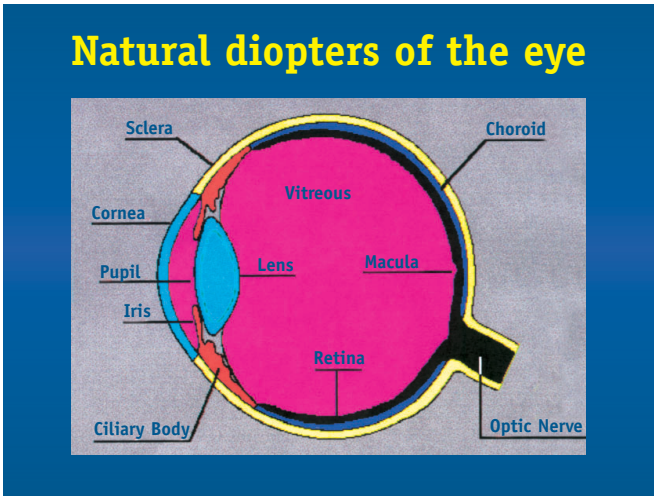
The first concern of the surgeon is to use highly bio-compatible materials. Bio-compatibility of intra ocular lenses is a huge subject which is out of the scope of this paper. The second concern of the surgeon should be to implant IOLs allowing high visual comfort.

Bio-compatibility is partly defined by the European community in ISO norms. Visual comfort, on the contrary, is less easy to put in norms. A thorough knowledge of the optical parameters of the IOLs can already be of great help.

Besides the above mentioned IOL specifications, it would be useful to have more details concerning transparency, thickness and induction of chromatic and spherical aberrations of each IOL.

Basic optics

The anterior segment of the eye is built of several diopters (figure 1).



The first diopter is the cornea which separates two materials of different refractive indices: air (refractive index of 1) and aqueous humour (refractive index of 1.336.) The second diopter is the anterior surface of the crystalline lens which separates the aqueous humour (refractive index of 1.336) and the lens cortex (refractive index of 1.386) and the third diopter is the posterior surface of the crystalline lens which separates the lens cortex and the vitreous humour. The vitreous has an identical refractive index compared to the aqueous humour (1.336). It must be understood that the lens itself is composed of two different tissues with two different refractive indices: the cortex (1.386) and the core (1.406). The overall refractive power of the anterior segment of the eye is approximately 60 diopters, the crystalline lens contributing for approximately 20 diopters. In the ideal eye, the refractive power of the anterior segment of the eye will focus parallel light exactly on the macula and more specifically, the yellow fraction of the visible light spectrum will be focused on the macula and absorbed by the xantophyll pigment of the macula. In case the eye is too large, the anterior segment will focus parallel beams of light before the retina (axial myopia) and in case the eye is too small the anterior segment will focus parallel beams of light behind the retina (axial hypermetropia). Most of the refractive errors are so called axial although a certain percentage of refractive errors are due to abnormal refractive power of the anterior segment (cornea or lens). Nevertheless, when both the corneal refractive power and the axial length are known it is theoretically possible to calculate precisely the refractive power of the intra ocular lens allowing a perfect focussing of light on the retina. This means that when taking the natural intra ocular lens away, it is possible to replace it by a well defined artificial IOL (aphakic IOL) and additionally to correct the pre existing refractive errors.

Calculation of intra ocular lens power can thus be done with great precision. However in a certain percentage of cases, the clinical outcome is not as expected. Some patients will present a hyperopic shift which is due to a forward movement of the IOL after contraction the capsular bag in which the IOL has been placed. Capsular bag contraction may result in a hyperopic shift up to 4D. The most severe situation of capsular contraction is the capsular contraction syndrome, which is more often seen in hydrophilic IOLs compared to hydrophobic IOLs. This is suggestive of a bio compatibility based side effect which can be different and maybe specific for each IOL.

Bio-optical properties of IOL materials

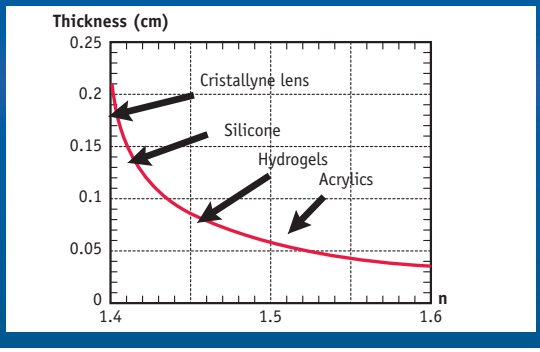
The refractive outcome will depend of the bio-material used. The optical characteristics of each bio-material will influence the shape of the IOL, the thickness of the IOL and consecutively the quality of vision.

Shape of the IOL

1. **IOL thickness and radius**
   An IOL is optically defined by its shape, meaning the radius of curvature of its anterior and posterior surface is defined by the refractive index of the bio-material used. The thickness of an IOL is inversely proportional to its refractive index.
   The range of indices of the different bio-materials available nowadays are shown on figure 2.

THE HIGHER THE REFRACTIVE INDEX THE THINNER THE INTRA OCULAR LENS

References: IOL of 20D
refractive index of natural lens: 1.386

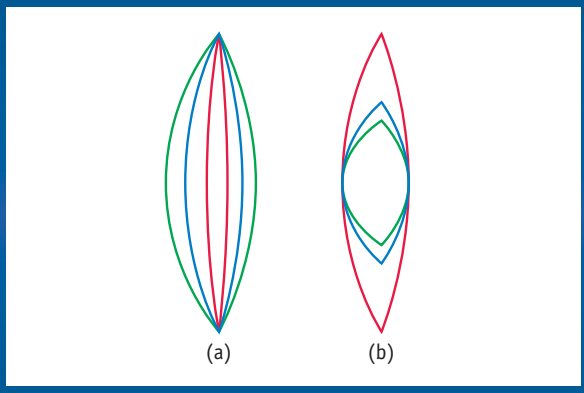


On figure 3, the thickness (cm) versus the refractive index (n) is reported.

Refractive index of modern bio materials

• Silicone (1st)	• n = 1.41
• Silicone (2nd)	• n = 1.43-1.46
• Hydrogels (1st)	• n = 1.43
• Hydrogels (2nd)	• n = 1.47
• Acrylics	• n = 1.47-1.55
• PMMA	• n = 1.49

A biconvex lens of 20 D will become thinner while the refractive index is increasing. For a well defined biconvex lens of 5.5 mm of diameter, thickness will increase and radius will become steeper by decreasing refractive indices (figure 4a)



How to keep the IOL thin while increasing the dioptric power?

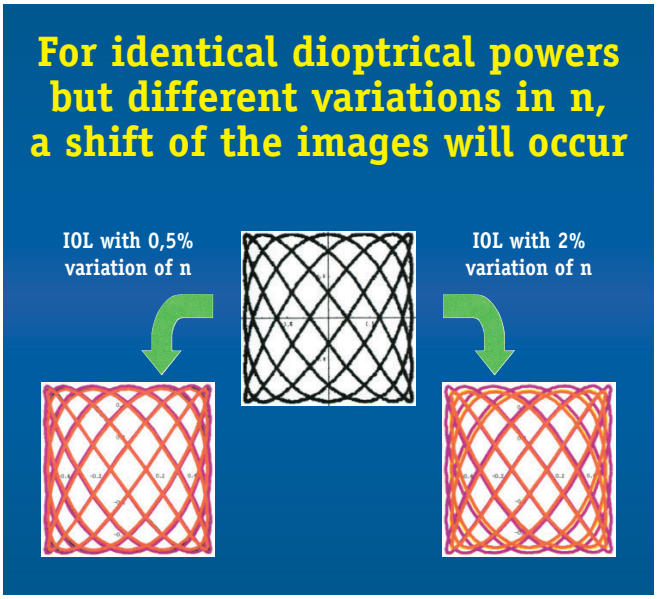
This will influence the optical aberrations which will be discussed later. The only way to flatten the radius of an IOL of specific refractive index is to enlarge the diameter of the optical zone (figure 4b).
This is the reason why silicone lenses are most often commercialised with large optical diameters.
To increase the dioptrical power of a given bio-material, the anterior curvature of the IOL must be higher. This will make the lens thicker and less foldable. One way to keep the thickness of an IOL constant despite the increase of dioptrical power, is by reducing the diameter of the optical zone. This is the reason why some lenses are lenticular with a diameter of 5.5, 5.6, 5.7, 5.8 depending of the dioptrical power surrounded by a thin flat boarder of such width that the 6 mm optical diameter is respected.

2. Transparency of the biomaterial

The transparency of the biomaterial will depend of the absorption of the visible spectrum of light. For all bio-materials this transparency reaches nearly the 100%. The transmission of light is the same for all bio-materials and is comparable with the transmission of light of the natural lens. PMMA is the exception. Its transmission range remains good for UV light which has to be compensated by an additional UV coating.

3. The chromatic aberrations

The chromatic aberrations depend of the wavelength. Each IOL will have a specific variation in refractive index for a given spectrum of light. If the variation is small, the chromatic aberrations will be small. If the variation is high, the chromatic aberrations will be more important (figure 5).

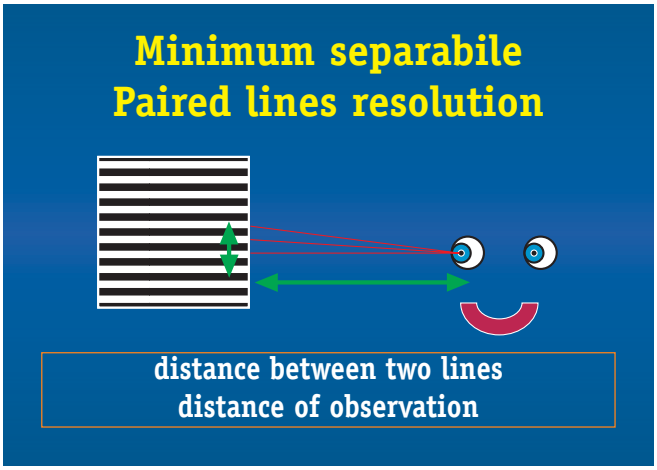


Chromatic aberrations may be very important and even vary during the day depending on the variations of the light spectrum.

4. Resolution of paired lines

The resolution of paired lines or "minimal separabile" concerns the capability of the eye to distinguish two separate lines at a certain distance of observation (figure 6).

The minimal separabile will vary depending of the refractive index, thus of the shape and thus of the dioptrical power of the IOL.

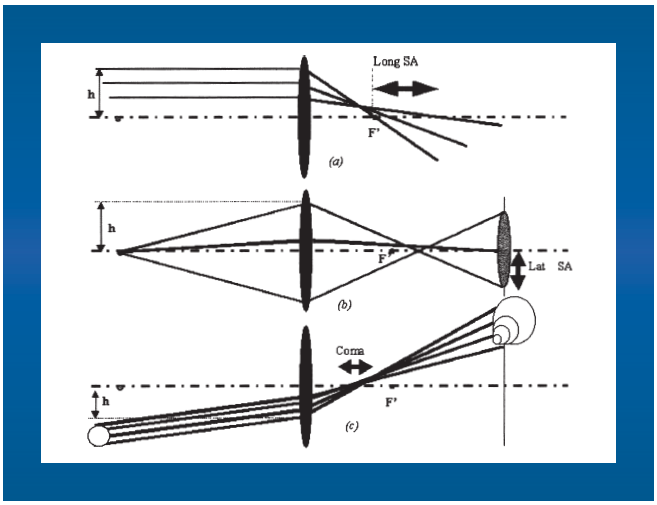


For identical anterior surface curvatures, dioptrical power and distance of observation, the influence of the refractive index is as follows :
n : 1.405 : 484 paired lines/mm
n : 1.410 : 398 paired lines/mm
n : 1.470 : 294 paired lines/mm
n : 1.550 : 277 paired lines/mm

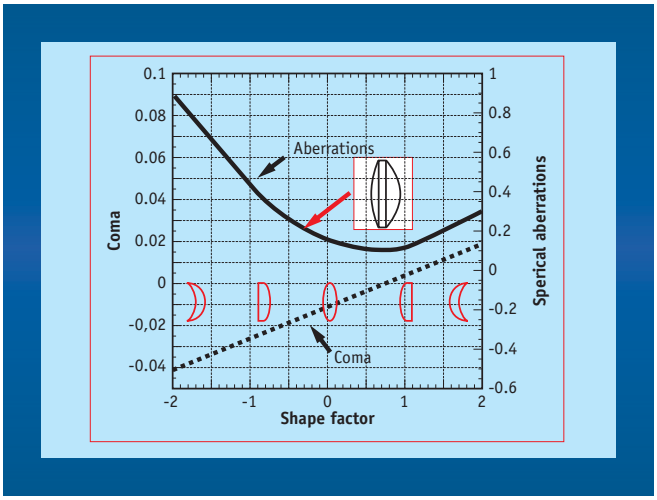
This means that the paired lines resolution of the IOLs decreases with increasing refractive index. Or the thinner the IOL, the lower the paired lines resolution.

5. The lateral and longitudinal spherical aberrations.

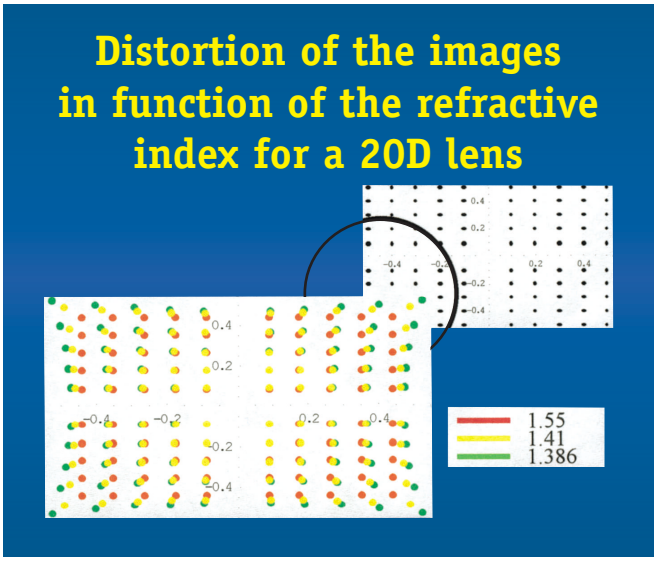
When looking at distance, parallel light rays will be broken following the rules of the biconvex lenses and resulting in an axial (or longitudinal) pattern of deviation.
When looking at near, the light rays will be broken following the rules of the biconvex IOL and resulting in a lateral pattern of deviation.



The coma aberrations are induced by lateral incoming light. A round object will become elongated (coma) after passage through a biconvex lens (fig 7).
Figure 8 illustrates the spherical and coma aberrations for different IOL shapes. The convex/plano shape induces theoretically the lowest amount of aberration.



6. Distortion of the images.
For a given dioptrical power of a biconvex IOL (ex. 20D), the distortion of the image will increase for decreasing refractive index or for thinner IOLs. (Figure 9).



Conclusion

When considering all these data, the thinnest IOL for a given dioptrical power, will be easier to insert through small incision but will give the patient more distortion of the images and a lesser paired lines resolution, thus a slightly lower visual comfort.
For these reasons the following advise can be given :

- for high myopia, IOLs of low refractive index are recommended
- for high hyperopia, IOLs of high refractive index are recommended
- for anisometropia, IOLs of different refractive index are recommended