Chapter 10

Cataract Surgery

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Abstract

Phacoemulsification is the most common ophthalmic surgery and it revolutionized cataract surgery. With the introduction of sutureless clear corneal incisions surgical time has been reduced, faster postoperative recovery enabled, and induced astigmatism lowered. Various premium intraocular lenses (IOLs) such as multifocal, accommodative and toric IOLs are designed to enable the best refractive outcomes. In order to further increase accuracy and precision femtosecond laser assisted cataract surgery (FLACS) has been introduced with ability to perform incisions, capsulorhexis and disassembly of the lens.

Most frequent long-term complication of cataract surgery is posterior capsule opacification (PCO). Another most common cause of patient dissatisfaction after uneventful surgery is pseudophakic dysphotopsia. Acrylic materials with a higher index of refraction and square edge designed IOLs are developed in order to minimise PCO, but on the other hand they seem to enhance dysphotopic phenomena in patients.

To achieve the best possible postoperative result, careful selection of patients, individual approach and patient education is mandatory.

Keywords: Phacoemulsification, clear corneal incision, intraocular lens, posterior capsule opacification, pseudophakic dysphotopsia

1. Introduction

Cataract surgery is the most common ophthalmic surgery, and one of the most frequently performed surgeries in general. A “cataract” refers to a focal or diffuse opacification of the crystalline lens, a structure that is normally opticaly clear. Hardening and clouding of the lens may result in a progressive loss of vision depending on its size, location and density. It is typically bilateral, compromises visual acuity and contrast sensitivity and increases glare. Cataract may form at any age due to a number of different etiologies such as systemic metabolic disease, use of different medications, ocular trauma, but most often is age related. As the lens ages, it increases in weight and thickness and decreases in accommodative power. In cross-sectional studies, the prevalence of cataracts is 50% in people between the ages of 65 and 74 and it increases to 70% in those over the age of 75 [1]. The pathogenesis of age-related cataracts is multifactorial and not completely understood. Different methods have been developed for cataract surgery, such as intracapsular and extracapsular extraction procedures, but the most common and widely accepted procedure is phacoemulsification, since its development in 1967, by Charles Kelman [2].

2. Phacoemulsification

The procedure of phacoemulsification has gained increasing popularity worldwide, since the introduction of sutureless clear corneal cataract incisions, due to several advantages over the traditional sutured scleral tunnels and limbal incisions [3]. Several surgical approaches have been suggested to allow for a faster and easier phacoemulsification technique. The introduction of clear corneal incisions to enter the anterior chamber and remove the cataract using phacoemulsification revolutionized cataract surgery [4]. This approach is the most popular and widely accepted. Clear corneal wounds have transformed cataract surgery by dramatically reducing surgical time, offering faster postoperative recovery, and lowering the induced astigmatism in comparison to scleral tunnel incisions [3].

3. Scleral tunnel incisions

Scleral incisions in phacoemulsification were firstly introduced by Girard and Hoffman [5]. The incision size is usually 3-7 mm in chord length [6]. Smaller incisions may be sutureless while larger tunnels often are sutured and periotomy is performed in both cases. Scleral tunnel construction could lead to several problems. An initial scleral tunnel that is too deep will create scleral disinsertion with exposure to the ciliary body leading to different problems with hemostasis, poor wound stability, early or posterior entry to the anterior chamber, and iris prolapse. On the other hand, an incision that is too shallow may result in tear of the tunnel roof and problems with water tightness of the wound [3]. Another thing that is of great importance is the length of scleral tunnel. A dissection that is too far into the cornea creates an anterior entry into the anterior chamber resulting in decreased maneuverability and corneal striae that interfere with visibility during subsequent steps. An incision that is too short would create problems with wound closure and iris prolapse [3]. Other complicaions include induced astigmatism, filtration, hyphema and Descemets membrane detachment.

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4. Limbal incisions

The differences in the healing effects of incisions at the limbus and the cornea are widely discussed in the literature [7-9]. Limbal incisions are likely to heal more quickly and are more resistant to deformation pressure than those in the cornea. Reasons for that are significant anatomical and physiological differences between them. Regular lamellar structure of collagen fibrils of the cornea stretch from limbus to limbus. It is arranged in a lattice formation and provides the primary structural support of the cornea and its transparency. The cornea is avascular.

On the other hand, at the limbus, this regular structure is no longer present. Vascular arcades are evident, providing a potential source of fibroblasts [10] in the effects of clear corneal and scleral or limbal incisions, related to differences in the respective structures where the incisions are made.

In comparison to limbal incisions, clear corneal incisions also appear to increase the likelihood of endophthalmitis [11, 12].

5. Clear Corneal Incisions (CCIs)

Sutureless clear corneal incisions are the most common incisions for cataract surgery with phacoemulsification, replacing scleral tunnel and limbal incisions. There are several reasons for the popularity of clear corneal approach based on different advantages compared to scleral tunnel incisions. Some of them include reduced procedure time, lower induced astigmatism, faster visual recovery and less complications.

The aim of cataract surgery today is rapid visual rehabilitation, the best possible uncorrected visual acuity, and minimal postoperative astigmatism. The phacoemulsification procedure results in less surgically induced astigmatism than extracapsular cataract extraction, in which the incision is much larger. Clear corneal incision is the most used type of incision in phacoemulsification surgery, because it is less time-consuming and does not require cauterization or wound suturing. The location of the CCI affects the degree of postoperative astigmatism. One of the possible complications of cataract surgery is surgically induced astigmatism (SIA), which is a major cause of functional disturbance and insufficient uncorrected visual acuity. CCI is made deliberately in the steepest meridian if astigmatism is addressed. It can be made at superior, oblique or temporal locations.Temporal CCI induces regular astigmatism 90 degrees away from the incision (with-the-rule astigmatism) thus minimizing the postoperative astigmatism [13-15]. It is known to induce the least postoperative astigmatism. Also, the smaller the CCI, the lesser the induced astigmatism. Oblique scleral tunnel incision predictably reduces astigmatism by simultaneously producing corneal flattening and steepening [16].

Some studies have shown that a small superior CCI induces greater postoperative astigmatism than a small supero-oblique CCI, and a small supero-oblique CCI induces higher postoperative astigmatism than a small temporal CCI [17-19]. Some authors reported that, although temporal

CCI is reported to result in the least induced astigmatism, locating the incision superotemporally or superonasally may ease surgical manipulations during the phacoemulsification cataract surgery for a right-handed surgeon who works from the 12 o'clock position relative to the patient [20]. Performing the procedure from the patient's temporal side may not be possible with the most operating tables, and locating the CCI temporally in the left eye may be difficult for a right-handed surgeon who sits at the 12 o'clock position.

Several groups of authors analyzed refractive astigmatism in patients who have had phacoemulsification cataract surgery performed by the oblique clear corneal incision. They provided evidence that the supero-oblique clear corneal incision does not induce the clinically significant amount of oblique astigmatism [21-23]. Also, evidence is provided that the superotemporal or superonasal CCI has minimal effect on corneal astigmatism [23]. Many studies investigated the influence of different factors, such as the type of a surgery, length of incision and its type (curved, straight, frown), location and width of incision (central vs. peripheral-limbal or scleral), presence or absence of a suture and the suturing method, on postoperative astigmatism [16, 19, 24, 25]. Any incisions that are made in the cornea have the potential to change the curvature and therefore the dioptric power of the cornea in that meridian. The location as well as the width of the incision affects the degree of postoperative astigmatism.Surgically induced astigmatism is positively correlated with incision size (larger incisions generating more astigmatism) and location (scleral or limbal incision inducing less astigmatism than clear corneal), though for small incisions the effect of location appears less critical [26, 27]. Wound construction also appears to have an effect, with square incisions reported to affect astigmatism the least [28]. Despite all the advantages of clear corneal incisions, they are not without problems. Reported disadvantages include poor wound healing [29], induction of irregular astigmatism [29], the risk of wound dehiscence following trivial trauma [30], and increased loss of endothelial cells [31].

5.1. Overview of the technique

Phacoemulsification in most cases begins with a 2.2 to 3.0 mm tunnel in the peripheral corneal to enter to the anterior chamber. Reduced incision size to 2.2 mm and smaller led to several innovations in instrumentation, phacoemulsification technology, and intraocular lens (IOL) design. Each step taken in reducing the incision size comes with mixed success but has led ultimately to measurable improvements in outcomes [32]. During intraocular surgery, the anterior chamber is stabilized with an ophthalmic viscoelastic device (OVD).Continuous curvilinear capsulorhexis is made at the anterior surface of the lens capsule, followed by hydrodissection that separates the capsule and cortex and hydrodelineation that separates the nucleus from epinucleus and cortex (in cases of medium or medium-hard nucleus). Phacoemulsification begins when the tip of a handpiece connected to the phaco machine is placed within the anterior chamber to fracture the lens into the small pieces and to aspirate the remaining small particles. Aspiration uses pumping to remove liquid and debris generated during the surgery. Pumping creates a partial vacuum and the negative pressure forces liquid out. To maintain the anterior chamber volume, irrigation of the saline-like solution is performed at the same time. After fragmentation and

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aspiration, insertion of the artificial intraocular foldable lens via injector follows. Continuous longitudinal ultrasound (US) has an inherent repulsive characteristic that can induce turbulence, cause chatter, and create substantial heat along the shaft of the phaco needle. Larger bore needles allow greater fluid flow allowing better cooling and transfer of larger fragments of nuclear material. Fortunately, none of the current generation phaco units rely solely on continuous longitudinal power [32]. Micropulse phacoemulsification is a result of advancements in phacoemulsification modalities that include less power use and shorter procedure times. The operating temperature of the needle in the incision is decreased [33, 34]. The next progression provided torsional phacoemulsification (Ozil, Alcon Laboratories, Inc.) with needle temperature also reduced [35]. Transversal phacoemulsification (Ellips, Abbott Medical Optics, Inc.), the next nonlongitudinal movement, has a similar effect. Each of these power modulations has resulted in improved ultrasonic efficiency and can use smaller gauge needles to effectively emulsify nuclear material [32].

6. Phacodynamics

Modern phacoemulsification machines generate the required vacuum and aspiration based on one of three pumping systems:

1. Peristaltic pump
2. Venturi pump
3. Diaphragm pump

1. Peristaltic pump

In this type of pump, the fluid is displaced through flexible tubing using a series of rollers on a rotating wheel. As the wheel rotates, the rollers move the fluid trapped between them, which result in more fluid being drawn into the tubing in the direction of rotation (Figure 1). The flow rate is directly proportional to the speed of the rotary mechanism. At low speeds of rotation a vacuum is not produced unless the tip is occluded. As the speed of rotation is increased, a vacuum is produced in the aspiration line without occlusion. A desired flow rate and vacuum is determined by the surgeon.

2. Venturi pump

There is no moving part in this pump. This type of pump works on Bernoulli's principle. When the speed of flow of a fluid is increased in one part, the pressure in that part is decreased. Compressed gas, such as air or nitrogen, flowing through a pipe (Figure 2) reduces the pressure in the next region and creates a partial vacuum within the rigid drainage cassette.

3. Diaphragm pump

In this type of pump, a flexible metal or rubber diaphragm moves up and down. This movement, along with the vertical motion of two valves, maintains the vacuum (Figure 3). Clinically, this type of pump is similar to the Venturi pump.

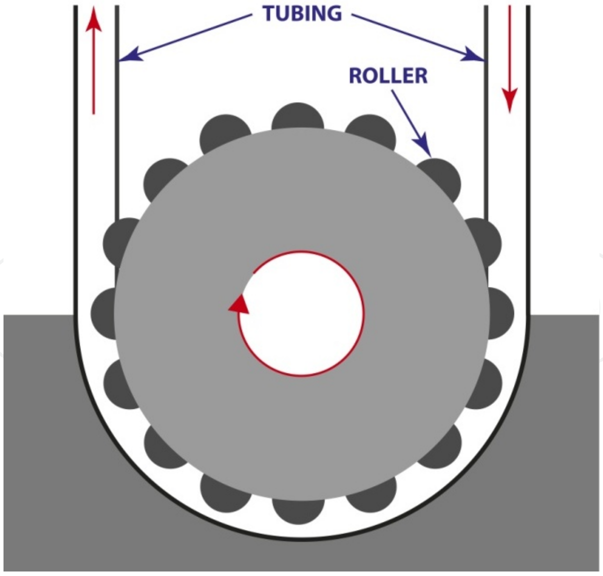

Figure 1. Peristaltic pump

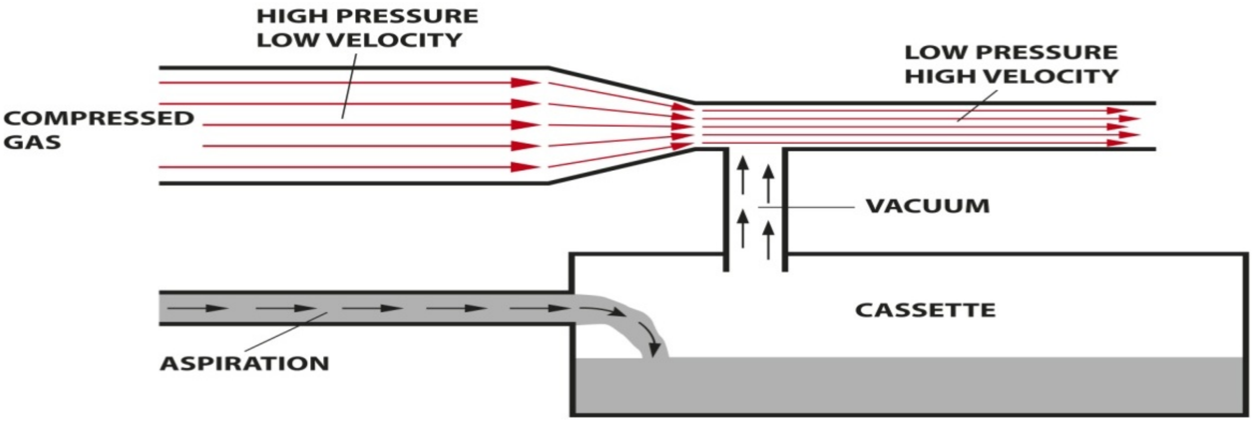

Figure 2. Venturi pump

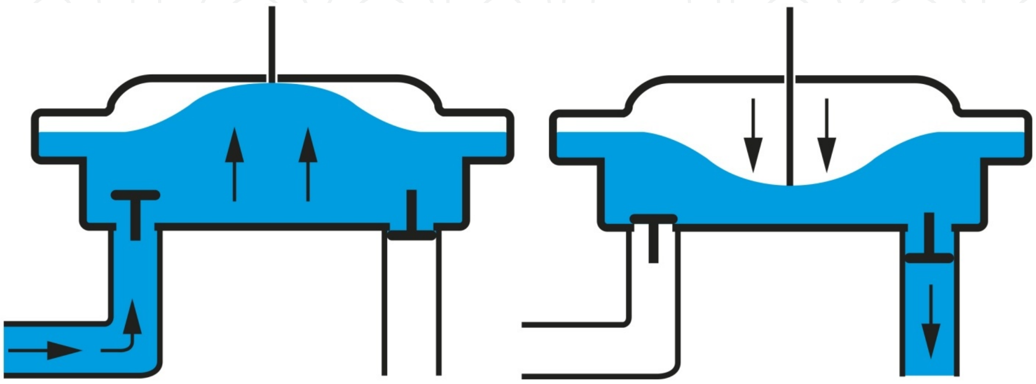

Figure 3. Diaphragm pump

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The peristaltic pump has a slower rise time unlike the Venturi and diaphragm pumps that have rapid flow rates and rise times. Rise time measures how rapidly a vacuum builds up once occlusion has occured at the aspiration tip. Flow rate measures the amount of fluid passing through the tubing (cc/min) and indicates how quickly events will progress once the aspiration tip is either suddenly occluded or suddenly cleared. Venturi and diaphragm pumps have higher flow rates and therefore they build up vacuums in the aspirate line without occlusion of the aspiration tip. Once the tip is occluded, a vacuum builds up rapidly [2, 36-38].

Peristaltic	Venturi
Flow based	Vacuum based
Vacuum created on occlusion of phaco tip	Vacuum created instantly via pump
Flow is constant until occlusion	Flow varies with vacuum level
Drains into a soft bag	Drains into a rigid cassette

Table 1. Differences between pumps, as reported by Devgan [38].

7. Intraocular Lenses (IOLs)

Nowadays, cataract surgery is not synonymous with lens extraction; it evolved in a more refined procedure due to advances in phacoemulsification procedure and intraocular lens technology [39]. The most frequent and the cheapest intraocular lenses are monofocal. After their implantation most patients need spectacles, at least for near vision. The goal of premium IOL design is to enable the best refractive outcome with restoration of vision for distance and near without spectacles. Multifocal and accommodative intraocular lenses, as well as toric IOLs for corneal astigmatism compensation, are considered premium IOLs. The aim of multifocal and accommodative premium IOLs is to allow the presbyopic patient to regain the ability to accommodate. The capacity of the eye to actively change its refractive power to create a sharp image on the retina of distant, intermediate, and near objects is called accommodation [40].

7.1. Multifocal IOLs

Multifocal IOLs focus light in more than one point. They are described as refractive, diffractive, and combinations of both optical principles. Also, they can be spherical and aspherical. They were first introduced in the 1980s [41, 42]. They consist of multiple circular, concentric areas that provide a continuous variation of the refractive power. Diffractive multifocal artificial lenses are based on the HuygensFresnel principle [43] presenting concentric rings that result in two or more coexisting retinal images and are independent of pupil size.

On the other hand, refractive IOLs are dependent on pupil size. Refraction is based on a change in direction of the light ray due to a change in the optical density of the material transmitting the light ray. Refractive IOLs provide usually good near vision but are mostly insufficient regarding very small prints [44]. Recent studies report very good results in most cases after implantation of a multifocal IOL, diffractive [45-47], refractive [46, 47], or hybrid diffractive-refractive [48]. Aspheric multifocals decrease higher-order aberrations of the ocular optical system, primarily by compensating for the increased positive spherical aberration of the cornea in older subjects [49, 50].They provide a significantly better near visual acuity compared to spherical multifocal IOLs, with no significant influence on night vision symptoms and contrast sensitivity [51]. Various studies have shown that uncorrected near vision is improved by implantation of a multifocal IOL in comparison to monofocal IOL, resulting in lower levels of spectacle dependence for near tasks without compromising distance visual acuity [52-58]. In general, multifocal IOLs are able to provide patients with excellent uncorrected distance and near visual acuity resulting in high levels of spectacle independence [49]. Although, the preceding discussion makes the multifocals very appealing, they are not devoid of problems. One of the main reasons for patient dissatisfaction is dysphotopsia [59, 60]. The most reported phenomena after multifocal IOL implantation are halos and glare [61, 62], especially in refractive multifocal IOLs [46]. In general, multifocal IOLs are associated with lower contrast sensitivity than monofocal IOLs [46]. Regarding that, diffractive multifocal IOLs appear to be equal or superior to refractive multifocal IOLs [63, 64]. Also, multifocal IOLs have been associated with higher levels of high order aberrations (HOAs) than monofocal IOLs [65]. Refractive multifocal IOLs performed better at intermediate than near distance [51, 66]. Diffractive multifocal IOLs with lower near additions have increased visual acuity at intermediate distance without decreasing near and distance visual acuity [48, 67]. Lately, it has been shown that intermediate visual acuity is increased with trifocal diffractive IOLs [68]. In preoperative evaluation, it is of great importance careful selection of patients, individual approach, patient s education and consideration of all benefits and side-effects of multifocal IOLs [69, 70].

7.2. Accommodative IOLs

An alternative to multifocal lenses are accommodative lenses, which are able to change position or shape in response to the accommodative reflex. They were designed to avoid the optical side effects of multifocal IOLs and to offer the best solution for presbyopia: an IOL of high-amplitude variable focality [71]. They are classified according to design into single-optic, dual-optic, and curvature change IOLs [72]. Accommodative lenses act like monofocal lenses, but provide better visual acuity for intermediate and distance vision. In comparison to multifocals, they are independent on pupil size and therefore provide less disphotopic effects and do not decrease contrast sensitivity. On the other hand, there is a variability of the postoperative outcome, greater risk for capsular contraction and opacification, and the need for further near vision correction [73]. Ideal IOL would allow the presbyopic patient to regain his or her ability to accommodate. Experiments have been conducted with refilling the capsular bag with a clear and elastic substance in order to achieve desirable accommodation, but unfortunately unsuccessfuly [74]. Also, different attempts with the change in position of the IOL or parts of it within the optical system in order to change the optical power of the optical system and to restore the patient's accommodation in that way have not resulted as expected [75]. Some of the ultrasound studies showed changes in the position of accommodating IOLs within the optical system in response to physiological or pharmaceutical stimuli [76], while

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others did not provide evidence of significant movement of those IOLs [77, 78]. Looking into a clinical practice, accommodating IOLs seems to be insufficient to result in large changes in the power of the optical system [75, 79].

7.3. Toric IOLs

Approximately 20% to 30% of patients who have cataract surgery have corneal astigmatism of 1.25 diopters (D) or higher and approximately 10% of patients have 2.00 D or higher [80-82]. Toric intraocular lenses are a predictable method of astigmatic correction with minimal impact to the cornea. Based on current evidence, it appears that a minimal amount of corneal astigmatism of approximately 1.25 D should be present before toric IOL implantation is considered [83]. They provide an opportunity for corneal astigmatism correction at the time of cataract surgery and for spectacle independence. But, effectiveness of torics is dependent on its orientation [84, 85]. A 10-degree error in rotation results in a 35% residual error in the magnitude of astigmatism. Since the beginning of the first implanted foldable toric intraocular lens in 1994 [86-89], many improvements in IOL material and design have been made to improve postoperative rotational stability and therefore improved visual outcomes following toric IOL implantation. Toric IOLs are made of hydrophobic acrylic, hydrophilic acrylic, silicone, or polymethylmethacrylate (PMMA) biomaterial. The IOL biomaterial plays a major role in the postoperative rotation of the IOL. After implantation of a toric IOL in the capsular bag, the anterior and posterior capsules fuse with the IOL, preventing IOL rotation [90]. Adhesions of the IOL to the capsular bag are thought to prevent IOL rotation. Lombardo et al. found that hydrophobic acrylic IOLs showed the highest adhesive properties, followed by hydrophilic acrylic IOLs, PMMA IOLs, and finally silicone IOLs [91]. Oshika et al. showed the strongest IOL–capsular bag adhesions for acrylic IOLs, followed by PMMA and silicone IOLs [92]. Acrylic IOLs generally form the strongest adhesions with the capsular bag [90]. Also, IOL design contributes to the stability of the lens in the capsular bag and avoidance of postoperative IOL rotation. It has been shown that the overall IOL diameter and haptic design are major factors in the prevention of IOL rotation [93-95]. Currently available toric IOLs have a total IOL diameter ranging from 11.0 mm to 13.0 mm. The lens with longer IOL diameter was found to have much better rotational stability than the lens with shorter diameter [94]. Two haptic designs are available: plate-haptic and loop-haptic. When comparing the postoperative rotation of plate versus loop-haptic silicone IOLs, some studies found significantly higher postoperative rotation with loop-haptic IOLs than with plate-haptic IOLs [93]. Others compared plate-haptic and loop-haptic acrylic IOLs and did not find a significant difference in postoperative rotation, suggesting that in acrylic IOLs, plate and loop haptics have both good rotational stability [96]. Toric IOLs are most effective in the correction of regular astigmatism, but they have been shown to be effective in patients with irregular corneal astigmatism, including keratoconus (only if the risk for progression is minimal) [97], pellucid marginal degeneration [98], and post-keratoplasty eyes [99, 100]. Not suitable for torics are patients with potential capsular bag instability, like those with pseudoexfoliation syndrome or trauma-induced zonulysis because zonular weakness affects IOL stability and may result in rotation or decentration of a toric IOL [83]. Multifocal toric IOLs gain for spectacle independence regarding distance, intermediate, and near vision. Evidence has been provided that the presence of 1.00 D or higher astigmatism in eyes with a multifocal IOL compromise distance and near visual acuity, showing the importance of an optimal astigmatism correction in these patients [101].

8. Complications

8.1. Posterior capsular opacification (PCO)

The most frequent long-term complication of cataract surgery remains posterior capsule opacification (PCO), an after cataract. In the past two decades, refinements in surgical technique and modifications in intraocular lens (IOL) design and material have led to a decrease in the incidence of PCO [102]. Symptoms of posterior capsule opacification include blurred vision and are similar to those of a normal cataract. Patients may also see streaks of light, halos, or excessive glare.

It has been shown that a sharp posterior optic edge inhibits migration of lens epithelial cells (LECs) behind the IOL optic and results in a lower incidence of PCO [103-106]. Most IOL designs, especially multipiece, have open-loop haptics that have a relatively narrow optic–haptic junction. The junction is thought to be an Achilles heel for LEC migration, and the narrower the junction, the better the optic-edge effect against LEC migration [106].

As intraocular lens (IOL) design [107, 108], the material [91, 109, 110], and the surgical technique [111, 112] play a crucial role in retarding the development of central posterior capsule opacification (PCO). Intraocular lens materials can be broadly divided into hydrophobic and hydrophilic based on their surface energy. Acrylic IOLs with a hydrophobic or hydrophilic surface are widely used in practice [113, 114].Single-piece hydrophilic acrylic IOLs with a modified square edge are also available. The PCO rate with these hydrophilic IOLs, which have an improved 360-degree sharp edge, is reportedly lower than with older hydrophilic models that had a sharp optic edge design except at the optic–haptic junction [115].

Studies [113, 116] have compared PCO between older hydrophilic IOL models and single-piece hydrophobic acrylic IOLs, with the results favoring the latter. Because IOL characteristics play a crucial role in preventing PCO, it is important to assess PCO formation after implantation of these IOLs. This would help clinicians and researchers understand the impact of IOL material and design on the development of PCO.

Several studies report low PCO rates with square-edged IOLs and increased PCO with hydrophilic IOLs [117, 118]. However, both IOL material and design are important factors in the development of PCO.

The mechanism of action is hypothetically caused by a mechanical barrier effect of a sharp optic edge [106], by contact inhibition of the migrating LECs at the capsular bend by the square edge [107], and/or by the high pressure exerted by IOLs with a square-edged optic profile on the posterior capsule bend [108]. Based on these findings, various IOLs with often only minor differences in material and design were launched. With the introduction of 1-piece (monobloc)

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IOL designs, which are easier to implant and to manufacture, there was concern about a loss of the barrier effect to the migration of LECs in the region of the optic–haptic junction. The broad-based bulky haptics of 1-piece IOLs extending from the optic rim inherently interfere with capsular bag fusion, thus bending the posterior capsule. However, comparing 1- and 3-piece Acrysof IOLs, no statistically significant difference in PCO was found in the long run [103]. A study comparing two models of 1-piece hydrophilic acrylic IOLs showed significantly less PCO in the eyes with an IOL with a square edge across the optic–haptic junction than matched eyes with an IOL without a square edge at the junction 1 year after surgery [117]. For the most part, a square posterior optic edge has been considered the major factor in the prevention of PCO formation. Hydrophobic acrylic IOLs are not manufactured from the same materials or by using the same processes. Therefore, the polymers used differ in their chemical structure, water content, and refractive indices. Material differences are also reflected by the tendency toward glistening formation. Microvacuoles within the IOL material can occur when the IOL is in an aqueous environment and water fills microscopic openings in the material. Typical with acrylic IOLs, glistenings appear as white sparkling areas over the entire IOL optic, which may impair the optical quality. The higher density of the acrylic polymer network may prevent the formation of microvacuoles and provide better visual outcomes. Several studies conclude that hydrophobic IOLs are better than hydrophilic IOLs in preventing PCO [113, 116, 117].However, most comparisons have been between hydrophilic IOLs with round edges and hydrophobic IOLs with sharp edges.Regarding IOL design, the theory that an IOL with a sharp posterior optic edge prevents PCO has gained acceptance. There are two theories of how a sharp-edged optic inhibits PCO formation [103-105]. One is the compression theory, which suggests that contact pressure between the posterior capsule and the IOL optic edge mechanically prevents cell migration[103]. The other is that a sharp optic edge induces the formation of a sharp capsular bend, which creates contact inhibition between migrating lens epithelial cells (LECs) [104, 105]. Experimental and clinical studies suggest that the sharper the capsular bend, the greater the preventive effect [106]. Analysis of the microstructure of the optic edge of currently available square-edged hydrophilic and hydrophobic acrylic IOLs showed a large variation in the deviation from a perfect square, not only between IOL designs but also between different powers of the same IOL design.

The optic–haptic junction is another important factor in preventing PCO. In one study [105], eyes with an IOL with a continuous 360-degree square edge had significantly less PCO than eyes with an IOL with a square edge that was interrupted at the optic–haptic junction. Accordingly, it is hard to say which IOL has a proper design in terms of preventing PCO. It would be ideal for clinical PCO comparison studies to evaluate IOLs with the same material or design, although this would be difficult using currently available IOLs.

There are few studies comparing hydrophilic IOLs with a sharp edge and hydrophobic IOLs with a sharp edge [109, 113, 116]. In a study with a 2-year follow-up, Kugelberg et al. [109] found that patients with the Acrysof SA60AT hydrophobic acrylic IOL had less PCO than patients with the BL27 hydrophilic acrylic IOL (Bausch & Lomb). Others found no significant differences in the PCO and Nd:YAG rates between the hydrophobic group and hydrophilic group 3 years after surgery [113, 116].

Animal [119] and clinical [108] studies show that IOL design, rather than IOL material, is the critical factor in minimizing LEC migration across the posterior capsule after IOL implantation. The continuous-edge IOL has two design characteristics that may have led to the significant decrease in PCO, and that is a 360-degree continuous square optic edge, and greater space between the optic and haptic at the optic–haptic junction to encourage apposition of the anterior capsule and posterior capsule. A continuous square edge around the optic and angled haptics allows close apposition of the IOL optic to the posterior capsule, which Nishi et al. [120] found inhibits LEC migration. A rabbit model study [121] found that the addition of a square edge across the optic–haptic junction decreased LEC migration behind the IOL optic over migration with an IOL of the same type but without a square edge at the optic–haptic junction.

In the treatment of PCO, neodymium: yttrium-aluminum-garnet (ND:YAG) laser is used to cut the clouded posterior capsule allowing light to transmit normally [122]. It can produce complications such as ocular inflammation, an increase in intraocular pressure, IOL damage, cystoid macular edema, and retinal detachment.

9. Pseudophakic dysphotopsia

One of the most common causes of patient dissatisfaction after uneventful cataract surgery is a pseudophakic dysphotopsia [123, 124]. It represents a set of subjective optical complaints following intraocular lens implantation and is categorized as positive and negative dysphotopsia. Positive dysphotopsia are bright artifacts on the retina that represent undesired optical images described by the patients as halos, arcs, light rings, flashes, and streaks. The phenomenon called negative dysphotopsia manifests as a temporal dark crescent-shaped shadow, similar to scotoma, and represents the absence of light reaching certain portions of the retina after in the-bag posterior chamber IOL implantation [125]. It has been first described almost 15 years ago, by Davison [126] and since then it is a matter of discussion in many scientific papers. The cause of this phenomena has been widely discussed in the literature and many explanations have been proposed such as optics with a sharp or truncated edge [124, 126, 127], IOL materials with high index of refraction [126-130], anatomical predispositions of the eye such as prominent globe [131], shallow orbit [131], anterior surface of the IOL more then 0.46 mm from the plane of posterior iris [131], brown iris [132], temporally located clear cornea incisions [132], a negative afterimage [133], neuroadaptation [133], and reflection of the anterior capsulotomy edge projected onto the nasal peripheral retina [134]. Negative dysphotopsia is more poorly tolerated than positive and could lead to IOL explantation [131, 135, 136]. Certain clinical manifestations have been recognized and nicely summarized by Masket and Fram [134].

Still, there has not been much theoretical exploration in the past to explain in detail and to validate all possible explanations of the negative dysphotopsia phenomenon. In the recent study, designed to evaluate negative dysphotopsia, Holladay et al. [125] used ray tracing simulation, using the Zemax optical design program and described "type 3 shadow-penumbra" as the optical mechanism that has been referred to as negative dysphotopsia and believe that it explains all 10 clinical manifestations enumerated by Masket and Fram [134].They concluded that primary optical factors for negative dyshotopsia are small pupil, a distance behind the pupil of ≥0.06 mm and ≤ 1.23 mm for acrylic (≥ 0.06 mm and ≤ 0.62 mm for silicone), a sharp-edged design (corner edge radii ≤ 0.05 mm) and functional nasal retina that extends anterior to the location of the shadow. The final parameter that determines whether the shadow is visible is the location of the anterior extent of the functional nasal retina. Secondary factors include the high index of refraction optic material, the patient's angle α, nasal location of the pupil relative to the optical axis, and transparent versus translucent status of the peripheral nasal capsule [125].

Holladay et al. showed that a sharp or truncated optic edge was the most significant factor in positive dysphotopsia[124].Advances in lens edge design have minimized such problems, but still a significant number of patients report of different photic phenomena [123, 124, 127, 137]. Square-edge IOL design appears to be the primary cause of reflected nighttime glare [124]. Radford et al. reported on overall incidence of 20.7% in the Akreos group and 21.3% in the SN60-AT group [127]. Also, a study of patient-reported glare symptoms found fewer symptoms with Akreos IOLs than with other acrylic lenses [138]. Osher reported the incidence of negative dysphotopsia 15.2% on the first postoperative day, decreasing to 3.2% after 1 year, then 2.4% after 2 and 3 years. Kinard et al. reported on 40% of study patients complaining about central flashes 1 year postoperatively, and 3% rating it with the highest score. They found that some of the patients originally thought to be a complete success had dissatisfaction from dysphotopsia but silently put up with it [139]. The mechanism of neuroadaptation is still the least understood of all factors involved in the process of pseudophakic dysphotopsia. As Jin et al. disscussed, there are patients who have 2-mm IOL dislocation who should have debilitating dysphotopsia and yet adapt very nicely. On the other hand, some have perfectly centred IOL with excellent vision, good coverage of the IOL edge by the anterior capsule, and still report severe symptoms of dysphotopsia long after surgery [137]. Holladay said that neural adaptation can mitigate and reduce symptoms but not eliminate them, just as halos with multifocal IOLs diminish with time but never disappear [140]. The positive symptoms seem to diminish with time, or the patients get more used to them. Regarding the IOL features that could contribute to dysphotopsia, hydrophobic acrylic lenses with higher refractive index have a greater risk of dysphotopsia [126-130]. On the other hand, hydrophilic acrylic intraocular lenses with lower refractive index could be superior in that matter due to less affinity toward dysphotopsia [126-130]. Bournas et al. showed that the lens optic diameter is negatively associated with the risk of dysphotopsia [141]. It is believed that with 6.0 mm, 6.5 mm, and 7.0 mm intraocular lenses are less likely to experience the photic phenomena because the edge line of the IOL is out of view [142, 143]. On the other hand, Arnold concluded that the optic size of the IOL does not correlate with any forms of dysphotopsia [144]. Four surgical methods were used to treat negative dysphotopsia: secondary piggyback IOL implantation, reverse optic capture, in-the-bag exchange, and iris suture fixation [131, 134, 136, 145]. Holladay explained that exchanging the posterior chamber IOL for an anterior chamber IOL or using a fully (not partially) rounded-edge IOL are the only two treatments that are sure to eliminate negative dysphotopsia. Exchanges for a silicone material, secondary piggyback IOLs, and reverse optic capture usually will improve the symptoms but cannot guarantee elimination of negative dysphotopsia [140]. Folden recently presented a Neodymium:Yag laser anterior capsulectomy as a surgical option in the management of negative dysphotopsia [146]. Osher believed that short term, transient symptoms of negative dysphotopsia were incision related, mostly at patients with clear temporal incision, were the cornea is not covered by the eyelid. He hypothesized that corneal edema-associated beveled temporal incision was related to the transient symptoms of dysphotopsia [132]. On the other hand, Cooke described a case where negative dysphotopsia resolved after IOL exchange with clear temporal incision, after prior surgery with scleral tunnel incision at 10.30 o'clock position, entirely covered by the upper lid [147]. Radford et al. stated that although 22% of patients who had a clear temporal incision and 66% of patients who had a superior scleral incision reported symptoms of dysphotopsia at 1 week, the difference between groups was not statistically significant. At 8 weeks 16% of patients with a clear temporal incision and 42% of patients with superior scleral incision reported symptoms of dysphotopsia, however the difference was not statistically significant again [127]. Also, additional studies comparing temporal clear corneal incisions with nasal [128] and superior [131] found no difference in the incidence of negative dysphotopsia. Although a significant number of patients report photic phenomena, it seems to resolve over time in the majority of cases [141, 144, 148]. They resolve by capsule opacification due to fibrosis, cortical adaptation, or a patients final compromise with the problem [149]. It is important to consider the amount of time between the surgery and telephone contact date because as time goes by, anterior capsule opacification (ACO) may shield the optic edge from light, protecting the patient from edge effects [150]. Holladay et al. agree with Hong et al.[151] that the spontaneous resolution or transient nature of negative dysphotopsia is a result of opacification (translucency/diffusivity) of the peripheral capsule. They stated that the opacification of the nasal capsule is the explanation for 12.8% of negative dysphotopsia that spontaneously resolved by 2 or 3 years of the original 15.2% in Osher's study [125], mentioned earlier.

10. Femtosecond Laser Assisted Cataract Surgery (FLACS)

Since premium intraocular lenses (IOLs) are getting more used for the achievement of the best refractive outcome, methods to increase accuracy and precision in cataract surgery are being investigated [152-154]. Femtosecond Laser assisted cataract surgery is one of the solutions with its ability to perform anterior capsulotomy, lens fragmentation, and to create self-sealing corneal incisions [155, 156]. The femtosecond laser (FSL) emits coherent optical pulses with a wavelength of 800 nm and duration on the order of 10^{-15} seconds. Due to its ability to alter delicate tissue in a precise and predictable way, it is used extensively in ophthalmology. Also, one of the major advantages is that it can cut tissue with almost no heat development. Today, there are many ongoing clinical studies utilizing the femtosecond lasers to perform several steps in cataract surgery such as incisions, capsulorhexis, and disassembly of the lens.

The femtosecond laser allows precision crafting of the lengths, angles, lanes, and shapes of clear corneal incisions to levels of consistency exceeding any manual technique [32]. Although

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FLACS can be a promising surgical modality, there are questions of its widespread utility and accessibility [157]. The laser system such as LenSx (Alcon, Fort Worth, TX) produces a kHz pulse train of femtosecond pulses. In order to view the patients eye and to localize specific targets, an optical coherence tomography (OCT) imaging device and a video camera microscope are used. It is generally used for the creation of single plane and multi-plane incisions in the cornea, anterior capsulotomy and phacofragmentation. A beam of low energy pulses of infrared light is focused by the laser into the eye, leading to a micro-volume photodisruption of a tissue. After scanning the beam, numerous micro-disruptions are created in order to form an anterior capsulotomy incision as well as lens fragmentation incision, which are programmed depending on the location, shape, and size. [157-159]. Femtosecond laser assisted cataract surgery showed a lot of advantages in comparison to conventional cataract surgery. Some of them are less induced coma and astigmatism, manipulation, and phacoemulsification time [160]. A lot of arguments can be found in the literature regarding the increased risk of postoperative endophthalmitis following manually created clear corneal incision [161, 162]. In that matter, femtosecond laser assisted cataract surgery could be superior for it may allow for more square architecture, which has proven more resistant to leakage, added stability, and reproducibility at various intraocular pressures (IOPs) [163-165]. Femtosecond lasers also provide more accurate, safe, and adjustable cuts for limbal relaxing incisions, as well as predictable capsulorhexis [166]. Capsulorhexis performed with femtosecond laser has a higher degree of circularity, less risk for incomplete capsulorhexis-IOL overlap, better IOL centration [167, 168], and greater strength [168, 169]. It has been shown that the unpredictable diameter observed in manual capsulorhexis can have effects on IOL centration, with subsequent poor refractive outcomes, unpredictable anterior chamber depths, and increased rates of posterior capsular opacification [170-172].Some studies provided evidence of easier phacoemulsification performed with femtosecond laser [165, 173], reduced ultrasound energy for all grades of cataract [173, 174], and even more predictable IOL power calculations with laser assisted cataract surgery [175]. Taking into account that ultrasound phacoemulsification could damage the corneal tissue [176, 177], femtosecond laser assisted cataract surgery promises improved safety and lesser complications in that way also. On the other hand, patients with dementia, tremor, or with deep set orbits might not be good candidates for FLACS, as well as patients with poor dilated pupil, posterior synechiae, iris floppy syndrome, small eyelid fissure, and ocular motor paralysis [157].

Long-term clinical studies of the outcomes of the femtosecond laser assisted cataract surgery will provide evidence for the confirmation of its superiority over phacoemulsification.

11. Conclusion

The procedure of phacoemulsification revolutionized cataract surgery, especially since the introduction of sutureless clear corneal cataract incisions, which has led to reduced surgical time, lower induced astigmatism, faster postoperative and visual recovery, and less complications. Advances in technology and knowledge from the fields of optics and biomaterials have led to the development of minimally invasive procedures, as well as numerous various premium intraocular lenses that are designed to enable the best refractive outcomes with one goal: restoration of vision for distance and near and spectacles independence. The development of acrylic materials with a higher index of refraction and square edge designed intraocular lenses in order to prevent posterior capsular opacification led to patients having portions of their retina exposed to reflected light from the optic edge ending with dysphotopsia on the other hand. To achieve the best possible postoperative result, careful selection of patients, individual approach, and patient's education is mandatory.

In order to increase accuracy and precision in cataract surgery, together with patient demands for additional safety, femtosecond laser assisted cataract surgery is offered and being investigated as one of the possible solutions. As it appears safe and with many benefits in providing the best possible outcomes for cataract surgery, it stays on long-term clinical studies to provide evidence for the confirmation of its superiority over phacoemulsification.

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