POSITIVE AND NEGATIVE DYSPHOTOPSIA AFTER CATARACT SURGERY.

Dr. H. Holden. **October 2017.**

BACKGROUND:

Dysphotopsia is not an uncommon problem and can affect up to 20% or more of post cataract surgery patients, with otherwise perfectly performed operations. Fortunately many cases resolve, but some patients remain plagued by the symptoms.

The symptoms of dysphotopsia can be a bright arc of light in the peripheral vision or glare symptoms with an “off the visual axis” point light source (Positive dysphotopsia or PD). Other versions of dysphotopsia included a dark arc like peripheral shadow or the patient feeling that they have had their peripheral vision constricted (Negative dysphotopsia or ND).

Current IOL design with ND & PD:

As small incision cataract surgery evolved the plan was to decrease the surgical wound size and use thinner foldable IOL’s to pass through the wounds. A thin IOL, much like thinner lighter glasses, requires a higher refractive index material for any diopter focussing power. The higher the refractive index of the IOL material with respect to the aqueous fluid, the more reflective the IOL surfaces are. If there was such a thing as an IOL with an identical refractive index to the aqueous, it would “optically vanish” when placed in the aqueous. It then would be useless as a refractive element. Aqueous has a refractive index of 1.336.

Currently the refractive index of materials used for IOL’s:

Acrylic, n = 1.55

PMMA, n = 1.49

Silicone, n = 1.46

Of note a natural human crystalline lens has a refractive index of around 1.386 to 1.406.

Negative Dysphotopsia (ND):

Recently Dr. Holladay et al (1) described how ND is the result of a gap in the rays which are not refracted by the anterior IOL surface and the rays that are. This is shown diagrammatically in figure 1, below:

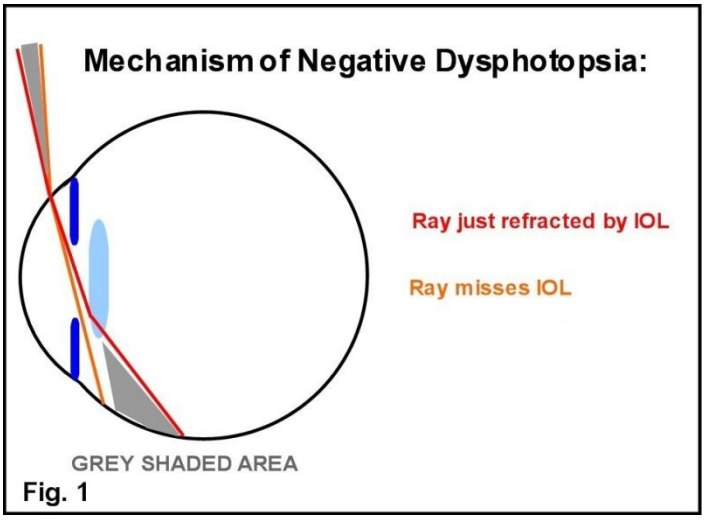


Fig. 1

However, the experience of ND does not require the presence of the light rays that miss out on being refracted by the IOL. If the light rays do manage to pass anterior to the IOL without interacting with it and reach functional nasal retina, it simply puts a brighter area more peripherally to the grey shadow of the IOL.

Figure 2 below explains this. Any rays in the peripheral vision to the ray drawn in red are simply not seen and the IOL effectively casts a retinal shadow in the zone of the retina anterior to this ray.

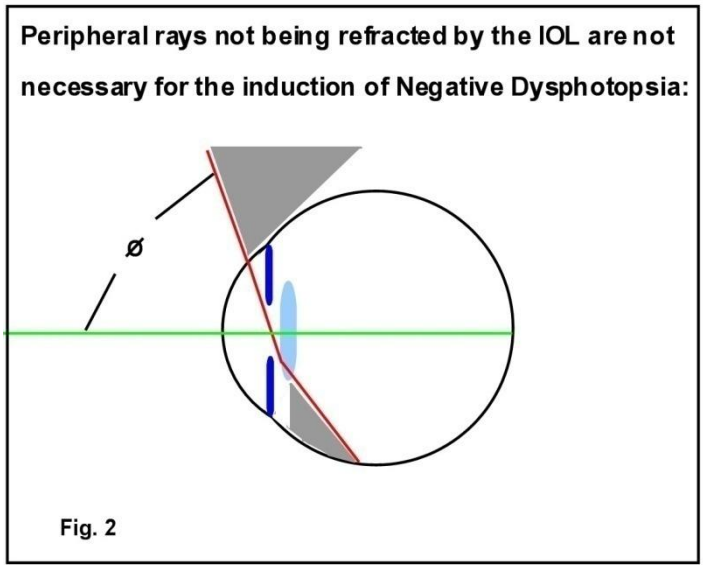


Fig. 2

The constricted field of view experienced by patients still happens, regardless of the ray that misses the anterior surface of the IOL. Also the further posteriorly the IOL sits from the iris plane and the cornea, the further posteriorly the shadow will be placed on the retina.

Therefore the position of the anterior refractive surface of the IOL is important.

All cataract surgeons know that the anterior surface of the natural crystalline lens sits significantly more anteriorly in the anterior chamber than the anterior surface of an IOL does after cataract surgery. Often the depth of the anterior chamber after a cataract surgery can appear to be at least twice the depth of its pre-operative value. This relates to the fact that the IOL is significantly thinner than the natural lens.

Positive Dysphotopsia (PD):

There is often talk of “internally reflected” and “totally internally reflected” light rays in papers on dysphotopsia. There is something about these that requires explaining:

A light ray can enter the front surface of the IOL from a very large range of angles especially with a moderately dilated pupil. With the cornea refracting the light too, light rays can potentially enter the IOL which have originated from 90 degrees or more to the temporal side of the visual axis. The field is more restricted on the nasal side, due to bridge of the nose.

Total internal reflection:

Any light travelling inside the IOL material at the critical angle *or greater than the critical angle,* with respect to the normal to the IOL surface it strikes, at any point, cannot escape *that surface* of the IOL and these rays are reflected back into the IOL. This is *total internal reflection*.

Figure 3 below demonstrates how a ray of light inside the IOL can acquire the critical angle or greater. The ray drawn in red shown in figure 3 is totally internally reflected. Any rays equal to or greater than the critical angle, with respect to the normal at the IOL peripheral edge, will be totally internally reflected. This is the effect which makes the edge of a lens or IOL, as viewed from its refractive surfaces, look shiny on the inside. This effect is the cause of “off visual axis” glare sources, which can be troublesome for patients with IOLs. The green lines show the normal to the surfaces:

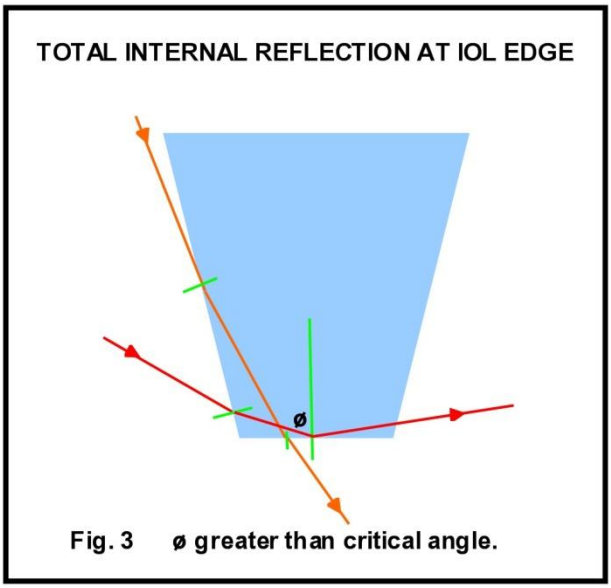


Fig. 3 ø greater than critical angle.

The critical angles for total internal reflection are close to 59.5 degrees for Acrylic, 63.7 degrees for PMMA and 66.2 degrees for Silicone.

On the other hand as also shown in figure 3, if the rays of light enter obliquely to the IOL edge (the ray drawn in orange) this ray does not reach the critical angle, so when they strike the internal IOL edge they pass through it, out of the IOL's edge. These rays also get variously refracted at the IOL's edges, depending on the exact shape of the edge. These rays become the scattered peripheral bright and dark bands of PD.

Figure 4 and 4b below shows a diagrammatic representation of the rays of PD:

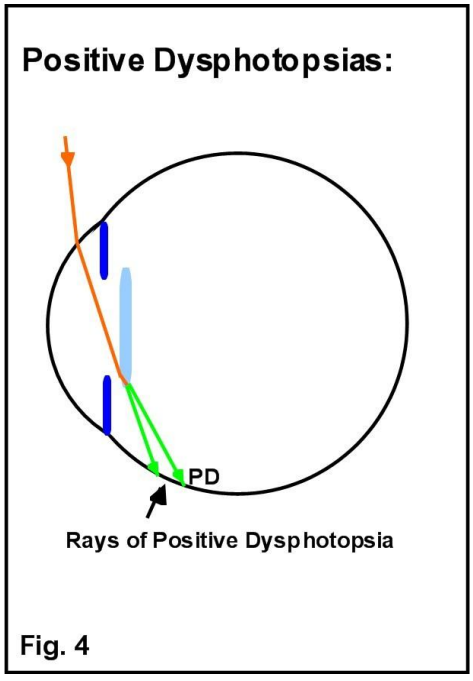


Fig. 4

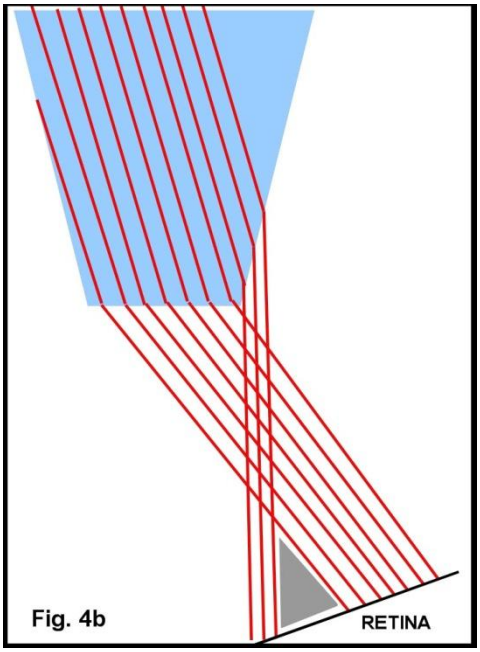


Fig. 4b

The rays of PD shown in green in figure 4 and red in figure 4b, are deviated by the IOL's edge architecture and are not in proper focus and have little meaningful relation to the geometric form of objects in the peripheral field. These rays create dark and light bands of light or "stripes" on the peripheral retina as shown in figure 4b. The exact nature and patterns of the light passing through the IOL edge depends on the edge design. Some of the shadows between the bands of light seen in figure 4b may be mistaken for the shadow of true ND.

Also, if the red rays shown in figure 4b, exiting from the IOL edge, exit into a plate haptic, if there is one in the region, due to the shallow angle, the rays are totally internally reflected inside the haptic (similar to a fibre-optic light pipe) and carried on to the Haptic's edge. If the plate Haptic folds forward in the capsular bag a little, these rays are directed anteriorly, away from the retina. This may be helpful in eliminating symptoms, provided the haptics are on the horizontal axis.

Other weaker scattered rays:

Light rays can be partially (or weakly) reflected by an IOL's convex surface acting as a convex mirror and partially *internally reflected* into the IOL substance by the posterior concave surface (as viewed from inside the IOL) acting as a concave mirror and also this applies to the internal IOL edges. These reflections are stronger the higher the refractive index of the IOL material.

Summary of ND & PD:

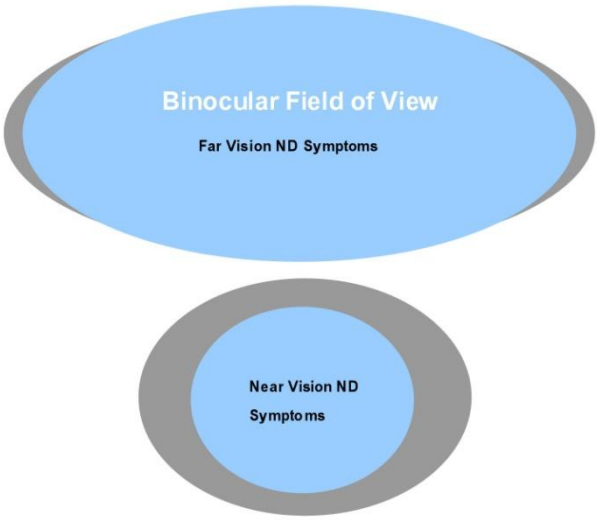
1) ND

The IOL shadow of ND is the result of peripheral rays from the visual field being refracted or deviated by the IOL, leaving an area of reduced peripheral retinal illumination. The further posteriorly the IOL sits, the further posteriorly sits its shadow.

The effects of ND are noticed in relatively bright and diffuse illumination, the darkened areas are more obvious because illumination is missing from the peripheral field that the patient expects, under the lighting conditions, should be there. This shadow is typically noticed more, falling on the anterior nasal retina, corresponding to the peripheral temporal visual field from the patient's perspective and likely more noticed by patients with more anteriorly placed functional nasal retina.

One other feature of ND is that with convergence to a near object within 30cm or so of the globes, the patient may notice the dark semicircular temporal field defects, rotate

more anteriorly and appear to constrict the peripheral field, more so than they do in the case when they gaze to a far away object with the globes in the primary position. The two semicircular peripheral temporal shaded areas may appear, from the binocular perspective, to join up, giving the patient the impression that when they gaze at a near object that they are staring down the centre of a dark pipe or tunnel. This effect is shown in the diagram below:



2) PD

PD is primarily caused by the lens edge architecture. If the incoming rays are oblique, the lens edge transmits these rays to the peripheral retina to generate light and dark stripes. With less oblique rays the lens edge *totally internally reflects* light. Both these ray types are “non functional” as they do not produce an image which clearly relates to object shapes or a clear focus in the peripheral vision. Instead they produce symptoms of PD. In addition the shiny or reflective qualities of the IOL surface can also reflect some light. These reflections increase with the refractive index of the IOL material.

While a diffused or opaque edge IOL might improve this situation a little, the information here suggests that the lens edge light rays of PD should be absorbed and eliminated in new IOL designs. This will also eliminate the variables of the specific IOL edge shape. The darker zones which are part of PD could in fact represent some variants of ND for some patients.

Currently, with existing lens technology, a rounded edge Silicone IOL (lower refractive index) is likely better than an Acrylic (higher refractive index) sharp edged IOL, for reducing the symptoms of PD.

IOL Position:

As noted above, the greater the spacing between the IOL and the Iris plane, or the more posteriorly the IOL sits, or the thinner the IOL, then the further that the IOL shadow of ND will encroach on the patient's peripheral visual field. Also the further posteriorly any bright rays of PD will encroach on the peripheral nasal retinal and peripheral visual field too.

The light rays that miss the anterior surface of the IOL completely, as shown in figure 1, simply illuminate the retina peripherally to the IOL shadow of ND, turning the perceived diffuse grey constriction of the temporal visual field, into a zone with a sharper more defined far peripheral outline. These rays are more likely to get through the further the IOL is located posteriorly.

Pupil size:

Symptoms of PD appear aggravated in patients with larger pupils because there are more opportunities for light rays to interact with the IOL's edge architecture. For any level of ambient lighting, younger patiens tend to have large pupils than older patients.

How new IOL's might be designed to improve ND & PD:

1) Use the lowest refractive index material and the thickest IOL possible consistent with being able to physically fold the IOL and ease of insertion and wound geometry.

While smaller wounds have been advocated to reduce SIA (surgically induced astigmatism) this also is associated with thinner optic IOL's which favour symptoms of dysphotopsia. Smaller wound size also means some degree of increased flow resistance in the irrigation pathway during coaxial phaco. This reduces anterior chamber stability and all other factors equal. Ideally, one might prefer a 1.8mm to 2.5mm wound, however, it appears that a 3mm to 3.5mm wound would accommodate thicker IOL's and still have minimal SIA, which can also be minimized in some cases by selecting the wound location. It is likely that the smallest diameter IOL should be 6mm diameter, not 5.5mm, in the interest of avoiding PD.

2) Since the light rays exiting the peripheral edge of the lens have little meaningful geometric relation to objects in the peripheral visual field and merely create PD, then the light rays exiting the IOL's peripheral edge are better eliminated by absorption. This involves darkening or blackening the edge of the IOL material *within the substance of the IOL,* at its periphery.

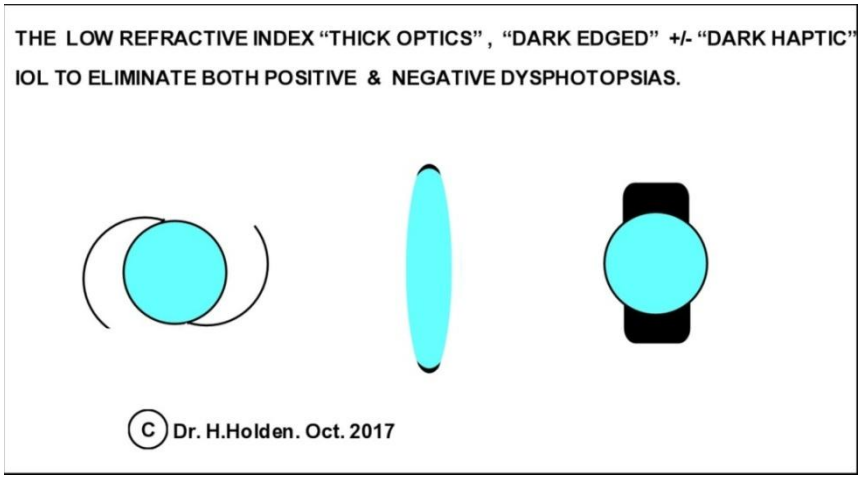
3) Since all symptoms of both PD and ND are expected to be worse the more posteriorly the IOL's anterior refractive surface sits, with respect to the cornea and Iris plane, then a thicker IOL design brings the IOL's anterior surface closer to the posterior iris more like the natural crystalline lens. This explains why reverse optic capture, pushing the IOL anteriorly, has helped to treat some patients with severe dysphotopsia. However there is a limit because excessive interaction of the IOL's anterior surface with the Iris's posterior pigment layer is better avoided.

The conclusion is that the cure for ND & PD is to change the design of current IOL's.

The available information suggests that it is better to aim for low refractive index material and thicker IOL's and a little larger wound geometry to insert them (if necessary) and to darken the IOL edge to *absorb* the rays that cause PD. This idea is the opposite to what has been done by manufacturers so far, which was to "diffuse the rays of PD" by having a frosted IOL edge and rounding the edge. I believe these non-optically functional and distracting rays are better absorbed instead.

It is also helpful, that whatever haptic design is used, that the haptics are darkened too, along with the IOL edge.

A diagram of what these "next generation IOL's" might look like is shown below. The haptics shown are for illustrative purposes and could be any shape. Also with a dark peripheral edge integral to the IOL body, the IOL edge shape design becomes unimportant and could be whatever is easier to manufacture. Ideally the darkening of the IOL far perimeter must be integral and diffused into the IOL material (not be a separate flange) so as to absorb any photons inside the lens body heading toward the edge.



Images/drawings of dark edge thick optics IOL's are Copyright Dr. H.Holden. Oct, 2017. For permission to use these images contact Dr. Holden at: Hugo.Holden9@gmail.com)

New IOL designs & IOL Patents:

Alcon labs have patented a plethora of IOL designs with nearly every imaginable form of modified edge. At the time this was done, the true cause of ND was not known. The lens edge was still being blamed for ND, when it was the cause of PD. As noted above, ND relates to the position of the anterior refractive surface of the IOL, not its edge design, which is a less significant factor.

For example the Alcon patent EP2146671-A2 published in 2010 is described as “Intraocular Lens with Peripheral Region Designed to Reduce Negative Dysphotopsia” and the patent document mentions many variables of “edge textures” or “edge opacities” and “Pluralities of undulations” and “Peripheral flanges” which could comprise the edge design covered by the patent.

One unfortunate thing here about the practice of patenting nearly every conceivable variable of a design, rather than patenting a very specific design, is that it creates a litigation risk for other IOL manufacturing companies wanting to R&D their own unique designs.

Without the intent to copy another inventor’s work, it is very easy for parts of designs to “appear similar to others” and look like Patent Infringements. The notion of “patent every variable of a design” can suppress the desire for other IOL companies to want to R&D new products themselves. Patents serve a better purpose when they are specific to a particular design, rather than to include a plethora of possible theoretical and untested variations which may not have any practical application. It is simply an anti-competitive legal instrument, holding back progress in medicine. Patenting a specific design is clearly not the legal advice Alcon and many other manufacturers receive when they apply for a Patent on an IOL design, or any other surgical products for that matter.

Reference:

1) Dr. J.T. Holladay et al. Negative Dysphotopsia: Causes and Rationale for Prevention and Treatment. JCRS, Vol 43, Issue 2, pg 263-275, 2017.

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