

Intraocular Lenses: A More Permanent Alternative

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Before the 1950s, cataracts, a loss of transparency of the human lens causing blindness, had been treated using procedures such as “couching” and various forms of intra- and extracapsular lens extraction (ICCE, ECCE). Minimizing surgical complications and attaining good postoperative vision were the primary goals of the surgery. Correction of postoperative aphakia with spectacles was less than satisfactory for patients; their quality of vision was impacted by the magnification, visual aberrations, and field loss inherent in the high-powered positive lenses required to correct the post-surgical eye. Contact lenses provided a superior optical alternative to spectacles, but mobility in the elderly patients typically undergoing cataract surgery was a real problem, as contact lenses needed to be inserted and removed every day.

Sir Harold Ridley (Fig. 1) is universally accepted as the “father” of intraocular lenses (IOL). He was the first to conceptualize a lens that could be surgically implanted in the eye to compensate for the loss of optical power that occurs when the cataractous lens is removed. Noting that fighter pilots injured during the early years of World War II with Plexiglass splinters permanently lodged in their eyes showed no adverse responses, he designed a polymethyl methacrylate (PMMA) optic to replace the cataractous lens in the eye. In 1949 he performed the first surgery to implant a plexiglass intraocular lens. Although the prescription was far from ideal due to errors in the calculation of the refractive index of the natural lens, the surgery was considered a success [1]. Ridley IOLs were used in hundreds of similar surgeries over the next decade, with successful outcomes reported in about 70% of cases. Difficulties in maintaining the lens location in the posterior chamber of the eye and centered on the pupil were the main causes of failure. Amazingly, although a small number of visionary surgeons followed Ridley’s lead in the use of intraocular lenses to correct for cataract extraction, it would not be until the late 1980s before it became the preferred method of correction.

From the 1950s through the 1980s, the history of IOL development would be a leap-frogging of technologies in the placement of the IOL in the eye, IOL mechanical design, surgical technique, and diagnostic equipment for measuring the intraocular length of the eye. During this period the lens material of choice was PMMA, with rigid metal or PMMA haptics requiring a large incision size, polypropylene haptics being introduced to help with centering the lens as the capsular bag collapsed during the healing process [2].

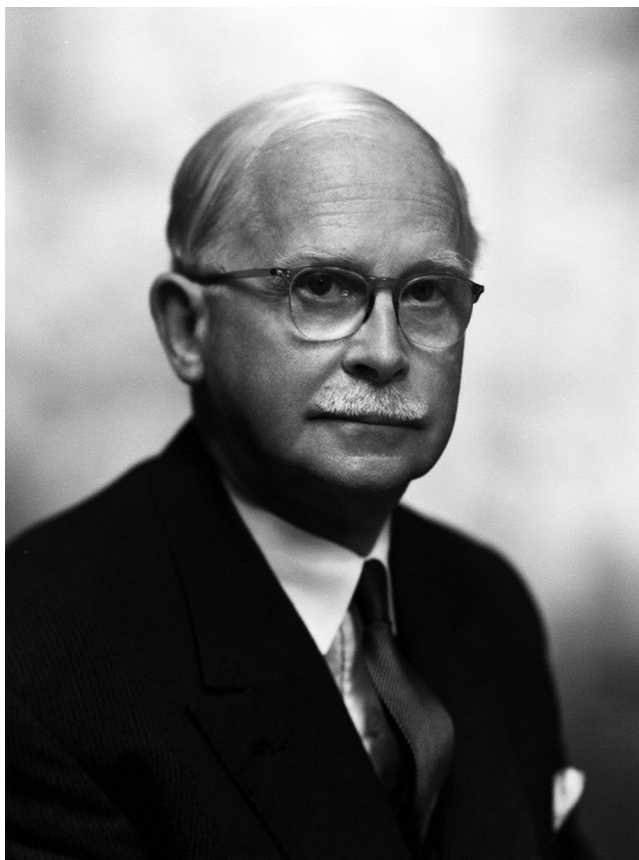
In 1984, the first silicone IOL lens, designed by Marzocco and introduced by STAAR, was brought to the marketplace. The huge advantage of this flexible lens was that it could be introduced through the incision into the eye in a folded configuration, allowing a decrease in the surgical incision size. The incision length is related to the induction of post-surgical corneal astigmatism [3], so this signaled the beginning of a drive toward smaller incision sizes that continues to this day. Ridley’s original incision was essentially the full diameter of the cornea, while today incisions can be as small as 2 mm, using a dedicated injector to fold and introduce the lens through the incision. It was not until the early 2000s that convergence of these technologies brought a standard of procedure that is the norm in the United States even today [2]. This involves a cataract extraction in the capsule via phacoemulsification under topical intracameral anesthesia. The replacement IOL is a flexible, one-piece lens with a square posterior edge

(to reduce posterior capsule opacification), introduced through a 3.0-mm or smaller incision in the cornea and placed fully within the capsular bag, with a slight vault against the posterior surface of the capsule.

Having spent 50 years developing this procedure to be the preferred option for all cataract surgeries, even in children, the industry moved its sights to optimizing the optical performance of IOLs. In 1989 David Atchison identified the considerable increase in spherical aberration created by removing the natural lens and recommended spherical surfaced lens forms that would correct the majority of this aberration [4]. He followed this with the suggestion that using aspheric surfaces would not be beneficial, due to the aberrations induced by tilt and decentration of the final IOL after healing. Not to be deterred, Antonio Guirao and several colleagues, including Pablo Artal and Sverker Norrby, measured the image quality of the normal population with age and then of the typical pseudophakic population. Led by Norrby, an IOL was developed to correct the average spherical aberration of the post-surgical IOL implanted eye. The lens, released to the market by Abbott Medical Optics (AMO) as the TecnisIOL, was designed with an aspheric anterior lens surface and consideration of the typical decentrations that occur with IOL surgical placement

and postoperative healing. A rapid response from Alcon provided lenses that corrected a portion of the spherical aberration of the eye and IOL in combination, and Bausch and Lomb provided a spherical aberration-free IOL design, ignoring the spherical aberration inherent in the aphakic eye. All three lenses met with successful use by surgeons around the world, the more technology minded exploring the concept of using all three lenses along with Zernike analysis of corneal topography measurements to determine which lens would come closest to nullifying the spherical aberration of an individual eye.

The next challenge was correcting near vision in the pseudophakic eye, which of course, has no accommodation after removal of the natural lens. Early attempts at multizonal IOLs for correcting presbyopia demonstrated marginal success due to poor image quality and led to withdrawal from the market by the early 1990s, but in 1997 AMO released a simultaneous refractive multifocal lens (distance, intermediate, and near zones of the design were within the patient's pupil under normal illumination) that gained traction in the marketplace until the early 2000s, when complaints of reduced contrast and halos at night led to a reduction in use [2]. About this time Alcon introduced a diffractive bifocal IOL design, based on patents bought from 3M but updated with a smaller optic zone (only the central 3.6 mm encapsulated the bifocal diffractive element) and an apodized energy profile. The lens had greatest near power at the center of the pupil (equal distance and near), and a shift biased toward distance power moving from the center to the periphery of the optic zone, with all light focused at distance outside the 3.6-mm central diffractive zone. Under its marketed name of ReSTOR, this product met with great enthusiasm when presented to clinicians and continues to grow in popularity, especially in the latest version, which has a lower add power (reduced from +4 D in the original design to +3 D).



▲ Fig. 1. Sir Harold Ridley, universally accepted as the “father” of IOLs, being the first to devise, produce, and implant the first PMMA IOL. (© National Portrait Gallery, London. Sir (Nicholas) Harold Lloyd Ridley by Bassano Ltd., half-plate film negative, 19 May 1972, NPG x171529.)

AMO responded with a modified refractive multifocal marketed as the ReZoom in 2005, and then released a diffractive design in 2010, which was similar to the Alcon product, without the apodization feature. Although these types of designs are generally successful, some patients do experience reduced contrast, ghosting, and doubling with large pupil sizes, particularly in lenses that are decentered relative to the center of the pupil, as one might expect with designs of this type.

Stuart Cummings, a surgeon, observed in 1989 that patients who had plate haptic silicone IOLs inserted often showed better near reading performance than those fitted with other conventional loop haptic IOL designs, leading him to invent a lens specifically designed to optimize this feature. By adding a weakened portion or “hinge” to the plate haptic, the silicone lens was designed to bend under the intraocular forces occurring with ciliary muscle contraction during accommodation. In this way, the optics of the lens were traditional monofocal spherical surfaces, but good image quality could be provided at both distance and near as the optic of the lens moved forward with the accommodative response. Brought to the market under the tradename Crystalens in 2005, this lens was the first, and is still the only, IOL to have the claim approved by the FDA that it demonstrates “accommodation” of up to 1 D. The exact mechanism of action has not been verified, but it is most probably a combination of optic displacement, optic tilt, and optic zone distortion brought about by the accommodative forces of the eye increasing the depth of field. Regardless of the mechanism, clinical studies have shown superior near vision over monofocal lenses, while maintaining equivalent distance visual acuity.

Correction of postoperative astigmatism induced by surgery was always an issue with cataract surgery, as large incisions closed by sutures led to significant changes in corneal topography [3]. Typically these changes would be corrected by progressive spectacles worn by the pseudophakic patient postoperatively. However, the acceptance of multifocal IOLs through the 2000s in conjunction with small, sutureless incision sizes led to an expectation from many patients that they could spend most of their waking hours without a distance spectacle correction. This paradigm opened the demand for toric IOLs in those patients who had significant corneal astigmatism prior to cataract surgery. Although offered to the industry in 1994 by STAAR on their plate silicone lens platform, significant adoption of toric IOLs only began with the introduction of the Acrysof Toric IOL by Alcon in 2005. Although optically the design is straightforward, a successful toric IOL must demonstrate stability of the cylinder axis from lens placement at the time of surgery until complete healing 3 to 6 months postoperatively. This lens, along with competitor offerings, typically shows stability that makes the use of toric lenses a benefit in eyes with 1.25 D of astigmatism or greater postoperatively.

IOLs have come a long way since their beginnings in 1949, and today they are the preferred method of correction following cataract surgery regardless of patient age or refractive status.

References

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