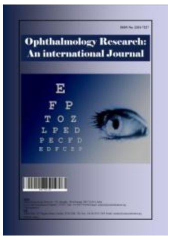

Ophthalmology Research: An International Journal

11(3): 1-9, 2019; Article no.OR.53726
ISSN: 2321-7227

Intra Ocular Lens Technology - A Review of Journey from Its Inception

Ragni Kumari[1], Mrinal Ranjan Srivastava[2*], Pragati Garg[3] and Rajiv Janardhanan[4]

[1]Department of Optometry, Era University, Lucknow, India.
[2]Department of Community Medicine, Dumka Medical College, Dumka, India.
[3]Department of Ophthalmology, Era Lucknow Medical College & Hospital, Era University, Lucknow, India.
[4]Institute of Public Health, Amity University, Noida, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author RK designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors MRS and PG managed the analyses of the study. Author RJ managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/OR/2019/v11i330129
Editor(s):
(1) Dr. Stephen G. Schwartz, Department of Clinical Ophthalmology, Bascom Palmer Eye Institute, University of Miami Miller School of Medicine, USA.
Reviewers:
(1) Gabor Nemeth, Borsod-Abaúj-Zemplén County Hospital and University Teaching Hospital, Hungary.
(2) Italo Giuffre', Catholic University of Rome, Italy.
(3) Shubha Ghonsikar Jhavar, Govt. Medical College, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/53726

Review Article

Received 04 November 2019
Accepted 09 January 2020
Published 14 January 2020

ABSTRACT

Aim: To understand the advancement and development in Intraocular lens.
Introduction: Now a day cataract surgery is the most commonly performed surgical procedure in the world. Removing the opaque, cataractous lens and replacing it with an artificial lens to achieve near to normal visual acuity post operatively is not only accepted but by and large a mandatory norm.
Findings: The lenses used for the purpose are called Intra Ocular Lens. Ridley's brilliance has improved the lives of many millions of people. The gradual improvement in IOL design, first in making flexible lenses, then the ever-improving optical outcomes have meant that vision after cataract surgery has never been better – in the developed world.
Conclusion: We have come a long way in terms of IOL design, but many people with cataracts in rural areas of the developing world, need help to catch up.

**Corresponding author: E-mail: dr.mrinal.srivastava@gmail.com;*

Keywords: Cataract; extra capsular; intracapsular; surgery; IOL (Intraocular Lens Implant).

1. INTRODUCTION

Now a day cataract surgery is the most commonly performed surgical procedure in the world. Removing the opaque, cataractous lens and replacing it with an artificial lens to achieve near to normal visual acuity post operatively is not only accepted but by and large a mandatory norm. The lenses used for the purpose are called Intra Ocular Lens.

Cataract surgery, the largest form of commonly performed surgical technique in the world today, has an memorable history. The earliest example, cataract "couching", was initially reported around three thousand years ago in India in their ancient text, the Mahabharata. Couching is a process that should be consigned to historical textbooks: the pressing down of cloudy lenses into the vitreous with a thorn or a needle. It leaves the patient aphakic (but with some visual function) requiring a high hyperopic prescription lens to compensate. While it still occurs today in Progress in recent times has been rapid, such that modern surgical techniques for extracting the human lens appear to be nothing short of astonishing when compared to what was performed just thirty years ago. Incision size reductions and the use of phacoemulsification have revolutionized cataract surgery. Further a second revolution; the implantation of the intraocular lens (IOL).

Invention of an implantable, well tolerated and techniqually feasible lens has been a revolution on cataract surgery.

2. ORIGINS OF IOL

The true beginning of the IOL goes back to time of Second World War. Against a backdrop of the Battle of Britain, where aircraft fought for air supremacy in the skies over the south of England, Harold Ridley was a civilian ophthalmologist who had operated his eye on Royal Air Force pilots with eye injuries. On August 15, 1940, inspiration stuck. A pilot's Perspex canopy had shattered, sending numerous splinters of PolyMethylMethAcrylate (PMMA, Fig. 1) into his eyes. Ridley performed a total of 19 operations on the pilot, saving the vision in one eye. During the process, he realized that the body's immune system had not reacted against the PMMA splinters; unlike glass splinters, they remained inert in the eye. Ridley recognized that this material could be used for artificial lenses, and that these could be implanted into the eye to replace the natural lenses removed during cataract surgery [1-3].

Fig. 1. Scanning electron micrograph of a Ridley intraocular lens made from PMMA

At the same time as history views this as a pivotal moment in the development of the field, many in the ophthalmic establishment at the time strongly disapproved of Ridley's work. Nevertheless, others followed his example, including Warren Reese, the first American to implant an IOL, and the Ridley-designed IOLs began to be implanted widely with great success. Complications did occur, including severe hyphema, downward decentration, iris atrophy, glaucoma, anterior and posterior dislocation, and inflammation, meaning that approximately 15 percent of the Ridley implants were eventually removed.

It took until the 1970s before IOL implantation after cataract surgery was considered to be a standard procedure.

3. IOL MATERIALS

PMMA as the material used to make IOLs had many advantages but it also had one major disadvantage: the big corneal incision size required to implant it as PMMA is rigid. Resulting in a large wound that needs to be stitched closed. This can induce astigmatism and, compared with modern cataract surgery, requires a prolonged recovery time. Another driver for smaller incision holes occurred when Charles Kelman introduced phacoemulsification in 1967; surgeons made a small incision for the phaco tip, but then had to enlarge it to place the lens. Something had to be done about the incision size – and that meant flexible, and therefore foldable, IOLs [1,4,5].

Advantages and Disadvantages of PMMA:

Advantages:

1. Extensive clinical experience
2. Suitable for single piece IOLs, three-piece lenses and IOL haptics
3. Excellent biocompatibility
4. Hydrophobic surface
5. Outstanding optical properties – high light transmissibility
6. Can add UV-absorbing materials
7. Inexpensive

Disadvantages:

1. Rigid – meaning that the incision size needs to be at least as big as the diameter of the IOL.
2. The incision needs to be sewed shut – this can induce post-operative astigmatism.

Hydrophilic Acrylic: Hydrophilic acrylic is a quite heterogeneous material group and has high water content. These lenses are cut in the dehydrated state and then hydrated and stored in solution. The IOL water content varies between IOL to IOL and it can be as high as 38%. A meta analysis on PCO showed that the hydrophilic acrylic lenses are more prone to develop PCO than hydrophobic acrylic lenses or silicone lenses [6]. This may be because of the high water content that "inviting" more lens epithelial cells (LEC) in growth or the truth that the optic edge of IOLs in this group is never as sharp as with the hydrophobic materials [4], therefore inducing a less sharp bend of the capsule at the edge and being a less effective barrier to regenerating LECs.

Disadvantages: Lens opacification of the optic material due to calcification [5,7,8].

Silicone: In the past decade, we have been seeing a continuous decline in the use of silicone IOLs. Whereas silicone is a very good IOL material, especially concerning its PCO blocking effect [9], it cannot be used for a mono bloc open-loop lens. This lens design is the preferred choice for use with preloaded injectors that allow implantation through incisions smaller than 2.8 mm, which appears to be the current trend. When using an injector for small incisions, there is a risk of tearing of the optic at the optic-haptic junction or kinking of the haptics during injection with multi piece open-loop IOLs [9].

Foldable IOL:

1. Foldable Hydrophobic Acrylic:

At present the most commonly used material group [10], these polymers of acrylate are foldable under room temperature. The materials with low water content, a high refractive index have high memory, which also makes the material suitable for the haptics of a monobloc open-loop IOL. This group of material unfolds in a controlled fashion and has been shown to have a good uveal and excellent capsular biocompatibility. The two main companies of this group are AMO Acrylic (Santa Ana, CA) and Acrysof (Alcon, Fort Worth, TX).

A critical property of an acrylic material is glass transition temperature (Tg) – the temperature at which a material changes from a hard and brittle state to a more flexible state – and this varies by polymer structure. Accordingly, it's important to bear in mind Tg when folding IOLs – if an IOL material has a high Tg, it's important not to fold it in a cold environment.

Disadvantage:

1. One of the drawbacks of this material group has been intralenticular changes. Small water incorporation in the optic material called glistening can occur in hydrophobic materials, predominantly seen with the Acrysof material. Over time, the glistening can increase, but evidence to this date does not indicate any effect on visual function.
2. The other drawback has been dysphotopsias reported with this high refractive index material. The most frequent positive dysphotopsia was edge glare, which was due to internal reflections at the rectangular edge of the Acrysof IOL under mesopic conditions with a large pupil, typically induced by a light source from the side and reported as a peripheral arc of light by patients [11]. Its lead changes in optic geometry, these dysphotopsias have been reduced significantly with newer hydrophobic acrylic models.

Hydrophilic Foldable IOLs: The first foldable IOLs were developed in the 1950s, and were made of hydrogels. Hydrogels are hydrophilic networks of polymers that swell extensively on contact with water; they vary in size and properties, depending in part on their water content. In the hydrated state, hydrogels are flexible, clear, and non-immunogenic and resemble living tissue – making them an excellent material to make foldable IOLs from (albeit a material that was considerably more expensive than PMMA). As water saturation determines hydrogel size, it means that you can implant a semi-hydrated lens through a small incision, and it will expand in the eye as it becomes fully hydrated.

Silicone Foldable IOL: The first foldable silicone IOL (Fig. 2) was implanted in human eyes in the 1978 by Kai-yi Zhou [7]. These were rapidly adopted, and foldable silicone IOLs conquered the market in the 1980s. In 1989, AMO introduced the PhacoFlex model SI-18, the first commercially available three-piece silicone IOL platform for use after clear corneal small incision phacoemulsification. This was followed in 1997 by the first FDA-approved multifocal IOL, the Array (also manufactured by AMO), which also contained a silicone lens, and for a long time dominated the multifocal IOL market.

Silicone is a synthetic polymer constructed as an organic polysiloxane molecule. These molecules consist of periodically repeated silicon-oxygen-groups. This arrangement is the backbone for a polymer, which is identical for all silicone IOLs. Bound to the silicon atom are side chains, which influence the properties of the material. First-generation silicone materials (like polydimethylsiloxane) had methyl side chains. Second-generation silicones have the methyl side chains replaced with vinyl groups.

Besides smaller incision sizes, foldable IOLs were insertable using single-use applicators or implantation devices, making the procedure easier for the surgeon, and reducing the risk of ocular infection. An added bonus is that the incision sizes used when introducing foldable IOLs are so small relative to rigid lenses, they are normally self-sealing, produce less astigmatism, and allow faster visual rehabilitation.

Light Filtering IOL: The entire IOL materials used today include ultraviolet (UV) light-blocking chromophores to filter the UV light. From in vitro and animal experiments, blue light was considered harmful due to short wavelength high energy light causing retinal damage by inducing more oxidative stress at the retinal level. Even though this has not been proven in humans, some manufacturers have introduced yellow-tinted IOLs to filter the short wavelength light.

Disadvantages:

1. One is a reduction in color contrast sensitivity, especially under mesopic conditions, and
2. Another is that the melatonin production in the brain may be altered, causing a change in the circadian rhythms that are steered by blue light levels in the eye [12]

Although till date no study has shown that a yellow lens causes a loss in contrast sensitivity, this may also be due to the lack of sensitivity of the psychophysical tests used.

4. INTRAOCULAR LENS DESIGNS

IOL lens design:-

1. Plate or open-loop style;
2. Angulated or planar haptics; special haptics for certain indications such as sulcus,
3. Optic shape and edge design; and
4. Optic geometry for certain indications such as toric, aspheric, or multifocal iols

Plate Haptic IOLs: One of the first foldable IOLs was a silicone plate haptic IOL (Fig. 2). Today, several manufacturers of hydrophilic IOLs still use a plate-style design, usually combined with small loop-like haptics at the four corners to allow better adaptation to capsule bag size.

Drawback: One main drawback of the plate-style design is the incomplete synthesis of the anterior and posterior capsule leaves along the plate haptic axis and, therefore, the lack of capsule bending at the optic edge. Due to this LECs migrate centrally onto the posterior capsule and cause the most common long-term problem after cataract surgery—PCO.

Some manufacturers have designed a cross-over between plate haptic and open-loop haptic design (Fig. 2). This allows better adaptability to capsule bag size variations and also reduces the zone of missing capsule bend.

Open-Loop IOLs:

Multipiece IOLs: Open-loop IOLs are held in place in the capsule bag by exerting a centripetal pressure on the capsule bag fornix and sometimes also the ciliary body, or in case of sulcus placement the ciliary sulcus. The haptics of an IOL should maintain their original configuration during the implantation procedure. This type of loop is the preferred type for IOLs dedicated for sulcus placement.

Single-Piece IOLs: New manufacturing methods led to the introduction of single-piece open-loop IOLs some years ago.Unlike three-piece IOLs, which usually consist of two different materials (optic and haptics) and need to be assembled by hand, these IOLs are produced in a single step from one material. Single-piece IOLs tend to be more resistant to damage when used with injectors and the production process is cheaper since less staff intensive. Next-generation one-piece IOLs, such as the Tecnis 1-Piece IOL, fit in a 360- degree square-edge design.

Haptic Angulations IOLs: The PCO preventative effect of sharp-edge optics suggests that it might be useful to maximize the barrier effect to migrating LECs at the posterior optic edge by pushing the IOL backward against the posterior capsule. This can be achieved with angulated. They were originally introduced because an angulation reduced iris shave in cases where the lens was placed in the sulcus. Consequently, such posterior vaulting characteristics can be found in many modern three-piece IOLs, with angulation of 5 to 10 degrees. However, studies showed that these designs do not lead to a smaller IOL to posterior capsule distance [12] and do not seem to have a better PCO-inhibiting effect than IOLs with little or no haptic angulation.

Even though the average capsule bag only has a diameter of about 10.4 mm [13], the variability is quite large with size ranging from 9.8 to 10.9 mm. For this reason and the fact that the bag ovalizes after lens implantation, especially in the case of weak zonules, most IOLs are oversized for the bag. This is especially true for the multipiece IOLs from the major manufacturers, which usually have an overall length of 13 mm. It looks the main reason for such oversizing is the need for the IOL to also be suitable for sulcus placement, even if a larger diameter would be preferable for this occasion [13].

Intraocular Lenses for Insufficient Capsule Support: In the case of capsule complications where a bag placement of an IOL is no longer possible, but the anterior capsule is intact, the IOL can be placed with the haptics in the sulcus. However, in order to ensure centration and axial stability of the IOL, an overall length (haptic to haptic) of at least 13 mm should be chosen. Ideally, especially in eyes with a larger sulcus diameter such as myopic eyes, 13.5 or 14 mm would be more appropriate.

There are some dedicated sulcus IOLs with such overall length often combined with a larger optic diameter of 6.5 or even 7 mm, both available as non foldable PMMA or foldable IOLs (Fig. 2). Foldable single-piece IOLs should be avoided for mentioned situations as their relatively thick haptics can cause rubbing on the posterior aspect of the iris with pigment dispersion.

Special Haptics-Accommodating Intraocular Lenses: Currently available accommodating IOLs are supposed to work according to the optic shift principle. Due to the contraction of ciliary muscle the anterior shift of the optic, resulting in an overall increase in refractive power of the eye. A 0.7-mm shift would be predicted to achieve 1 diopter of accommodation in an eye of normal dimensions. Accordingly, in a short eye, such a shift would cause more refractive change. These IOLs have in common a hinge-like junction of haptics to optic that should allow the shifting of the optic when the haptics are compressed. Measurements of IOL shift with present models have shown only very small amounts of IOL movement and to be very variable among eyes, both when stimulated with a near target or pilocarpine-induced ciliary muscle contraction [14-16]. Apart from lacking evidence of their function, these IOL designs have had significant amounts of PCO with most patients needing Nd:YAG capsulotomies within the first 2 years after surgery (Fig. 2) [17].

Intraocular Lens Optic Design:

Edge Design: During the past decade it has become clear that optic edge design plays an important role in the prevention of PCO. When the Acrysof lens (Alcon) was introduced in the early 1990s, several studies showed that PCO development was significantly less than with other IOLs [18-20]. This first was attributed to the acrylic material and to the surface properties of the IOL [21]. Later it could be shown that the sharp-edge design of the lens seemed to be the

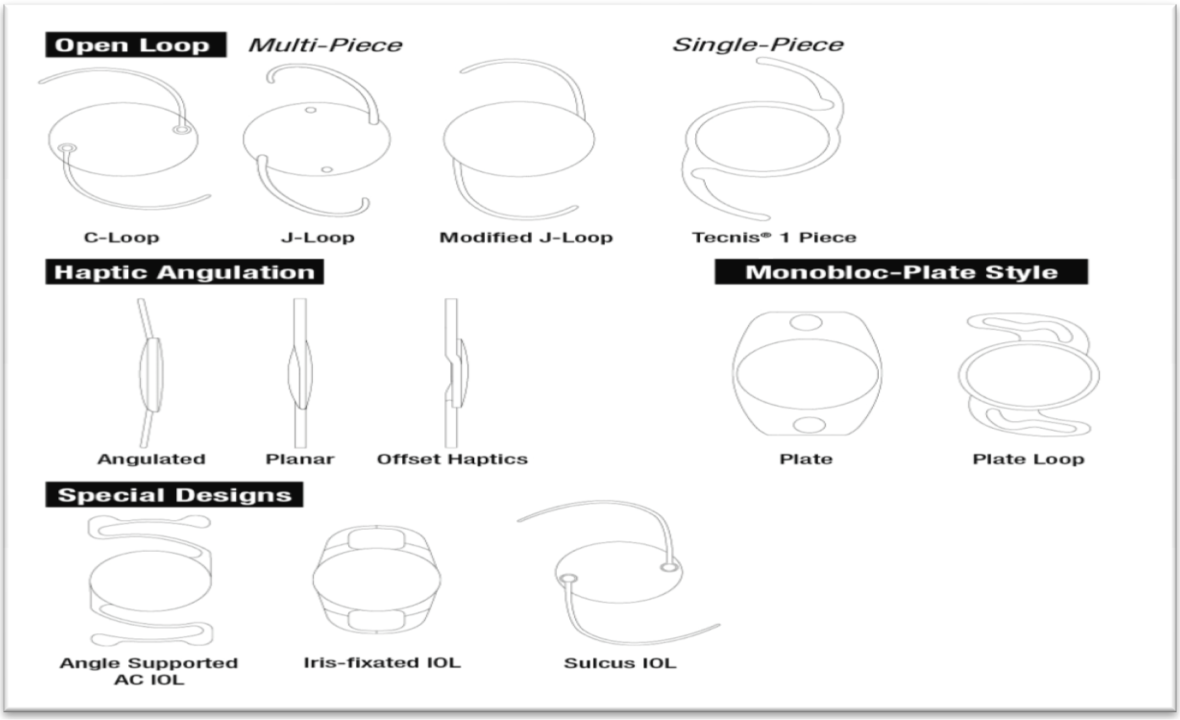

Fig. 2. IOLs designs

key factor for this effect [22]. The sharp IOL edge was a result of the manufacturing process, and its blocking effect on LEC migration, therefore, rather coincidental. Further studies confirmed that the rectangular shape of the IOL rim with its sharp edges, in combination with the acrylic material, was in fact the main reason for the reduced formation of PCO [23].

Studies by Nishi revealed that the discontinuous capsular bend seems to be a key factor for the preventative effect of a sharp-edge optic [23,24]. The capsular bend at the posterior optic edge causes mechanical pressure and/or contact inhibition of LEC growth on the posterior capsule (Fig. 2). In a meta-analysis of the randomized controlled trials comparing round and sharp-edge IOLs [25], there was a clear beneficial effect of sharp-edge IOLs concerning inhibition of PCO. This also confirmed that the sole modification of the posterior optic edge from a round edge to a sharp edge leads to a significant reduction of PCO by inducing a discontinuous bend at the posterior capsule [26,27].

Optic Geometry:

Biconvexity: Nearly all IOLs on the market have a symmetrically biconvex optic, meaning that the radius of curvature of the front and back surface are identical. Several manufacturers have an asymmetric biconvex optic, where the back surface curvature is relatively flat and constant throughout most of the power range and the anterior curvature is varied for IOL power. This causes a slight shift of the principal optical plane of the IOL and also implies that the lens should not be implanted front to back in the eye, apart from the angulation of the haptics being backward as well. In a symmetrically biconvex lens with no angulation, the IOL could be implanted front to back without a change in optical power [28].

Optical Zone: The majority IOLs have a full-size effective optical zone of 6 mm in the main range of IOL powers. So, the higher powered IOLs will have a thicker optic than the lower powers. This has the advantage of a full optic zone, but can make folding of the IOL or injecting with a shooter variable depending on IOL power. Some IOLs keep a constant center thickness of the optic and vary the effective optical zone, so varying the curvature of the optic and, for that reason, optic power. To my knowledge, there was only one manufacturer (Dr. Schmidt) that actually varied refractive index of the silicone material used for different powers, thereby keeping a constant effective optical zone and center thickness [13].

5. SPECIAL OPTICS

Multifocal Intraocular Lenses (1997): Multifocal IOLs (mIOL) are projected to overcome the postoperative lack of accommodation by dividing the incoming light onto two or more focal points. One zone of these is used for distance vision, the other for near or intermediate vision. These IOLs have shown to reduce the need for spectacle correction in daily life [28]. However, good refractive outcome and low residual astigmatism after surgery are key to success. Till date there are little published data available, but this strategy appears promising in some patients.

Toric Intraocular Lens (1998): With cataract surgery we can attempt to reduce pre exisiting corneal astigmatism using incisional techniques, such as placing the corneal incision on the steep axis, adding an opposite clear cornea incision (OCCI) on the same axis, or making limbal relaxing incisions (LRIs) on the steep axis. Most surgeons will use a 600-micron knife to perform LRIs. LRIs are able to reduce corneal astigmatism by as much as 3 diopters. The variability of the outcome is mainly due to inter patient differences in scarring of the corneal tissue, corneal rigidity, and corneal thickness [29].

Aspherical Intraocular Lenses (2004): Lenses in which the front surface is not curved as part of a sphere but is relatively flatter in the periphery—have hit the market and reportedly provide superior contrast sensitivity over the more traditional spherical IOLs. Currently, investigators at companies such as Alcon and Bausch & Lomb are studying the effects the aspheric IOLs on contrast sensitivity [30]. Since the lens helps compensate for the positive spherical aberration that can be induced by both the cornea and the lens itself, it provides a distinct improvement in modulation transfer function, which should assist in improving image quality, particularly in low-light situations [31].

Bausch & Lomb was the former to offer the aspheric IOL, in 2004. "The SofPort Advanced Optics (AO) aberration-free aspheric intraocular lens is a three-piece silicone lens with a 360-degree square edge, and PMMA haptics," [32].

6. CONCLUSION

Today, Ridley's genius has improved the lives of many millions of people. IOL use is not limited to cataract surgery, they have become an important method of improving refractive outcomes, as part of clear lens exchange. The gradual improvement in IOL design, first in making flexible lenses, then the ever-improving optical outcomes have meant that vision after cataract surgery has never been better –in the developed world. Alas, in developing countries, if patients do receive an IOL, for cost reasons it is likely to be a rigid PMMA lens. We have come a long way in terms of IOL design, but many people with cataracts in rural areas of the developing world, need help to catch up.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Apple DJ, Auffarth GU, Peng Q, Visessook N. Foldable intraocular lenses: Evolution, clinicopathologic correlations, and complications. Slack (Publ.); 2000. ISBN: 1556424353, 9781556424359.
2. Auffarth GU, Apple DJ. History of the development of intraocular lenses. Ophthalmologe. 2001;98:1017–28.
3. Auffarth GU, Schmidbauer J. Intraocular lenses. Ophthalmologe. 2001;98(11): 1011.
4. Beasley AM, Auffarth GU, von Recum AF. Intraocular lens implants: A biocompatibility review. J. Invest. Surg. 1996;9:399–413.
5. Auffarth GU, Wilcox M, Sims JC, et al. Analysis of 100 explanted one-piece and three-piece silicone intraocular lenses. Ophthalmology. 1995;102:1144–50.
6. Ridley NHL. The cure of aphakia, 1949. Intraocular lens implantation. Rosen, Haining and Arnott, C.V. Mosby, Toronto. 1984;37–41.
7. Zhou KY. Silicon intraocular lenses in 50 cataract cases. Chinese Medical Journal. 1983;96:175–176.
8. Apple DJ. Sir Harold Ridley and his fight for sight: He changed the world so that we

may better see it. Slack (Publ.). ISBN 1-55642-786-7; 2006.
9. Shankar C, From the Pages of History. History of intra ocular lens. Chettinad Health City Medical Journal. 2016;5(1):54-55.
10. Ridley NHL. Further experiences of intraocular acrylic lens surgery. Br. J. Ophthalmol. 1954;38:156–162.
11. Ridley NHL. Intraocular acrylic lenses – past, presence and future. Trans. Ophthalmol. Soc. UK. 1964;84:5–14.
12. Jay Yohendran. Intraocular lenses: A practical review for optometrists. 2 CPD in Australia, 1G in New Zealand; 2018.
13. Achieving Excellence in Cataract Surgery A Step-by-Step Approach Edited by D. Michael Colvard, MD, FACS Clinical Professor of Ophthalmology Doheny Eye Institute Keck School of Medicine University of Southern California Los Angeles, CA Medical Director of Colvard Eye Center Encino, CA.
14. Findl O, Kriechbaum K, Koeppl C, et al. Laserinterferometric measurement of the movement of an ‘accommodative’ intraocular lens. In: Guthoff R, Ludwig K, Eds. Current Aspects of Human Accommodation II. Heidelberg, Germany: Dr. Reinhard Kaden Verlag; 2003.
15. Koeppl C, Findl O, Menapace R, et al. Pilocarpine-induced shift of an accommodating intraocular lens: AT-45 Crystalens. J Cataract Refract Surg. 2005;31(7):1290-1297.
16. Hancox J, Spalton D, Heatley C, et al. Objective measurement of intraocular lens movement and dioptric change with a focus shift accommodating intraocular lens. J Cataract Refract Surg. 2006;32(7):1098-1103.
17. Findl O. Intraocular lenses for restoring accommodation: Hope and reality. J Refract Surg. 2005;21(4):321-323.
18. Hollick EJ, Spalton DJ, Ursell PG, et al. The effect of polymethylmethacrylate, silicone, and polyacrylic intraocular lenses on posterior capsular opacification 3 years after cataract surgery. Ophthalmology. 1999;106(1):49-54.
19. Ursell PG, Spalton DJ, Pande MV, et al. Relationship between intraocular lens biomaterials and posterior capsule opacification. J Cataract Refract Surg. 1998;24(3):352-360.
20. Sundelin K, Friberg-Riad Y, Ostberg A, Sjostrand J. Posterior capsule opacification with AcrySof and poly(methyl methacrylate) intraocular lenses. Comparative study with a 3-year follow-up. J Cataract Refract Surg. 2001;27(10): 1586-1590.
21. Hollick EJ, Spalton DJ, Ursell PG, Pande MV. Lens epithelial cell regression on the posterior capsule with different intraocular lens materials. Br J Ophthalmol. 1998;82(10):1182-1188.
22. Nishi O. Posterior capsule opacification. Part 1: experimental investigations. J Cataract Refract Surg. 1999;25(1):106-117.
23. Nishi O, Nishi K, Sakanishi K. Inhibition of migrating lens epithelial cells at the capsular bend created by the rectangular optic edge of a posterior chamber intraocular lens. Ophthalmic Surg Lasers. 1998;29(7):587-594.
24. Nishi O, Nishi K, Mano C, et al. The inhibition of lens epithelial cell migration by a discontinuous capsular bend created by a band-shaped circular loop or a capsule-bending ring. Ophthalmic Surg Lasers. 1998;29(2):119-125.
25. Findl O, Buehl W, Bauer P, Sycha T. Interventions for preventing posterior capsule opacification. Cochrane Database System Rev. 2007(3).
26. Buehl W, Menapace R, Findl O, et al. Long-term effect of optic edge design in a silicone intraocular lens on posterior capsule opacification. Am J Ophthalmol. 2007;143(6):913-919.
27. Buehl W, Findl O, Menapace R, et al. Long-term effect of optic edge design in an acrylic intraocular lens on posterior capsule opacification. J Cataract Refract Surg. 2005;31(5):954-961.
28. Leyland M, Zinicola E. Multifocal versus monofocal intraocular lenses after cataract extraction. Cochrane Database Syst Rev. 2003;3:CD003169.
29. Chernyak DA. Cyclotorsional eye motion occurring between wavefront measurement and refractive surgery. J Cataract Refract Surg. 2004;30(3):633-638.
30. Packer M, Fine IH, Hoffman RS, Piers PA. Prospective randomized trial of an anterior surface modified prolate intraocular lens. J Refract Surg. 2002;18: 692-696.
31. Mester U, Dillinger P, Anterist N. Impact of a modified optic design on visual function:

Clinical comparative study. J Cataract Refract Surg. 2003;29(4):652-660.

32. Lisa B. Samalonis. Aspheric IOLs: From theory to practice if implanted properly, aspheric lenses may provide improved visual function over traditional spherical IOLs. Review of Ophthalmology. (Published 15 June 2005) Available:https://www.reviewofophthalmology.com

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/53726