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Difficulties in Cataract Surgery

Edited by Artashes Zilfyan

DIFFICULTIES IN CATARACT SURGERY

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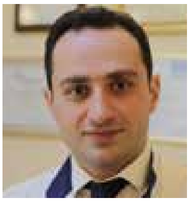
Meet the editor



Professor Artashes Zilfyan, MBA, PhD, is a chief ophthalmologist of Yerevan City. He is the founder and president of Association of Young Ophthalmologists in Armenia. He is the director of Eye Laser Center at MC "Shengavit." He is also a professor of Ophthalmology. His areas of specialization are minimally invasive cataract surgery—microcoaxial phacoemulsification—glaucoma nonpenetrating and penetrating surgery, using drains and shunts; treatment of keratoconus by crosslinking, keraring, and keratoplasty; and treatment of myopia, hyperopia, and astigmatism using Excimer laser Femto-LASIK.

He is the author of more than 75 publications and more than 45 scientific articles in international conferences and journals (mainly in ophthalmology on the subject ACAID syndrome of immune deviation of the eye for complicated and senile cataracts). He is the author and inventor of a new method of keratoconus diagnosis MMP9 as a main factor.

Contents

Preface

For thousands of years, cataract surgery continues to be the “pearl” of ophthalmic surgery. It is explained by the fact that cataract removal always leads to an increase in visual acuity of patients. A new technology of cataract removal, phacoemulsification, was introduced by Charles Kelman in 1967. Despite this, it was difficult for the surgeons to transform from extracapsular cataract extraction to the new method—phacoemulsification. At that time, there was a definite increase in the cost of surgery, which undoubtedly scared off both the doctor and the patient. At the same time, according to statistics, young surgeons achieved better results in phacoemulsification. This is assimilated by the fact that phacoemulsification is directly related to mastering and using the latest electronic equipment, as well as knowledge of a foreign language. Despite the difficulties presented during that time such as the absence of viscoelastics, capsulorhexis, hydrodelineation and hydrodissection, and corneal tunnel incisions, phacoemulsification became the main technique of cataract surgery. At the same time, mastering phacoemulsification is quite a difficult technology for the beginners. For example, when I performed my first phacoemulsification while working as the chief ophthalmologist of the Armenian army hospital, the surgery went very well without any complications. And by this time, I had only one fellowship WetLab. I thought that from the next day, I will no longer perform extracapsular cataract extraction. However, from the second day, I had complications of different types. Of course, I had to rethink my opinion and go through further trainings. It became clear that in the course of phacoemulsification, an ophthalmic surgeon may encounter numerous difficulties such as a dense brown +5 nucleus by Buratto classification, a narrow small pupil, a subluxation of the lens, a pseudoexfoliative syndrome, astigmatism, and much more.

Recently, in the ophthalmological practice, the method of femtolaser cataract surgery (FLACS) has been introduced. This method allows you to automatically perform the basic stages of cataract surgery—corneal incisions, capsulorhexis, nucleus fracture. At the same time, to apply the various techniques of cataract surgery, the surgeon must possess virtually all the necessary techniques. This is dictated by the fact that, as a rule, cataract itself is rarely isolated—senile. Nowadays, we meet many cases with complicated cataracts on the background of diabetes mellitus, hypertension, pseudoexfoliation syndrome, glaucoma, etc. All of the above conditions undoubtedly damage the hemato-ophthalmic barrier leading to disorders of the anterior chamber-associated immune deviation (ACAID) system, which very often leads to postoperative inflammatory complications. Knowledge of the basic rules of cataract surgery, the use of pupillary rings and iris retractors in narrow pupils, the use of capsular rings in subluxations of the lens, the use of special modes of phaco in severe late cataracts, and a comprehensive clinical way of thinking can undoubtedly reduce the complications of cataract surgery.

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Section 1

Cataract Surgery Complications

Chapter 1

Cataract Surgery in Patients with Uveitis: Preoperative and Surgical Considerations

Alejandro Rodriguez-Garcia and C. Stephen Foster

Additional information is available at the end of the chapter

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Abstract

Cataract is one of the most frequent visual impairment complications of uveitis, accounting for up to 40% of the visual loss seen in these patients. In general, uveitis patients differ from the general cataract population in that they are younger and have a higher rate of comorbidities, however the rates of inflammatory sequelae vary markedly among uveitic entities. Cataract development may be influenced by the cause and duration of uveitis, the degree of inflammation control, and the use of corticosteroid therapy. Cataract surgery in patients with uveitis represents a serious challenge due to pre-existing ocular comorbidities that may limit the visual outcome and difficult the surgical procedure; the need for preoperative control of inflammation; and the efficacy of postoperative management to avoid immediate and late ocular complications. A detailed ophthalmologic exam prior to surgery is essential to know the status of pre-existing pathologic changes, adjust the medical therapy to achieve absolute control of inflammation, establish a surgical plan, and deliver an objective visual prognosis to the patient or the relatives. The key point to surgical success is the absolute control of inflammation, meaning no cells in the anterior chamber for at least 3 months prior to surgery. Today, minimally invasive phacoemulsification with acrylic foldable intraocular lens implantation is the standard of care for most patients with uveitis. It must be taken into consideration that higher rates of intraoperative and postoperative complications may occur. Vision-limiting pathology related to pre-existing uveitis complications are the major contributing factors for limited postoperative visual outcome.

Keywords: uveitis, cataract, phacoemulsification, intraocular lens, steroids, macular edema, glaucoma

1. Introduction

Cataract represents a significant burden in the management and visual outcome of uveitis patients. Up to 40% of the visual loss seen in these patients is either solely or largely due to cataract [1]. Lens opacification is caused by repeated episodes or sustained intraocular inflammation characterized by the release of free oxygen radicals, lysosomal enzymes, immune complex deposition on the lens capsule, hypoxia, and altered composition of the aqueous humor [2]. The development of cataract depends on the type of uveitis, the degree and duration of the inflammatory process, and on the prolonged and excessive use of corticosteroids [3–5].

Cataract surgery in patients with uveitis represents a serious challenge for the anterior segment surgeon [6, 7]. Nowadays, clear cornea phacoemulsification with intraocular lens (IOL) implantation is the standard of care for most patients with uveitis [8, 9]. However, despite remarkable progress on surgical techniques and IOL materials, certain specific considerations should be taken into account regarding patient selection, preoperative preparation, as well as perioperative and postoperative management for successful long-term results [10, 11]. Nearly one-third of all uveitic eyes have small pupils, which represent a surgical technical difficulty [2]. In such cases, higher rates of additional intraoperative maneuvers are required to obtain proper visualization and phacoemulsification of the cataract [4, 12, 13]. And, while surgery is associated with an improvement in best corrected visual acuity (BCVA), higher rates of both, intraoperative and postoperative complications have been reported [14, 15]. Moreover, it has been shown that the final BCVA in uveitic eyes is worse than in non-uveitic ones [14]. Therefore, identifying the cause of uveitis and pre-existing pathologic changes that affect the visual outcome, achieving absolute control of inflammation before surgery, careful surgical planning, and solving intraoperative and postoperative complications are crucial to obtain a successful result (BCVA ≥ 20/40).

2. Epidemiology

Cataract is the most common ocular complication in children with chronic uveitis with an estimated rate from 35 to 52.0% [16]. In juvenile idiopathic arthritis (JIA)-associated uveitis, the prevalence varies from 40 to 60% and the incidence of new-onset cataract formation has been estimated as 0.04/eye-year [17, 18]. On the other hand, in adult patients it is one of the most frequent complications of uveitis with a prevalence rate as high as 50% as seen in Fuchs uveitis [6, 14, 19, 20]. In HLA-B27-associated anterior uveitis, the most common cause of uveitis in adults, cataract formation is the third most frequent complication with an estimated prevalence of 14%, and an incidence rate of 0.091 during follow-up time (**Table 1**) [21]. Cataract prevalence varies among different causes of uveitis and depends on multiple factors including etiology, localization of the inflammatory process, time elapsed between the onset and diagnosis of uveitis, the degree of inflammation, the clinical course, and the use of corticosteroids [1, 18, 22, 23].

Cause of uveitis	Cataract prevalence range (median)	Successful outcome BCVA ≥ 20/40 (Snellen)	Frequent complications	References
Fuchs uveitis	15–75% (50%)	83%	Intraoperative AC hemorrhage (3.6–76%) Hyphema Ocular hypertension (glaucoma) (3–35%) PCO (14.6%) Progressive vitreous opacification	[20, 27, 48, 49]
Herpetic uveitis	15–75% (24%)	72.2%	Viral reactivation Iris posterior synechiae Secondary glaucoma	[63, 151–153]
Juvenile idiopathic arthritis-associated uveitis	40–60% (50%)	60–70% (67%)	Exuberant postoperative inflammation Iris posterior synechiae Secondary glaucoma (25%) CME Cyclitic membrane Hypotony (Phthisis bulbi)	[4, 17, 18, 25, 26, 81, 95, 97–99, 101, 110]
HLA-B27 associated uveitis	9.2–20.1%	NA	Recurrent uveitis CME Iris synechiae	[21]
Pars planitis	36–42% (40%)	50–83%	Persistent vitritis (haze) CME (50%) Glaucoma (10%) PCO (10%) IOL Cocooning (29%) ERM Optic nerve atrophy	[23, 28, 140, 154]
Adamantiades-Behcet disease	21–26% (38.5%)	72.5% (42.4%)	Exuberant inflammation (12.5%) Iris posterior synechiae (17.5%) CME (12.5%) ERM (7.5%) Papillitis (optic nerve atrophy) (5%) PCO (37.5% most common)	[148, 155, 156]
Vogt-Koyanagi-Harada disease	10–35%	68%	Exuberant inflammation Iris anterior and posterior synechiae Pupillary membrane PCO (76%) Macular scarring	[135, 157]

Cause of uveitis	Cataract prevalence range (median)	Successful outcome BCVA ≥ 20/40 (Snellen)	Frequent complications	References
Sympathetic ophthalmia	31.8%	67.79% (72.2%)	PCO (77.7%) Glaucoma	[158]
Sarcoidosis	21%	61%	PCO (57.1%) Recurrent uveitis CME Glaucoma	[159]

AC = anterior chamber; PCO = posterior capsule opacification; CME = cystoid macular edema; ERM = epiretinal membrane.

Table 1. Prevalence, visual outcome, and complications of cataract surgery in uveitis.

3. Clinical characteristics of diverse forms of uveitis

In general, the uveitic population differs from the general population suffering from cataract in that they are younger and have a higher rate of comorbidities [15]. However, the rates of inflammatory sequelae vary markedly among uveitic entities [7, 24]. For this reason, each uveitis syndrome must be analyzed separately with respect to ocular complications and visual outcome [6, 14] (**Table 1**). While Fuchs uveitis regularly has the best visual prognosis and the least postoperative complications, JIA-associated uveitis has one of the most fear prognosis due to frequent pre-existing pathology, difficulties in reaching absolute control of inflammation, and multiple intraoperative and postoperative complications [4, 25–27].

4. Preoperative evaluation

A correct classification and etiologic diagnosis of the uveitic entity is very helpful to establish the appropriate surgical strategy and to determine the prognosis [8]. Moreover, a complete preoperative ophthalmologic examination is essential since pre-existing pathology will have significant therapeutic and prognostic visual implications [16, 28]. For instance, corneal opacity, vitreous haze, macular edema, and optic nerve atrophy usually result in a poor visual outcome [6, 19]. Therefore, it is very important that the patient and/or their relatives have an objective report on the status of the eye to be operated in order to have a realistic expectation of the final visual result. Ancillary diagnostic tests are always necessary to detect pre-existing pathologic changes that will allow us to render a more accurate visual prognosis. In most cases, it is helpful to perform a macular function test. Several methods are available for this purpose including the potential acuity meter (PAM), the laser interferometer (LI), and the focal electroretinogram (fERG) [29, 30]. The PAM test has proven an accuracy of 84% in patients with poor visual acuity (<20/40) [30]. On the other hand, LI has shown a lower accuracy (65%) and a tendency for over-predicting vision compared to the PAM in these patients [29, 30]. Focal cone ERG is very sensitive for detecting macular pathology, showing 91% accuracy in eyes with poor visual acuity [30].

Linear A-B ultrasound is necessary to identify vitreous hemorrhage and opacity, as well as posterior segment changes like, retinal detachment, optic nerve swelling, and sclerochoroidal thickness [31]. Another very useful device is high-frequency ultrabiomicroscopy (UBM), which generates high-resolution images at an almost histological level. *In vivo* image sections may be obtained up to 3–6 mm in depth, permitting visualization of anterior segment structures [32]. Frequent indications for UBM in uveitis include uveitis-glaucoma-hyphema syndrome (UGH), sclerouveitis, herpetic anterior uveitis, pars planitis, pseudophakic uveitis, hypotony, peripheral toxocariasis, and ciliary body pathology [32, 33].

Retina fluorescein angiography (FA) allows the detection of many different forms of posterior segment inflammatory changes. It is used to evaluate the activity and extent of chorioretinitis and optic nerve involvement; identify macular edema and choroidal neovascularization; diagnose certain posterior uveitic entities with typical features; evaluate retinal vascular involvement and neovascularization; and to monitor the therapeutic response [34]. However, many inflammatory changes occur in the peripheral retina where visualization may be difficult with conventional angiography. Wide field scanning laser ophthalmoscopy performs ultra-wide angle FA allowing clear identification of peripheral lesions and accurate documentation of disease progression [35]. This recently new image technology has replaced conventional angiography for the diagnosis and monitoring of intermediate and many forms of posterior uveitis [35].

Indocyanine green angiography (ICGA) allows the detection of choroidal inflammation. Two patterns of choroidal vasculitis have been described: primary inflammatory choriocapillaropathy and stromal inflammatory vasculopathy [36]. The first pattern is characterized by non-perfusion of the choriocapillaris found in entities like, multiple evanescent white dot syndrome, acute posterior multifocal placoid pigment epitheliopathy, multifocal choroiditis, and serpiginous choroidopathy [36]. The choroidal stromal inflammatory vasculopathy pattern is seen in active Vogt-Koyanagi-Harada disease (VKH), ocular sarcoidosis, tuberculosis, and birdshot chorioretinopathy [37]. In Behcet's disease, as in other forms of uveitis, both ICGA vascular patterns may be seen at different stages of inflammation [38].

Today, the most frequently used imaging technique to detect and monitor macular inflammatory changes is optical coherence tomography (OCT). With an axial resolution in the 5–7 μm range, it provides close to an *in-vivo* histologic view of the retina [39]. There are several types of OCT available for clinical purposes. The spectral-domain OCT is the most used method [40]. It allows high-speed, accurate images of the retina, particularly macular pathology like, cystoid and diffuse macular edema, subretinal fluid accumulation, epiretinal membrane formation, macular holes, and choroidal neovascularization [41]. Longer wavelength OCT systems, including the swept-source technology and en-face imaging, enhance the detection of subtle microstructural changes in chorioretinal disorders by improving imaging of the choroid [42–44]. A technique that produces high-resolution cross-sectional images of the entire choroid called enhanced depth imaging technique (EDI-OCT) has identified increased subfoveal choroidal thickness in patients with active Behcet [45] and VKH disease, as well as loss of focal hyperreflectivity of the inner choroid in the acute and convalescent phases of VKH [46].

Once the preoperative evaluation is completed, a postoperative visual prognosis may be assumed, therapeutic adjustments may be applied, and a surgical plan is prepared based on pre-existing pathologic findings.

5. Preoperative preparation and therapeutic strategies

The key to surgical success in patients with uveitic cataract is the absolute control of inflammation, meaning no cells in the anterior chamber for at least 3 months prior to surgery [7]. This requisite is crucial to obtain an optimal surgical result and to minimize postoperative complications [7, 24]. Active uveitis at the time of cataract surgery has been associated with worse visual outcomes [15, 47]. Moreover, postoperative cystoid macular edema (CME) is more likely to develop in eyes with active inflammation within a 3-month period before surgery (relative risk 6.19) than those under control [41]. However, this general consensus of no cells in the anterior chamber prior to surgery has its exemptions [2]. In Fuchs uveitis, minimal but persistent anterior chamber cells and flare are frequently found despite intensive and sustained treatment with topical corticosteroids [48]. Hence, anti-inflammatory treatment is not indicated for the low-grade anterior chamber reaction seen in Fuchs uveitis and only occasionally, a short-course of corticosteroids is indicated for symptomatic exacerbations [49]. Other exemptions are related to the necessity for prompt surgical intervention in cases like, lens-induced uveitis, cyclitic membrane formation with hypotony, persistent vitreous opacity or hemorrhage, and retinal detachment [50, 51].

Preoperative management depends specifically on the type and etiology of uveitis. For inactive idiopathic anterior non-granulomatous uveitis as for Fuchs uveitis, topical administration of prednisolone acetate 1% four times a day, starting 3–7 days before surgery may be sufficient to avoid an outburst of postoperative inflammation [24]. On the contrary, patients with JIA-associated uveitis, anterior granulomatous uveitis, intermediate, posterior, and panuveitis also require oral prednisone (1.0 mg/kg/day) starting 3 days before surgery and continued for a week after cataract removal and then tapered slowly according to the inflammatory status [52, 53]. Preoperative oral steroids have been shown to be effective in reducing the risk of CME [41]. If patients are on immunosuppressive chemotherapy and/or biologics, they should be continued at current dosage [11]. In case that systemic corticosteroids are contraindicated (e.g., diabetes mellitus, metabolic disease, acid-peptic disease, obesity, or osteoporosis), periocular administration (transseptal or sub-Tenon's) of triamcinolone acetonide (40 mg/ml) should be considered [54, 55]. Alternative immunosuppressive agents like, cyclosporin-A, tacrolimus, or anti-metabolites may be administered to these patients considering that most of these medications require a longer period of time (usually 4–6 weeks) to reach an optimal therapeutic effect [56].

The use of topical non-steroidal anti-inflammatory drugs (NSAIDs) like, ketorolac 0.4%, nepafenac 0.15%, or bromfenac 0.09%, have become a standard of care practice for the perioperative management of inflammation, pain, surgical-induced miosis, and cystoid macular edema in uneventful and also in uveitic cataract surgery [57–59]. A systematic review found high-quality evidence that topical NSAIDs are more effective than topical steroids in preventing the short-term pseudophakic CME in non-uveitic cataract surgery [60]. On the other hand, a recent evidence-based review conducted by the American Academy of Ophthalmology found that the claimed made about the synergistic effect of combined topical steroids and NSAIDs remains unproven [61]. In addition, NSAIDs have only a short-term therapeutic effect on prompt visual recovery and reduction of established CME, but no effect on the long-term visual outcome [57, 58, 61]. There is good collective clinical evidence and rationale that the application of a topical NSAID 3 days before surgery reduces CME and improves vision in the short-term [61]. Because the COX-2 enzyme is inducible and mostly responsible for the inflammatory process, the selective inhibitory effect of nepafenac and bromfenac makes them more suitable for this purpose [62]. Nepafenac has shown the shortest time to reach maximal concentration and the greatest aqueous humor peak concentration compared to ketorolac and bromfenac in eyes having cataract surgery [62]. After the surgical procedure, topical NSAIDs use is usually extended for 4–6 weeks [1, 10].

There are other special conditions in uveitis in which certain specific actions should be taken before cataract extraction is performed. Such is the case of herpetic uveitis in which prophylactic anti-viral therapy with acyclovir or valacyclovir should be administered at least 1 week before surgery in order to avoid recurrent viral infection [63, 64]. Other special consideration is the preoperative management of prominent band keratopathy interfering with cataract visualization which may be treated with EDTA 1–2% calcium chelation, or Excimer laser PTK before cataract surgery [65, 66].

Cataract and glaucoma frequently coexist as uveitis complications, and a combined surgical procedure may be associated with an increased risk of glaucoma surgery failure [67, 68]. In such cases, it may result better to perform a clear cornea small-incision cataract extraction first, followed later on by filtration surgery or a valve implantation with anti-metabolites [69, 70]. One must consider that uveitic glaucoma eyes operated for trabeculectomy with mitomycin-C which had previous cataract surgery or granulomatous uveitis, have a higher risk of surgical failure (RR = 2.957, P = 0.0344, and RR = 3.805, P = 0.0106, respectively) [71]. A higher risk of glaucoma surgical failure has also been associated with idiopathic, intermediate, and Fuchs uveitis; active intraocular inflammation at the time of surgery; and relapse of uveitis [72]. Moreover, the success rate of filtration surgery in uveitic eyes is significantly lower than that of non-uveitic, and many patients with successful intraocular pressure (IOP) control still require anti-glaucoma therapy to maintain adequate IOP levels in the postoperative period [72].

Posterior vitrectomy and cataract extraction may be an alternative for patients with prominent posterior segment pathology including vitreous opacity, hemorrhage, cystoid macular edema, and tractional retinal detachment [73]. There is reasonable evidence that cataract phacoemulsification combined with posterior vitrectomy has a favorable visual outcome for some patients with refractory inflammation, particularly those with significant vitreous opacity and chronic macular edema [13, 74]. In children, this combined surgical approach has been used for JIA-associated uveitis, pars planitis, and other forms of posterior uveitis [75].

However, this technique is not exempt of serious postoperative complications like, glaucoma, macular edema, and exuberant inflammation [75, 76]. For specific cases with various ocular complications, multiple combined surgical strategies have been postulated including phacoemulsification with IOL implantation, posterior vitrectomy, intravitreal sustained-release corticosteroid injection, and glaucoma tube implantation with promising results [77].

6. Surgical technique and intraoperative maneuvers

Nowadays, small clear corneal incision phacoemulsification surgery is preferred over extracapsular cataract extraction (ECCE) and lensectomy for most patients with uveitis [78, 79]. Since cataract surgery in these patients is frequently complicated by corneal opacification, iris synechiae, pupillary and cyclitic membranes, among others, the surgical technique should be minimally invasive with precise and delicate maneuvers [10, 24] (**Figure 1**). Most studies report a higher rate of additional maneuvers, notably iris and pupillary manipulation within a range between 19 and 67% of eyes [4–6, 25].

Dealing with unexpected intraoperative complications like, corneal stromal edema; anterior chamber hemorrhage; pigment dispersion; posterior capsule rupture with vitreous exposure is key to achieve the best surgical outcome possible [6, 19, 75]. The first challenge that the surgeon faces is an adequate exposure and visualization of the cataract. Iris synechiolysis, pupillary membrane removal, and pupil distension with iris hooks or iris stretch devices are frequently required for proper cataract visualization [80, 81]. There is no general consensus on what is the best way to deal with the pathologic changes of the anterior segment encountered in uveitic eyes. However, it is generally agreed that

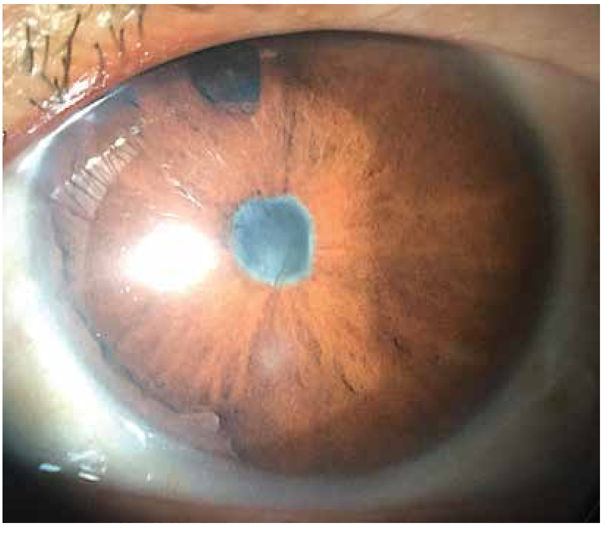

Figure 1. Anterior segment appearance of a patient with Vogt-Koyanagi-Harada disease showing extensive peripheral anterior and posterior synechiae, shallow anterior chamber and a pupillary membrane in front of a secondary cataract.

attempts should be made to minimize surgical maneuvers in order to lessen tissue manipulation and trauma as possible [6, 24, 26].

The capsulorhexis should measure between 5 and 6 mm in diameter because smaller apertures are frequently associated with capsular phimosis and posterior iris synechiae to the anterior capsule remnant [82–84] (**Figure 2**). On the other hand, larger diameter capsulorhexis may affect the IOL centration and stability [83]. The phacoemulsification technique may vary depending on the density and zonular status of the cataract, but an effort should be made to use the less ultrasound power and time possible, to perform vigorous cortical and posterior capsule cleaning, and to avoid posterior capsule rupture [11, 19]. Avoiding the latter is crucial to obtain a good postoperative result, especially in chronic and recurrent uveitis like, herpetic uveitis, pars planitis, VKH disease, toxoplasmosis, among others [6, 24, 85]. In these cases, posterior capsule rupture with vitreous exposure may be a contraindication for IOL implantation due to a high probability of postoperative excessive and persistent inflammation [12, 86]. In uveitic eyes with encapsulated and subluxated IOLs with extensive fibrosis, IOL removal may be necessary at some point of the postoperative period to control severe inflammation and reduce its consequences [87–89]. For eyes with extensive membrane formation in the anterior vitreous, vitrectomy after performing a posterior central capsulorhexis must be considered [90].

Decision making regarding the type of IOL to be used; anterior or posterior chamber IOL implantation; possible IOL sulcus fixation; combined filtration surgery, MIGS, or valve implantation; central posterior capsulorhexis after PC-IOL implantation with anterior vitrectomy; lensectomy, as well as posterior vitrectomy with or without retinal surgery are frequently met during uveitic cataract surgery, and the surgeon must be prepared to make the best decision for the particular case [91–94]. The implantation of a foldable IOL "in the bag" is ideal for most cases of uveitis with certain exceptions [4, 95]. Until now, it is not clear how to proceed in children with uveitic cataract, and randomized controlled trials (RCT) are necessary to elucidate

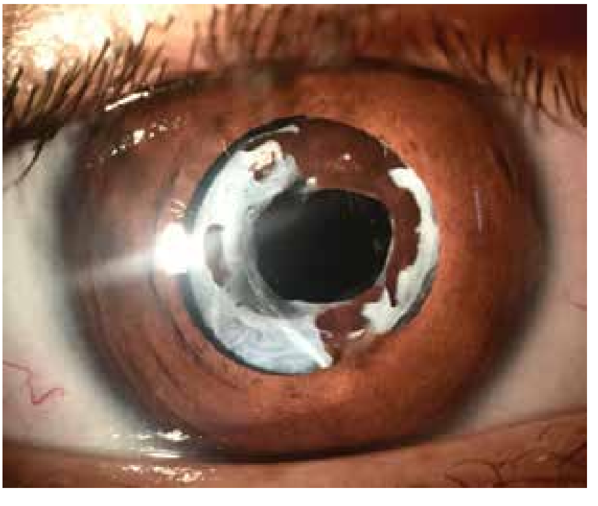

Figure 2. Patient with ankylosing spondylitis and HLA-B27-associated uveitis after cataract surgery showing capsular phimosis and partial adherence of the pigmentary epithelium of the iris to the anterior capsule remnant.

this matter [4, 25, 26, 81]. Historically, uveitic cataract surgery during childhood has been associated with a higher rate of surgical complications, particularly excessive postoperative inflammation [6, 10]. In the past, this situation made that the preferred surgical techniques for cataract extraction in this group including ECCE with posterior pars plana vitrectomy or lensectomy [4, 95]. However, recent evidence favors the implantation of foldable PC-IOLs in children with uveitis, including patients with JIA-associated iridocyclitis [25, 26, 96–101].

Intraocular corticosteroids can be administered during surgery. Intracameral dexamethasone phosphate (400 μg/0.1 ml) or intravitreal triamcinolone (4 mg/0.1 ml) injection (IVTA) may be administered intraoperatively, except in advanced secondary glaucoma or known steroid-responsive patients [4, 102]. A prospective and comparative RCT between oral corticosteroids and preservative-free IVTA injection showed no differences in postoperative anterior chamber reaction, IOP levels, and central macular thickness (CMT) [103]. Another study found a better effect of IVTA versus orbital floor TA on macular edema and postoperative inflammation after cataract surgery in patients with uveitis [55]. However, IVTA injections have a temporary effect therefore, may require repeated injections which are not exempt of serious ocular complications like, elevated IOP (30–43% eyes), bacterial endophthalmitis, vitreous hemorrhage, and retinal detachment [104]. For those eyes at higher risk for intravitreal injection, sub-Tenon's or transseptal TA can be administered at the end of surgery [19].

Intravitreal steroid sustained-release devices containing fluocinolone acetonide 0.59 mg or dexamethasone phosphate 0.7 mg have proven to be beneficial for the control of inflammation, prevention of CME, or reduction of CMT if applied a few days to weeks before or during cataract surgery [105]. Although no general consensus exists on the appropriate surgical time, it seems reasonable to perform the cataract surgery within 4–6 weeks from the last steroid implantation [105–107]. The most fear complication of sustained-release steroid devices is ocular hypertension (OHT). A meta-analysis found that 66% of eyes develop OHT after the implantation of the 0.59 mg fluocinolone acetonide device, compared to 32% following 4 mg IVTA, and only 15% with the 0.7 mg dexamethasone implant [108]. Risk factors for developing OHT include, pre-existing glaucoma, higher baseline IOP, younger age, OHT following previous injection, uveitis, higher steroid dosage, and fluocinolone implant [108]. A new sustained-release implant containing 0.19 mg fluocinolone acetonide has shown promising results improving visual acuity and reducing CMT with a significant reduction of IOP compared to the dexamethasone implant and IVTA [109].

7. Considerations for intraocular lenses

The general consensus regarding cataract surgery in patients with uveitis is that implantation of IOLs may be safely performed when ocular inflammation is completely abolished for a minimum period of 3 months [4, 7]. However, a debate still exists if an IOL should be implanted in specific circumstances like, lens-induced uveitis, JIA-associated iridocyclitis, young children with posterior or panuveitis, and intraoperative rupture of the posterior capsule with vitreous exposure [25, 26, 91, 110]. The implantation of an IOL triggers different intraocular responses including inflammation and foreign body reaction, as well as activation of the complement and coagulation cascades [83, 111–113]. These reactions along with the breakdown of the blood-aqueous barrier induced by surgery may increase cellular adhesion and lens epithelial cell (LEC) proliferation on the anterior surface of the IOL, resulting in anterior capsule phimosis, fibrosis, and posterior capsule opacification (PCO) [114]. With the advent of technologic development, many advances have been made to reduce IOL-induced reactions and to improve their biocompatibility [115]. The inflammatory response induced by IOLs is inversely related to its biocompatibility, so the higher the biocompatibility, the lower the inflammatory response [15, 83, 115]. Even though they were considered biologically inert, the first IOLs made of polymethyl-methacrylate (PMMA) were capable of producing foreign body reaction, as well as activate the complement and coagulation cascades [113, 116].

Different strategies have been used to reduce the host response, including the modification of the IOL surface by making it hydrophilic, like in heparin-coated PMMA IOLs, or hydrophobic such as surface passivated [83]. Heparin surface-modified IOLs have improved biocompatibility compared with unmodified PMMA IOLs in eyes at risk for severe postoperative inflammation, including those with uveitis [117, 118].

Foldable IOLs may be hydrophobic, including silicone IOLs or hydrophilic, and both surfaces have demonstrated to be relatively inert [114, 119]. Hydrophobic surfaces resist cell adhesion while hydrophilic ones reduce electrostatic forces and cellular adhesion, preventing the attraction of inflammatory cells and their activation, as well as adherence of fibroblasts to the IOL surface [120, 121].

Anterior capsule phimosis has been related to the degree of fibrotic reaction produced by pro-inflammatory cytokines released by residual LEC [122, 123]. Careful vacuuming the undersurface of the anterior capsule helps to reduce the number of LEC [82, 124]. Capsular phimosis has been reported more frequently with hydrogel (poly-HEMA) than acrylic, and silicone IOLs [83, 125]. Foreign body giant cell precipitates are less frequently seen in hydrophilic than on hydrophobic IOL surfaces and heparin-coated PMMA IOLs [115, 126]. The frequency of posterior capsule opacification (PCO) is highest with PMMA IOLs, less with silicone and minimal with acrylic IOLs [124, 127].

Few studies have evaluated the visual outcome following cataract surgery in uveitis with silicone IOL implantation. Overall, only 30% of eyes have achieved 20/40 of better vision with silicone IOLs, fewer than any other type of IOL [15]. Silicone was the first material available for foldable IOLs, but its use has declined particularly because it cannot be used for a monobloc open-loop designed, the preferred choice for preloaded injectors that allow implantation through small corneal incisions [128].

With the advent of acrylic foldable IOLs, the biocompatibility issue has become a minor concern, but controversy still exists of which material, hydrophilic or hydrophobic is best suitable for patients with uveitis [120, 126, 129]. Since the lens is surrounded by aqueous humor, it was thought that hydrophilic materials were more biocompatible than hydrophobic for patients with uveitis [89, 92]. However, there is insufficient evidence to determine the effects of different types of IOL materials, including hydrophobic and hydrophilic acrylic IOLs in patients with uveitis [129]. Results from the largest RCT provide only preliminary evidence that acrylic IOLs may perform better than silicone IOLs in terms of improving vision and reducing the chances of postoperative inflammation and complications [129, 130]. A large multicenter RCT with standardized outcome measurements is necessary to properly address the surgical outcome of patients with uveitic cataract.

8. Immediate postoperative management

The postoperative management is as important as the preoperative preparation and the surgical procedure itself. Since the first postoperative moments, intense topical corticosteroids (1% prednisolone acetate hourly), topical NSAIDs (anti-COX-2 selective), topical wide spectrum antibiotics (fourth generation fluoroquinolones), overnight steroid ointment, as well as mydriatic-cycloplegic combinations (e.g., 1% tropicamide + 5% phenylephrine every 6-hours × 5–7 days) should be administered [11, 24, 131]. Topical corticosteroids are wined down according to the grade of anterior chamber inflammatory reaction, the presence of glaucoma, or OHT in steroid-responders [54]. In case the patient was given systemic corticosteroids, they should be maintained at immunosuppressive levels (1 mg/kg/day) for 7–10 days before reducing them slowly to a minimum dose of 7.5 mg/day [56]. In case the patient is on immunosuppressive chemotherapy or biologic therapy, it should be continued at maintenance dose [19, 131]. Systemic anti-virals used for herpetic uveitis should be kept at therapeutic dose for 7–14 days postoperative, and then reduced to prophylactic levels (acyclovir, 600–800 mg/day and valacyclovir 500–1000 mg/day) for several weeks to months before stopping them [63, 64, 132].

9. Postoperative complications and their management

Postoperative complications after cataract surgery in patients with uveitis are relatively frequent [8]. The reported prevalence of complications is higher in ECCE than in phacoemulsification [78, 79, 133]. The risk for postoperative complications also depends on the type of uveitis and the degree of ocular involvement [8, 12, 85] (**Table 1**). Despite all preventive measurements taken before and during surgery, the most frequent and fear postoperative complication is the outburst of inflammation out of expected proportions [5]. Significant inflammation characterized by >2+ anterior chamber cells, extensive protein exudation with fibrin and plasmoid bodies formation, as well as fibrinoid membranes covering the pupil, and hypopyon may be seen [7, 19, 24, 134]. This aggressive inflammatory response is commonly associated with early postoperative iris synechiae formation and pupillary inflammatory membranes, particularly in disorders like JIA-associated uveitis, and VKH, among others [4, 6, 131, 135]. The best way to deal with this unexpected postoperative inflammatory response consists on avoiding it by previous absolute control of inflammation and the implementation of perioperative measurements discussed before. Nevertheless, in those cases in which a significant inflammatory reaction occurs, an adjustment to the systemic prednisone dose and the administration of atropine 1% will help to control the inflammation [52–54].

Other immediate postoperative complications that may be seen are hyphema and significant pigment dispersion throughout the anterior segment [19, 24]. Pigment dispersion is related to a variety of factors including, surgical trauma, small pupil, and age [24, 83, 91]. In both cases, regular tonometry is mandatory for opportune detection of severe OHT related to clogging of the trabecular meshwork by ghost cells or pigment, respectively [6]. If anti-glaucoma therapy is required, prostaglandin analogs as well as alpha-adrenergic drugs should be avoided as possible because they may exacerbate the inflammatory process [69]. In some patients with corneal stromal edema and Descemet folds due to high IOP, oral carbonic anhydrase inhibitors (e.g., acetazolamide 250 mg, 3–4 times a day) may be administered [69]. If the IOP becomes uncontrollable with medical therapy, filtration surgery or valve implantation should be considered to avoid further optic nerve damage [69, 136]. Finally, an excessive postoperative inflammatory process may produce significant vitreous opacity and membrane formation [5]. Once acute infectious endophthalmitis has been ruled out in such cases, aggressive anti-inflammatory therapy with systemic, periocular, and even intravitreal corticosteroids should be administered [52, 54, 55, 106]. If vitreous condensation and organization persist, a pars plana vitrectomy with or without intravitreal corticosteroid injection should be performed [13, 73, 75, 137].

In the late postoperative period, ocular complications are usually related with recurrent intraocular inflammation occurring from 8.3 to 53% of cases [8, 12, 85, 133]. Recurrent postoperative uveitis may produce anterior and/or posterior iris synechiae which may cause an angle or pupillary block glaucoma, respectively [69].

Certainly one of the most frequent ocular complications observed in this late period is posterior capsule opacification seen in up to 58% of cases [82, 83, 85, 124, 133]. Nd-Yag laser capsulotomy usually resolves this problem, but in some cases retrolental hyaloid-vitreous opacification or significant deposition of pigment and inflammatory debris on the IOL surface may occur therefore, recurrent low-energy Nd-Yag laser and other operative procedures may be needed for polishing the IOL [82, 138]. It must be considered that Nd-Yag laser capsulotomy in patients with uveitis is associated with a higher risk for vision-threatening complications, including OHT, CME, IOL damage or luxation, as well as retinal detachment [40, 139].

Another very important visual-threatening postoperative complication is macular edema occurring from 33 to 56% after ECCE and from 12 to 59% after phacoemulsification [12, 85, 133, 140]. The appearance of CME depends on multiple factors including the cause of uveitis and the type of surgical procedure performed [41]. Treatment of uveitic macular edema (UME) includes the administration of periocular injections of depot corticosteroids [54, 141]. However, as stated before, IVTA has shown to be superior to orbital floor injection for the treatment of UME [55, 142]. OHT is a potential complication of both types of steroid administration and should always be considered, particularly after repeated intravitreal injections [55, 108, 143]. Sustained-delivery corticosteroid devices may also be administered for this purpose [105, 106, 144]. In patients with bilateral UME, steroid-responders or those who do not accept periocular or intravitreal corticosteroid injections, oral prednisone along with oral carbonic anhydrase inhibitor (e.g., acetazolamide 250 mg every 12 hours) may be administered [54]. Epiretinal membrane formation is more commonly seen in patients with chronic

UME with a prevalence ranging from 15 to 56% [12, 145, 146]. Treatment consists of pars plana vitrectomy and internal limiting membrane delamination [73, 146, 147].

Other less common, but serious complications is retinal detachment and hypotony [5, 26]. Hypotony may be related to the retinal detachment per se, or to a low aqueous humor production due to inflammation of the ciliary process, or tractional detachment of the ciliary body due to cyclitic membrane formation [26]. Postoperative hypotony may evolve to pthisis bulbi [10, 88]. Both complications should be attended immediately by retinopexy, and/or posterior vitrectomy with cyclitic membrane and sometimes intraocular lens removal, as well as peri- or intraocular corticosteroid administration [87, 88].

10. Prognosis and visual outcome

The outcome of cataract surgery in patients with uveitis is less predictable than in other causes of cataract. Many factors may contribute to this uncertainty including, pre-existing pathologic changes, intraoperative technical challenges, the impact of postoperative exuberant inflammation, and the reversibility of postoperative complications derived from it [14]. Vision-limiting pathology related to pre-existing uveitis complications, especially macular edema and optic neuropathy are probably the major contributing factors for limited postoperative visual outcome [8, 15, 85].

Different studies suggest that visual prognosis varies according to uveitis subtypes [5, 15, 26]. For instance, the proportion of eyes achieving 20/40 or better vision is better in Fuchs uveitis and worse in Behcet's disease, VKH disease, or sympathetic ophthalmia [20, 27, 47, 148]. In general, diseases that spare the posterior segment have a better prognosis than those affecting it, particularly macular and optic nerve involvement [5, 6, 8, 85]. In addition, acute uveitic entities tend to be associated with better outcome than chronic ones [12].

Uveitic cataract surgery has been associated with worse postoperative visual acuity, higher IOP, and more than double prevalence of UME when compared with non-uveitic cataract surgery [14]. Moreover, the visual outcome following uveitic cataract extraction is not as good as that of age-related cataract surgery with the exception of Fuchs uveitis [27, 149]. Systematic reviews found a successful visual outcome (20/40 or better) in 96% of eyes with age-related cataract surgery compared to 70% in uveitic eyes undergoing either phacoemulsification or ECCE [15, 149]. ECCE and phacoemulsification seem to have similar visual outcomes compared to half less successful rate after pars plana lensectomy [15]. With respect to the comparable visual results reported between ECCE and phacoemulsification, it must be taken into account that most ECCE trials have more exclusion criteria than phacoemulsification studies, favoring better visual outcomes [15, 85, 150].

Finally, regarding IOL implantation, more eyes (71%) undergoing cataract surgery with IOL implantation than eyes left aphakic (52%) achieved a BCVA ≥ 20/40 vision postoperatively [14]. Eyes receiving acrylic IOLs or heparin surface-modified PMMA had better visual outcomes than those receiving non-heparin-PMMA or silicone IOLs [14, 15, 83, 94].

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Section 2

Non Standard and Difficult Cases in Cataract Surgery

Chapter 2

Strategies for Managing Difficult Cases

Baris Komur

Additional information is available at the end of the chapter

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Abstract

Standard cataract surgery is considered as low-risk surgery for both patients and the surgeon, but some eyes have higher risk of complication due to some reasons that are generally known or can be predicted preoperatively. Knowing risky eyes and management of possible complications is important point for achieving good visual outcome after cataract surgery. We issued most encountered problems during surgery and some solutions to manage these difficult cases.

Keywords: small pupil, brunescent, hard, white, cataract, weak zonules, zonulopathy, postural problems, shallow anterior chamber, posterior polar, reverse pupillary block

1. Introduction

In ophthalmology, the clinical management of patients is constantly evolving and complication rate is getting low. On the other hand, patient expectations are increasing. Currently, the patient now expects excellent uncorrected visual acuity following cataract surgery [1]. Although routine cataract surgery considered as low-risk surgery for both patients and the surgeon, some eyes have higher risk of complication during cataract surgery. Operations on such difficult cases are also more likely to yield a poor visual outcome which is defined as best corrected vision less than 6/60 after surgery [2].

It is extremely important to recognize when eyes are at greater risk, and act accordingly, to reduce complications. Also, before the operation takes place, it is better to spare extra time on these difficult cases, explaining that surgery is somewhat different and difficult than "routine cataract surgery" and poor outcome is a possibility. Some patients may want to take a second opinion from another clinic, letting or even encouraging them to do so will be a better option than trying to explain complication may occur at every clinic after an undesired result occured. The patients should have realistic expectations, and understand possible complications and their other ocular problems [3]. This approach makes patients expectations much more realistic and improves postoperative compliance and follow-up. In rare cases, patients with complicated cataract will be happy if they achieve some improvement in their vision.

It is also important to prepare for difficult case both mentally and physically. Mentally, the surgeon must know what to do if any complication occurs, physically, the surgeon must prepare all the equipment to manage a possible complication, like pupil devices for small pupils, capsule tension rings (CTR) for weak zonules, sutures for scleral fixation or Cionni ring fixation and vitrectomy devices in the case of capsular rupture and vitreous loss.

In this chapter, we discuss some frequently encountered difficult situations and their solutions.

2. Small pupil

It is very important to obtain sufficient pupillary dilation that lasts for the duration of the cataract surgery. A small pupil is defined as having a diameter equal to or less than 4 mm; in these cases, although experienced surgeon can continue to surgery without any manipulation; beginner surgeon must enlarge the pupil. The surgeon must plan the operation very carefully, taking into consideration all possible situations. Methods used to deal with small pupil, must aim good return of pupil function, not causing esthetically bad results or functional problems such as photophobia and diplopia. The postoperative esthetic results of this type of surgery are potentially disturbing for the patient; any surgical alteration of the pupil may have a significant effect on its function with side effects such as iatrogenic glare that can be debilitating [4].

Preoperatively using a nonsteroidal anti-inflammatory drug (NSAID) in addition to cycloplegics and mydriatics may reduce probability of pupil contraction during the operation [5–7]. There are preparations, containing NSAID for intraoperative usage, approved by the US Food and Drug Administration, also there are some preparations combining both mydriatics and NSAIDs which can be used intraoperatively, but these preparations may not be available worldwide or may be very expensive [8–10]. Another (cheaper) option is 0.5 mL of 1:1000 preservative free adrenaline diluted in 10 mL of balanced salt solution (BSS); this is injected at the beginning of surgery, through the side-port incision or added to the infusion bottle (4 IU of 1:1000 adrenaline in 500 cc) [11, 12].

Even with pharmacological dilation, pupil may still not be large enough to allow safe surgery. Although there is no absolutely safe pupil size, generally if pupil allows creation of an adequate capsulorrhexis, it also may be sufficient for the remaining steps of the surgical procedure. Safe pupil size may depend on surgical expertise, cataract hardness, patient compliance and other anatomical restrictions.

First thing to try after failed pharmacological dilation may be viscomydriasis, which is injecting viscoelastic substance (VES) toward the iris, hoping a peripheral displacement of the central portion of the iris, resulting in expansion of the pupil. Keep in mind that, VES will enlarge the pupil only when it is anterior chamber (AC); the effect of VES is less when phacoemulsification and aspiration begins. High molecular weight cohesive products will be more effective for this purpose.

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Synechiolysis can be utilized, when pupil is fixed by adhesions between the iris and the underlying lens capsule (posterior synechiae). Synechiae is broken with a blunt spatula or VES cannula that is inserted through a paracentesis, while AC filled with VES. Excessive traction may cause bleeding. Fibrous pupillary band also must be removed with a forceps for capsulorrhexis or vitreoretinal surgery [13].

Pupil stretching is more invasive procedure that induces numerous, very fine partial ruptures of the sphincter that induce mydriasis. Pupil stretching must be performed under VES protection to maintain AC depth. Two hooks are introduced into the AC; the pupil is engaged at two opposite points; and the surgeon applies peripheral pressure, sufficient to ensure moderate and controlled relaxation of the pupil edge to increase mydriasis. Repetitive gentle and progressive "push-pull" movements of the instruments are recommended. With this, rupture of the sphincter is minimized. Rapid movements may cause serious damage to the sphincter. The hook is inserted through the side-port incision and through the main incision; it is used to stretch the pupil in several different and opposite directions (initially at the 12 and 6 o'clock positions and then at the 3 and 9 o'clock positions). Then, oblique positions can be used if needed (**Figure 1**).

There are also one-handed dilators are available; inserted through the main incision, these devices stretch the pupil with a single maneuver. These instruments have been designed as a handpiece with a narrow cannula containing several hooks (between 2 and 4), with a fixed hook on its outside edge. There are fewer possibilities for adjustment with this technique and the dilator instrument itself can be expensive [14].

Sphincterotomy is an invasive procedure but useful in cases in which the sclerosis of the iris tissue is restricted to the central zone, typical of the senile pupil, capsular pseudoexfoliation, postinflammatory miosis, or iatrogenic inflammation resulting from the prolonged use of miotics. The microincisions (mini-sphincterotomies), usually 6–8, are created using fine microscissors. The incisions continue radially for approximately two-thirds of the length of the iris sphincter (**Figure 2**). The length of the corneal incision through which the scissors are inserted determines the degree of circumferential extension of the incisions [15].

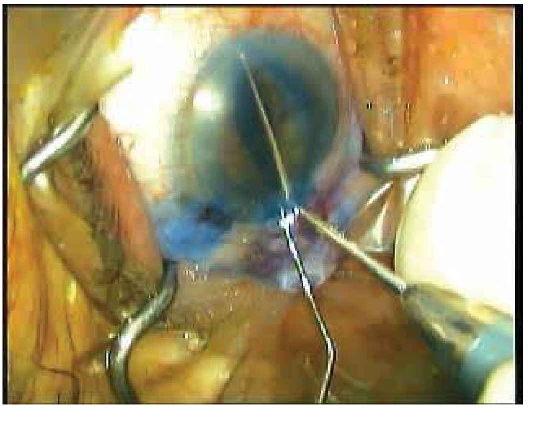

Figure 1. Pupil streching with two instruments.

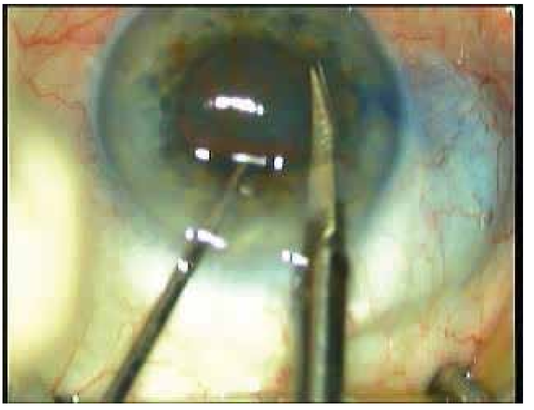

Figure 2. Mini-sphincterotomies with fine scissors.

In some cases, even after pupil stretching; size may still not be sufficient or iris laxity may cause repeated aspiration of the iris tissue itself by phaco tip. In these cases, mechanical hook retractors (dilator hooks) or iris rings can be used. Iris tissue must be sufficiently elastic to allow distention without causing lacerations. Technique for positioning iris hooks involves the creation of limbal paracenteses for the insertion of the hooks under VES. Iris hooks engage pupil margin and pull it centrifugally with silicone fragment that is engaged at the limbus. Generally, four hooks are positioned, producing a square-shaped iris. Positions of limbal paracenteses are important. For correct stretching, hooks should pull in a direction parallel to iris plane and iris must not be elevated. For this reason, incisions made close as possible to the limbus with an appropriate orientation (**Figure 3**). Once hooks positioned, the surgeon can cut the excess to avoid displacement of the hooks if the patient moves his or her eye, if topical anesthesia chosen. Iris hooks can be removed quite easily through the insertion incisions. Hooks create mydriasis that is adequate for surgery but not excessively large that can cause lax pupil postoperatively.

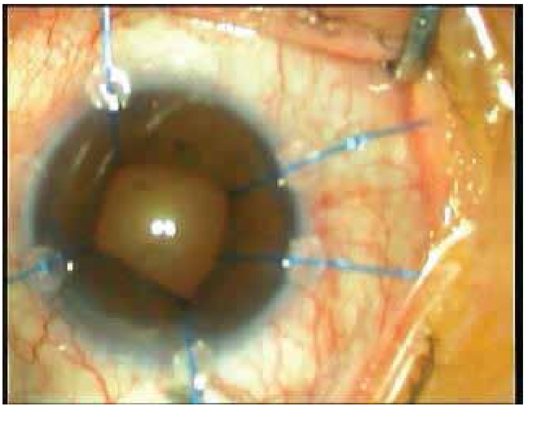

Figure 3. Iris hooks direction are better when parallel to iris plane and iris is not elevated.

Pupil expansion rings are another set of instruments designed to enlarge pupil without damaging the sphincter. These can be complete or incomplete rings; some are manufactured in polymethylmethacrylate (PMMA), others are silicone or expandable hydrogel [16]. Recently, Malyugin presented a new pupil expander [17, 18]. The use of this device also appears to be easier and faster compared to iris hooks and other pupil expansion rings. This device may be safer for dealing with a small pupil, particularly in eyes with intraoperative floppy iris syndrome. This device is a one-piece device of 5-0 Prolene. Circular buttonholes engage the pupil edge and expand the pupil. This ring has a number of advantages: it is easy to implant and induces less trauma and stretching forces are evenly distributed over the pupil edge. This may be useful in patients in which cutting the iris tissue should be avoided (e.g., iris rubeosis, chronic iritis, or systemic coagulopathies). After the surgery, the appearance of the majority of pupils is more or less the same as preoperatively, and functional activity is preserved. Additional corneal incisions are not necessary, and device is inserted through the main incision using an injector. Only negative point may be the cost of Malyugin ring.

Regardless of the method used to expand the pupil, at the end of surgery, the pupil must be constricted to avoid it being captured by part of the optic, adhering to the capsule, or other deformities.

3. Hard nucleus

Dense cataracts have always been considered challenging in phacoemulsification. The problems encountered in hard cataracts are determined not just by the hardness and the dimensions of the nucleus but also by the poor degree of hydration of the lens, absence of the red reflex, a capsule that is thin and fragile and weak or absent zonules.

Corneal tunnel should be made slightly shorter and larger. This structure will reduce the danger of wound burn, and the surgeon will probably use much ultrasound energy.

Capsulorrhexis should ideally be intact if the surgeon wishes to perform phacoemulsification. A reduced red reflex associated with the density of cataract, reduces the visualization of the anterior capsule. Changing the angle of the microscope's coaxial light beam may produce better visibility of the capsule. If the visibility remains insufficient, vital dyes (such as trypan blue) may be useful. It improves visibility of capsule during capsulorrhexis and phacoemulsification, which help the surgeon to avoid traumatizing the edge of capsulorrhexis. Adequate use of VES is important for flattening convex shape of the anterior lens surface, increasing AC depth (which has been reduced due to the large volume of the crystalline lens) to reduce zonular stretch and orient the rhexis in the desired direction [19]. Capsulorrhexis should ideally be a large rhexis (5.5–6.0 mm) to ease manipulations in the bag. In the event of difficulties, a large rhexis can also allow luxation of the nucleus in the AC and converting extracapsular cataract extraction. Beware that, too large capsulorrhexis may also make them unable to capture the optic of intraocular lens (IOL) in the event of posterior capsule rupture. In extremely mature cataracts, the anterior capsule may contain deposits of calcium or dense focal plaques, in these areas, the surgeon can cut through these dense areas with scissors.

Hydrodissection must be performed delicately. After half of the hydrodissection completed, center of raised nucleus should be pressed with cannula to depress the nucleus posteriorly; a further hydrodissection is performed on the opposite side (if needed, the surgeon can combine viscodissection procedure to rotate the nucleus). This pressing is important as the anterior shift of the large brunescent nucleus during hydrodissection may cause a capsule-lenticular blockage. In this case, if the surgeon proceeds with further and aggressive injections of liquid below the nucleus, the posterior capsule may be distended and ruptured. There may be strong corticocapsular adhesions that interfere with rotation of the nucleus; this procedure must be performed delicately without excessive force being applied. Before the surgeon begins ultrasound, it is essential that the nucleus rotate freely inside the capsular bag.

Weak zonules may be associated with the advanced age of these patients, with previous traumatic episodes that may have gone unnoticed, or with various reasons. The posterior capsule will have a greater tendency to shift toward the phaco tip even with a minimal degree of postocclusion surge. If the surgeon suspects clinically significant zonular weakness then he or she should not hesitate to use a capsular tension ring (CTR). There is a debate regarding the most suitable timing for this particular maneuver; some surgeons believe that the tension ring should be inserted as soon as any degree of weakness is observed, usually prior to the phacoemulsification procedure, while others feel that it should be inserted prior to irrigation/aspiration or before IOL is implanted.

These cataracts must be operated by expert surgeons who know modification of parameters and techniques to manage hard cataracts. When removing these nuclei, many surgeons proceed with sculpting procedures, but using techniques like “phaco chop” and the “stop and chop” technique that reduce the capsular and zonular stress, may reduce complications in these eyes [20, 21]. The “quick chop” technique is a variation of the “phaco chop” with a reduction in the amount of ultrasound used and manual fragmentation required. This allows reduction of energy with a reduction in the risk of wound burn, shortened operating times, and a reduction in the amount of stress to the zonules. Technique involves use of high vacuum and a chopper; the phaco tip is used as a pivot point to fracture the nucleus into pieces, moving them toward the chopper, which has been pushed from top down in front of the phaco tip. Regardless of the technique preferred by the modern surgeon (divide and conquer, stop and chop, chop), the basic principle is the same, to create multiple, small-size fragments. These fragments are larger and much denser than those of other types of nucleus. Comparing a standard cataract, the vacuum is much higher and occasional short bursts of ultrasound (20–40%) will be required. During this step, non-dominant hand movements are essential.

In the past, blockage of the tubing by rigid nuclear fragments was a frequent problem, as these pieces may occlude the phaco tip resulting in poor followability and in excessive turbulence which causes trauma to the endothelium. Thanks to modern phacoemulsification machines that considerably reduce the amount of energy and heat produced with increased followability associated with reduced vibration of the fragments inside the phaco tip. This technology is implemented by various companies [22, 23]. Despite this technology, signs that the surgeon must recognize when the phaco tip is partially or completely occluded are sudden appearance of emulsified milky material in front of the ultrasound tip and suddenly decreased

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followability. Posterior capsule is frequently thinner and stretched by the large volume of the lens; it will be weak and flaccid and will tend to be aspirated into the phaco tip with a major risk of rupture. Also, these cases generally have an absence or reduced amount of an epinucleus to protect the posterior capsule, forcing the surgeon to work closer to the posterior capsule and the equatorial periphery. Therefore, it is advisable for several small injections of a dispersive VES, behind the nucleus during phacoemulsification, injecting it into various areas to create a thin yet uniform layer of VES between the nucleus and the posterior capsule, creating an artificial epinucleus that separates the posterior capsule from the operating plane. Because of its intrinsic properties, it is not easily aspirated by the phaco tip, and this facilitates the safe emulsification of the fragments.

Once the nucleus has been completely removed, the remaining portion of the surgery is like a standard cataract. However, at the end of the procedure, if the capsular bag appears to be too compromised as it will not support the IOL, the surgeon may consider to implant a posterior chamber IOL with transscleral or iris fixation or an anterior chamber IOL.

4. Posterior polar cataracts

Posterior polar cataract is a type of congenital cataract that occurs in the central cortex adjacent to the posterior capsule. There is an increased risk of a posterior capsular tear during cataract surgery because a capsular defect is often present. Even if a discrete capsular defect is not detected (usually visible as small vacuole), there is an increased risk of a capsular complication. Hydrodissection increases the risk of blowing out the posterior capsule. While some authors did hydrodissection in multiple quadrants with tiny amount of fluid without allowing the wave to transmit across the posterior capsule, cortical cleaving hydrodissection is considered a contraindication in eyes with posterior polar cataract [24]. A weak point can produce hydraulic posterior capsule rupture during hydrodissection. Meanwhile, hydrodelineation, which is the separation between the nucleus and the epinucleus, is mandatory. It is worth mentioning that the surgeon should avoid vigorous decompression of the capsular bag after the delineation. In addition, nuclear rotation is contraindicated as it can act as a trephine to the posterior capsule. Some authors described a technique that was described for dense and posterior polar cataract called inside-out delineation [25]. In this technique, a trench is first sculpted and a right-angled cannula is used to subsequently direct the fluid perpendicularly to the lens fibers in the desired plane through one wall of the trench. This would avoid the possibility of inadvertent subcapsular injection and overcome the difficulty of introducing cannula to a significant depth in a dense cataract.

Capsular stress must be minimized by lowering the irrigation bottle height, reducing flow and vacuum settings which is named as slow-motion phaco, maintaining a stable anterior chamber (avoid surge and chamber bounce), and minimizing manipulations of the lens [26]. Attempting to polish any residual posterior capsular plaque in the area where the posterior polar cataract was located can easily create a tear in the weakened/defective posterior capsule. Leaving a small plaque may affect the patient's vision postoperatively, but it is much better to just perform a laser posterior capsulotomy when necessary.

5. Traumatic cataract

Cataract surgery in traumatized eyes is one of the most difficult clinical situations an anterior segment surgeon is likely to encounter. Preoperative good examination is essential. Presence and extent of phacodonesis and decentration of the lens zonular disinsertion must be recorded. A wrinkled anterior capsular surface may indicate discontinuity of the capsule itself or the zonules. It should be remembered that the integrity of the capsule may be compromised even with contusive (not penetrating) trauma [27].

Sometimes it is possible to examine the fundus depending on the opacity of the media, and its examination should include identification of holes, retinal lacerations, or retinal edema. The presence of subretinal or suprachoroidal hemorrhage should lead to greater prognostic caution, as any degree of suprachoroidal hemorrhage would cause posterior pressure during surgery.

If fundus examination is not possible, only B-scan may modify the surgeon's approach to the cataract surgery itself. When a suprachoroidal hemorrhage is detected, the surgeon should consider a pars plana vitrectomy. A computed tomography (CT) scan of the orbit is indicated if the surgeon suspects the presence of an intraocular or intraorbital foreign body. With an open corneal and/or scleral laceration, generally good slit-lamp examination will be impossible, making surgical planning more critical. If a penetration of anterior capsule present, cornea is sutured without removing the cataract; capsule may heal by itself with a little opacity [28].

A foreign body of a ferrous nature must be removed, as it could lead to ocular siderosis, while inert foreign bodies (such as glass) are well tolerated even when left in eye [29, 30]. Choice of local or general anesthesia depends on the surgeon expertise and clinical situation. Conjunctival peritomy must leave a room for pars plana sclerotomy, suturing of an IOL with scleral fixation or insertion of a Cionni ring. Conjuntiva should be spared for possible glaucoma surgery in the future. If anterior hyaloid is partly exposed, a dispersive VES can tamponade the vitreous. Dispersive VES may also provide protection for the endothelium, as endothelial cell density has been already reduced by the trauma [31].

Using vital dyes such as trypan blue has advantages: useful for finding thorn point of a capsule if needed.

With significant zonular damage, CTR can also be used to stabilize the bag. If the zonular damage involves more than 4 h (90°), suturing a Cionni ring can strengthen the area of greater zonular weakness [32]. This will improve the stability of the lens during all of the successive steps of the operation.

If introduction of ring is impossible prior to phaco, the surgeon can enhance zonular support with flexible nylon iris retractors or special capsule hooks introduced through a limbal incision, these hooks support the edge of capsulorrhexis (**Figure 4**). After emulsification of nucleus, CTR or Cionni ring can be positioned much more easily.

In case of vitreous present in anterior chamber, the surgeon must always avoid aspirating vitreous. Any traction exerted on anterior vitreous can create retinal tears and eventually lead to retinal detachment. Once vitreous removed from anterior chamber, the surgeon should then concentrate on the lens material.

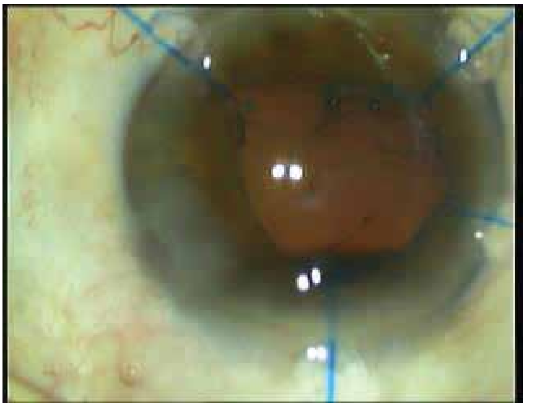

Figure 4. Iris hooks support the edge of capsulorrhexis vertically, acting like artifical zonules.

For soft nucleus, phacoaspiration of nucleus is generally safe and rapid. If there is a rupture of anterior or posterior capsule, manual aspiration with a Simcoe cannula and/or automated bimanual or coaxial irrigation and aspiration can be utilized. For harder nucleus, main principle is to reduce traction forces on remaining zonules. Many variations of delicate divide and conquer and particularly, phaco chop techniques can be chosen with low parameters of slow-motion phaco as described previously. If there is a significant zonular weakness and/or posterior capsular defect with a large lateral or inferior movement of the nucleus, then converting to manual extracapsular or intracapsular extraction techniques may be the only option.

It may be difficult for the surgeon to aspirate cortical material due to a lack of resistance of zonular fibers and manipulation may increase zonular dialysis. Using tangential movement as opposes to radial may be beneficial. If there is a capsular rupture, intact anterior hyaloid may covered with VES, after the surgeon can complete the removal of the cortex using manual dry aspiration. This technique utilizes a 25- or 27-gauge cannula attached to a 3-mL syringe, chamber filled with VES without allowing vitreous escape.

If there is an inadequate capsular support, the surgeon may try to suture one or both haptics of IOL to the sclera or the iris. With inadequate capsular support, the surgeon has several types of IOL such as scleral fixation, iris suture fixation, angle-supported anterior chamber IOL, or iris enclavation IOL. IOL Choice depends on the surgeon expertise and clinical situation.

After IOL has been inserted and appears to be well-centered, fixation can be confirmed using “Bounce test.” This test is decentering the optic toward each one of two haptics and then releasing it. IOL should recenter spontaneously.

6. Femtosecond laser assistance in difficult cases

For white intumescent cataracts, using femtosecond laser to make capsulorrhexis without decompressing the anterior chamber allows round capsulorrhexis without any radial tears.

The surgeon may want to use additional vital dye to ensure the integrity of capsulorrhexis [33]. In traumatic cases and weak zonules even there is vitreous in the anterior chamber, femtosecond laser can make round capsulorrhexis.

Femtosecond laser assistance cataract surgery (FLACS) does not provide superior outcomes in all cases. In a recent study, two patients with bilateral posterior polar cataracts underwent traditional phacoemulsification in one eye and FLACS in the other eye. In both cases, the eye treated with FLACS developed a posterior capsule rupture during lens removal [34]. Caution may also be needed in the use of FLACS in glaucoma as docking procedure may raise intraocular pressure [35, 36]. In presence of silicone oil in AC, FLACS may result incomplete capsulotomy and lens fragmentation [37].

Use of femtosecond lasers in cataract surgery is continuing to evolve, together with its potential applications, but we think that its cost must be reduced to become popular among clinics.

7. Conclusions

Cataract surgery in difficult cases can be both enjoyable and troublesome. Knowing that every case has its own distinct features, the surgeon must treat each case in a unique way. We summarized some of the most encountered problems and solutions in this chapter. Each technique must be practiced preferably in animal's eyes or in simulation environments and then in easy standard cases. Before to try techniques for real difficult cases in real difficult situations, the surgeon must feel confident and relaxed about using mentioned techniques.

Conflict of interest

The author did not have a conflict of interest for any products mentioned in the above text.

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Analysis of the Disturbances Caused by Intraocular Forced Convection Mechanism Failure

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Additional information is available at the end of the chapter

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Abstract

In this chapter, we show the refractive error treatment result of a patient, the first author, who restarted in 2000, after a 4-year break, at the study start. According to previous publications, the treatment consists of rehydration and elimination of agglutinated, dehydrated and deposited metabolic residues in the cornea, the trabecular meshwork, the crystalline lens and the retina, as a consequence of the failure in the mechanism of intraocular mass transfer by forced convection. However, the forced movement of the metabolic mass to rehydrate one region can cause dehydration in another region. Therefore, the patient developed posterior and capsular cataract in their respective eyes, right and left. This dehydration, during the treatment, increases the difficulties for the success of the treatment. The first part is a chronological record of the most important components of the treatment. Then, the research method and the material used are discussed. The main symptoms and signs are analyzed and correlated with the failure of the mass transfer process and the accumulation of metabolic residues. The anatomy of binocular vision is analyzed as a part of the forced convection mechanism, and in conclusion, the report shows the main oculomotor functions, topographic mapping of corneas over an interval of 17 months.

Keywords: cataract, glaucoma, saccadic movement, torsional movement, refractive error, uveitis, floaters

1. Introduction

The research began in 1996 when the first author (will be called the patient) realized that after 4 h of working on a computer, his vision was blurred and, after performing other activities, the view was retrieved. Then, the patient realized the possibility of regaining his vision, which was showing the beginning of the symptoms of presbyopia. The patient presented visual acuity OD 6/10 and OS 9/10 and corrective lenses NV, OD +0.25 and OS +0.75. Work interruption occurred in the same year due to anterior recurrent uveitis of unknown cause in the left eye, which increased the intraocular pressure to 40 mmHg in the first crisis. Two years before the start on this study, the patient had his first two cases of uveitis, but the most important crisis occurred after the study began and the patient took a few days to get medical help. To control intraocular pressure, the patient received three intraocular injection on alternate days. Even with the patient's narrative that he did not feel well, the doctor reduced the dosage of medications. The patient still felt pain when pressing the left eye in the superior nasal position through the superior eyelid. The patient returned to the doctor after 2 days, having noticed the blurred image in the left eye. The physician diagnosed the recurrence of uveitis and intraocular pressure at 40 mmHg. At the end of treatment, the pain in the sclera did not exist. Many other painful inflammations had occurred in the left eye, but at this early stage, physicians consulted in Brazil and France did not prescribe any treatment. Treatment was started the next day after uveitis was diagnosed. At that time when the pain symptom occurred in the sclera, the patient used a medication eye-drop prescribed for the treatment of uveitis to impede damage progression. A single drop once was sufficient to eliminate the symptom and avoid uveitis, but when the symptom did not go away, the patient used another dose the next day. On June 15, 1998, the patient had visual acuity 8/10, with corrective lenses. The research for vision recovery was restarted in the year 2000 after an oculomotor relaxation procedure, advised by the patient's brother, who had read in a self-help book on eyesight.

After 2009, the same ophthalmologist periodically examines the patient, but sometimes the patient looks for another professional in order to obtain information from the doctor when he first examines the patient. A posterior cataract had developed in the right eye and capsular in the left eye. **Table 1** shows the lenses prescribed by doctors. The prescribed lenses do not change the direction of the elimination treatment of the intraocular metabolic residues. In 2012, ophthalmologists informed the patient that, without surgical intervention in the left eye, the patient would have great difficulty in passing the eye examination to renew his driver's license, scheduled for 2014. So, 15 days before the date of renewal, the patient underwent 12 sessions of 30-min exercise on different days with occlusion of the right eye and added 2 days without exercises. The patient was approved in the exam.

Although the patient perceived changes in visual perception during treatment progress, however, it was not possible to establish treatment phases through these changes. The changes in visual perception depend on the element being observed. The observed element can be an object, a light source or an image, with or without letters, that is near or far, in a certain environment. The environment can be dark, or light, with or without diffused light, under the influence of various luminous intensities. In addition to the environment, visual perception is severely influenced by dehydration, agglutination and the amount of metabolic residues accumulated.

The physical characteristics of the residue disposed orally vary with the progress of the treatment of recovery of sight. Eliminated residue is the one with the least resistance to movement. The movement resistance depends on the location of the accumulation region and the

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Calendar date	Rx		Spherical	Cylindrical	Axis
1975	D.V.	O.D.	—	—	—
		O.S.	—	—	—
	N.V.	O.D.	+0.25	—	—
		O.S.	+0.25	—	—
1994	D.V.	O.D.	—	—	—
		O.S.	—	—	—
	N.V.	O.D.	+2.50	0.50	35°
		O.S.	+2.50	0.50	155°
December 02, 1996	D.V.	O.D.	—	—	—
		O.S.	—	—	—
	N.V.	O.D.	+0.50	—	—
		O.S.	+0.75	—	—
1997	D.V.	O.D.	+1.50	0.50	30°
		O.S.	+1.50	0.25	140°
	N.V.	O.D.	+2.50	0.50	30°
		O.S.	+2.50	0.25	140°
1999	D.V.	O.D.	+1.50	0.50	35°
		O.S.	+1.50	0.50	140°
	N.V.	O.D.	+3.50	0.50	35°
		O.S.	+3.50	0.50	140°
July 18, 2003	D.V.	O.D.	+1.50	0.50	180°
		O.S.	1.25	—	—
	N.V.	O.D.	+2.50	0.50	180°
		O.S.	+2.50	—	—
June 20, 2006	D.V.	O.D.	+1.25	0.50	65°
		O.S.	+1.00	0.50	125°
	N.V.	O.D.	+2.75	0.50	65°
		O.S.	+2.75	0.50	125°
June 30, 2006	D.V.	O.D.	+1.25	−0.50	30°
		O.S.	+1.00	−0.50	155°
	N.V.	O.D.	+2.75	−0.50	30°
		O.S.	+2.75	−0.50	155°
March 19, 2007	D.V.	O.D.	+1.00	−0.50	35°
		O.S.	+1.00	−0.50	120°
	N.V.	O.D.	+2.25	—	—
		O.S.	−2.25	—	—

Calendar date	Rx		Spherical	Cylindrical	Axis
October 01, 2012	D.V.	O.D.	—	−0.50	100°
		O.S.	−0.50	−1.50	100°
	N.V.	O.D.	+2.50	add	—
		O.S.	+2.50	add	—
November 12, 2012	D.V.	O.D.	+0.50	−0.75	90°
		O.S.	−1.00	−0.75	105°
	N.V.	O.D.	+3.25	−0.75	90°
		O.S.	+1.75	−0.75	105°
February 07, 2013	D.V.	O.D.	−0.75	—	—
		O.S.	−2.00	—	—
	N.V.	O.D.	+2.25	add	—
		O.S.	+2.25	add	—
July 22, 2013	D.V.	O.D.	+0.50	−1.25	85°
		O.S.	−1.50	−1.00	105°
	N.V.	O.D.	+2.75	add	—
		O.S.	+2.75	add	—

Table 1. Lenses prescribed by doctors.

physical and biochemical characteristics. These characteristics are mainly associated with the compositions of their components, viscosity, dehydration, color, transparency and acidity. Some of these characteristics can be observed in oral elimination.

At the beginning of treatment, it was very easy to perceive the negative afterimage, but it has not been observed for a long time. This pathology was solved. Initially, the appearance of new floaters was observed. Then, there were floaters that changed their appearance, one divided into two, maintaining a discreet connection. The oldest floater had already added new expansion, but kept its round, black core. Sometimes after the beginning of treatment, the oldest floater changes in appearance and returns to the initial appearance.

When the light source, in a dark environment, is refracted in light rays projected on the retina, it may suggest the beginning of the residue elimination phase; the perception of the colored arc, around the light source, indicates residues with a high index of refraction, very dehydrated, with great viscosity; blurry sight can indicate residues available on the cornea for disposal.

The intraocular process of accumulation of metabolic residues, as well as its intraocular process of elimination of metabolic residues, occurs essentially through the involuntary oculomotor movement that acts with the objective of producing the best projection in the temporal retina. In the process of eliminating the accumulated metabolic residue, the patient voluntarily interferes in the oculomotor movement so that the metabolic residue interferes in the projected image in the temporal retina, and then, the involuntary movement rehydrates the accumulated residues in the region, reduces its viscosity, and produces the best projection in the temporal retina. Much attention, just as there is anterior ocular torsional movement, due to the difficulty of adaptation of the cornea, a posterior ocular torsional movement can occur, cause physical tension in the optic nerve and cause normal tension glaucoma.

2. Method

Teamwork was used to interview professionals and patients. Team studies, based on the interpretation of symptoms, among others, corneal burning, tear production and resistance to visual adaptation to a fixed target, performed through the horizontal periodic movement of the head (the duration of the exercise is within the range of 5-30 min). Studies of anatomy and biophysics of the eyes as a system of dynamic action are made. Simulation of a physical model to reproduce the studies of Scheiner, apud [1], was used to associate the main refractive errors and the patient's symptomatology. Simulation of a hypothetical mathematical model was made to study the daily intraocular pressure variation. As the main form of treatment progress evaluation, a light source, at the same distance, was initially used to measure the diameter of its dispersion, evaluated in the number of adjacent diameters of the source. At the present, a traffic light is used as the light source for measurement. Visual acuity and corrective lens parameters are not used to evaluate the reduction of intraocular metabolic residue.

3. Eyesight regeneration and analysis of symptoms and signs

3.1. Materials

In this section, the main materials used for vision recovery are listed in alphabetical order, together with a brief description of the use.

Corrective lenses, **+19 D, +10 D, +5 D, +2.5 D, −5D:** Negative lenses were abandoned shortly after starting treatment because they did not present difficulties during exercises. Corrective lenses have been included in vision recovery exercises because anyone, without accumulation of intraocular metabolic residue, can read a text with any corrective lens.

Cotton-polyester fabric, nylon mesh: Light obstruction acts as a load for oculomotor movement. The mesh with thicker wire requires more oculomotor effort. By having a greater aperture in its mesh, the nylon mesh interferes in the elimination of the metabolic residues that are sheltered by the shadow of the light obstructed by its wires. The cotton-polyester fabric, by having a smaller opening in its mesh, can eliminate the residuals left by the nylon mesh.

Eyewear (temporal): Occlusion of temporal visual fields to increase the power of the rectus and ciliary muscles without the help of the oblique muscles.

Eyewear (nasal): Occlusion of the nasal visual fields to stimulate the movements related to the projection of the image in the nasal retina (needed but with little use).

Pinhole glasses: Used only at the beginning of treatment as a test. The use of these glasses can cause patient well-being because it eliminates a small volume of metabolic residue, but the volume eliminated is insufficient to solve the problems of refraction error. In addition, its use is not recommended during activities involving patient control or movement, such as driving a vehicle or walking. The holes in the lenses select the visual axis direction, and Scheiner's experiment apud [1] shows that the selection of the visual direction presents to the patient's target at different distances, making it impossible to evaluate the distance of the target and cause an accident.

Sun: Treatment using sunlight has been used several times because it is a source of light with greater intraocular penetration power. It is because of its power that, when looking at the Sun, one or more regions become dark. This strong light causes movements in the dehydrated and viscous metabolic residue that becomes opaque for some time, the accumulation region. Opacity ends due to involuntary intraocular movement. It is the involuntary movement of adaptation to the dark.

Compact fluorescent lamp: Used as fixation point.

Treadmill equipment: Ocular exercise performed on a treadmill does not cause sleep. Six is a great speed for the exercises. It is necessary that there is ample front and lateral visual space.

3.2. Symptoms and signs

During the exercises, there may be, in one or both eyes, fiery sensation along with bloodshot eye. After, there may be itching. Sweat can be severe on one side of the head or on both sides. Exercises can stimulate bruxism, pain in the jaw joint, tongue, and marks on the face. Although there is no direct relationship in many cases, this takes a lot of time and effort to perform the image fusion in a certain direction, or to maintain the fusion of images during the movement of the fixation point. By carrying out the exertion for a long time, it can divert the attention of the patient and it passes on to transmit force to these other parts of the body. After the exercises, sight may become blurry or there may be some other painless modification. For a short time, there may be a foreign body sensation in the cornea or intraocular. There may be acute pain of short duration.

Auditory perception: In 2003, on routine examination, the patient became aware of the absence of 6 kHz frequency perception and the presence of permanent noise, only in the left ear. In the analysis performed by an otorhinolaryngologist, no other pathology was found. In subsequent years, the patient was evaluated to verify the evolution of auditory perception. The patient began to perceive small hearing in the frequency of 6 kHz and reduced the perception in the adjacent frequencies, including in the right ear. Currently, the patient has noticed some relationship between the exercises for recovery of sight and the perceived noise, because the noise in the right ear stops and the amplitude of the remaining noise varies with the direction of the exercise. Then, among the criteria of choice of exercises are the direction of greater variation in the amplitude of the noise and displacement of fixed images. Thus, the variation in noise should be considered, in the choice of the exercise for the eyesight recovery.

Dizziness: Exercising may cause dizziness, and in this way, the patient should hold onto the equipment support during the exercises.

Imbalance: May be perceptible or imperceptible. The imperceptible can cause the patient to knock down nearby objects, can in certain situations move one or more steps, as if drunk, for a short time, can cause pain in the sciatic nerve, and can produce dry callus on the bottom of the feet (**Figure 1**). Sometime later, they suffered fatigue in the right leg. Tiredness settled in the upper posterior region of the knee and then settled in the upper posterior region of the thigh, and the same symptom started in the left leg. This caused a great deal of suffering. It was not thought to be due to muscle strain. The hypothesis was that there was a problem of balance, since the dry callus had already been treated, and balance requires many activities of the lower limbs. Early in the morning, when the patient was seated, he began the eye exercise with eyewear (temporal), to strengthen and straighten the muscles, the symptoms immediately disappeared. The patient worked all day with the symptom of one who had walked for a long time. Two days later, the patient spent a lot of time with the symptom of muscle relaxation in both legs.

Torticollis: The most common signs are the sensation of contraction and pain on one side of the neck that can radiate to the back. It can be caused by stimuli of recurring displacement of the projected image on the retina.

3.3. Analysis of some ocular pathologies

The analysis was based on the progress of the recovery of the patient's vision, in addition to the conclusions reached in our other publications. The ocular refractive error has its origin in the accumulation, dehydration and agglutination of the intraocular metabolic residue [2] caused by the defect in the mechanical system of mass transfer in the cornea (between the corneal layers) [2–4], trabecular meshwork [5], lens [6] and retina [7, 8]. Congenital and acquired pathologies increased the mass transfer deficiency.

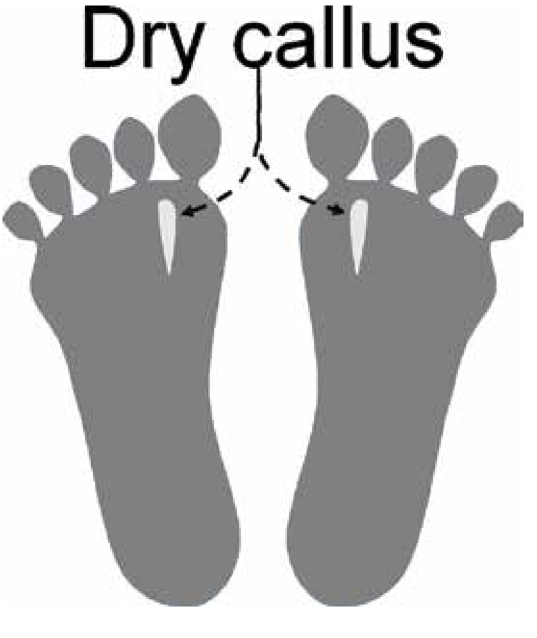

Figure 1. Diagram showing the dry callus location.

Cataract: It is the accumulation of dehydrated metabolic residue in the lens. As the residue is translucent, its dehydration is opaque.

Because it is an accumulation, it is natural to increase the volume and rigidity of the lens, as well as to associate the age of the person with its consequences, among them visual acuity. During the exercises, there may be an intraocular foreign body sensation as well as a small, rapid and uncomfortable intraocular pain because of cataracts.

Dark adaptation: The eye takes longer than 20 min to fully adapt from bright sunlight to dark [9].

The eyes are organs of the visual system. The eye transmits the luminous image to the retina that, through electrochemical impulses, transmits to the brain. The image interpretation can trigger a physical protection action, that is, the person through the image can move the hand or foot to perform a body protection action. The hand and foot take well less than 20 min to make the maximum displacement. So "the eye is a radar that spends 20 minutes to identify an attack, and in defence, it can trigger a missile attacking the target in a minute, so this radar is not for this operation." This means a serious visual impairment. A person without accumulated intraocular metabolic residue can look at the sun and then read a text written in black ink on white paper. In the appendix, it is shown that the adaptation time to the dark is not greater than 0.24 s (Eq. 7).

Glaucoma:

- **Open-angle:** It is caused by slow obstruction of the trabecular meshwork, resulting in increased eye pressure.

In Ref. [5], *it shows how the metabolic residues coming from the cornea can slowly obstruct the trabecular meshwork, increasing the resistance of the aqueous humor and, consequently, increasing the intraocular pressure.*

- **Angle-closure:** It is the result of the closing of the angle between the iris and the cornea.

The accumulation of dehydrated metabolic residue causes formation of a large refractive error and may cause defective coordination between the movement of the lens and the movement of the oculomotor muscles. See in keratoconus analysis.

- **Normal-tension:** The optic nerve is damaged without the eye pressure being too high [5].

The accumulation of intraocular metabolic residue modifies the shape, volume and mass of the eye, and as a result, the oculomotor muscles move out of their ergonomic movement and change the position of the eye in the ocular cavity. These changes can strain the optic nerve.

Eye movements [10]:

- **Conjugate:** They are those that preserve the angular relationship between the right and left eyes.
- **Saccadic:** They are very fast jumps from one eye position to another.

Saccadic and vergence movements are acquired pathologies associated with agglutinated metabolic residues. These clusters form intraocular lenses, which project images into the retina, in different places.

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In 1619, Scheiner described these images apud [1]. *Then, when the visual axis changes agglutination, the image of interest jumps from the fovea to another location. This jump causes a rapid movement of the eye in the opposite direction (saccadic movement) to transfer the image to fovea. If the jump of the eye causes the return of the visual axis to the anterior agglutination in order to cause recurrent periodic movement, then it can cause photosensitive epilepsy* [2].

- **Vergence:** Eye movement for fusion of retinal images and obtaining binocular vision.

Floaters: These are deposits of metabolic residue, in the cornea or lens, with various sizes, shape, consistency and refractive index and can be transparent, translucent or opaque.

During treatment, the oldest floater is opaque, but on many days, it presents itself in different forms and opacity. Another floater was divided in two and maintained connection between both.

Headache: This is a warning symptom of a greater problem that is occurring in the body.

You should not take medicine and you should do exercises. If you delay in taking action, the treatment is much longer. Precisely, on the day that the writing of this work is being finalized, the right eyeball of the patient presented a pain sensation, similar to the occurrence, shortly after the injection in the left eye of the same patient. It is probable that the right eye has performed movements that cause mechanical tension in the optic nerve. If immediate corrective action is not provided, it can cause glaucoma with normal pressure. In both cases, the treatment is the same given in relation to the imperceptible imbalance of the body, motor coordination and increase of the power of the rectus muscles.

Keratoconus: Changes of the cornea to a cone-like shape and its thickness reduction.

The torsional accommodation of the cornea is a movement of variation of the radius of its curvature. This may be caused by personal habits and ocular structure, which can progressively increase the radius of curvature, causing keratoconus, or by modifying its cylindrical periphery to the conical shape, blocking the drainage of the aqueous humor, causing angle-closure glaucoma. **Figure 2** *shows the two possibilities.*

Ocular dominance: This is the fixation of the eye with less movement (called the dominant eye) on the target and the adjustment of the contralateral one.

In Ref. [4], *it is treated as visual impairment.*

Phosphene: This can be directly induced by retina mechanical stimulation. It is easy to check when rubbing or applying pressure to closed eyes.

In Ref. [7], *it is written without naming the acquired pathology. "The metabolic secretions are accumulated in the retina forming clusters without any regularity therefore when the eyes are pressed on*

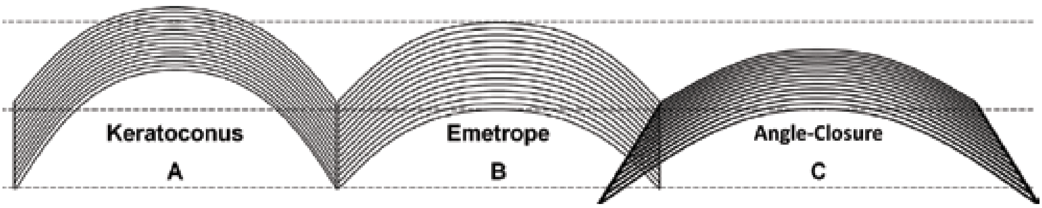

Figure 2. Scheme of the formation of keratoconus, and the angular closure.

by the hands, the photoreceptors are also pressed, and the process affects its biochemical transduction that produces an electrical signal to the brain which interprets it as a light signal." At the present, only, some blue dots are still perceived.

Photophobia: It is a symptom of abnormal light sensitivity.

When the iris fails to reduce interference from the brightness of the incident light to improve the sharpness of the temporal retinal projection. This is one of the effects of accumulation of intraocular metabolic residue. If the physician needs to use different corrective lenses between the exams with and without dilated pupils, it is necessary to verify the need to eliminate the stagnant metabolic residues in regions that are not usually used to design images in the retina.

Refractive error

- **Myopia:** When there is a need for the use of concave lens, to correct the convergence of light rays.
- **Hyperopia:** When there is a need for the use of convective lens, to correct the convergence of light rays.
- **Presbyopia:** When there is a need for the use of bifocal or progressive lens, to correct the convergence of light rays.
- **Astigmatism:** When there is a need for the use of cylindrical lens, to correct the convergence of light rays.

In Ref. [2], *it is shown that refractive error causing myopia, hyperopia, presbyopia and astigmatism has the same origin: dehydration and agglutination, intraocular, of accumulated metabolic residues.*

4. Binocular vision anatomy

Binocular eyesight uses the image fusion for greater visual accuracy. **Figure 3** shows, schematically, the main elements to explain the oculomotor control mechanism, obtained from the images projected on the retina.

Binocular vision of the fixation point on a screen (F in **Figure 3**) occurs when the visual axes of the eyes converge at this point. The F-point protrudes into the central fovea at points F_R and F_L (**Figure 3**), respectively, in the right and left eyes. The two visual axes define the visual plane. The visual plane intercepts the retina in both eyes on two anatomical horizontal meridians, in the right and left eyes. Each anatomical horizontal meridian has two sides, the temporal and the nasal. The nasal anatomical horizontal meridian includes a segment, corresponding to the optic disc, which does not send an image to the brain.

The nasal anatomical horizontal meridian intercepts the neural communication periphery of the optic nerve, closer to the left fovea, at the P_{LL} point (**Figure 3**). In the right eye, the P_{LR} retinal point is the closest to the fovea, obtained by the interception of the temporal anatomical horizontal meridian with the corresponding neural communication periphery of the

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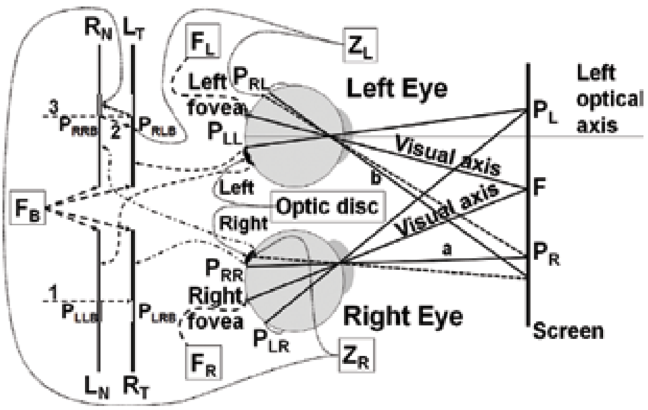

Figure 3. Binocular vision representation scheme.

contralateral optic disc (projection of the contralateral blind spot periphery). If the P_{LL} and P_{LR} retinal points are the neurologically corresponding signals to the P_L screen point retinal projections, the image fusion is perfect. The projection on the right temporal anatomical horizontal meridian, containing the P_{LR} point, sends the visual signals to the ipsilateral cerebral hemisphere in the R_T line (right temporal side), shown in **Figure 3**. The projection on the left nasal anatomical horizontal meridian, containing the P_{LL} point, sends the visual signals to the contralateral cerebral hemisphere, in the L_N line (left nasal side), shown in **Figure 3**. In the L_N line, there is a small segment for the optic disc representation. The arrow "1" locates in the brain at the intersection with the L_N line and the neural point P_{LLB} (left horizontal nasal anatomical meridian) corresponding to the signal received from P_{LL} retinal point and reaches the R_T line at the neural point P_{LRB} (right horizontal temporal anatomical meridian) corresponding to the signal received from P_{LR} retinal point. If the P_{LLB} and P_{LRB} neural points are the neurologically corresponding signals to the P_L screen point retinal projections, the images fusion is perfect, that is, the horizontal diameter of the contralateral blind spot is projected on the R_T line white highlight, indicated by "1" arrow.

The nasal anatomical horizontal meridian intercepts the neural communication periphery of the optic nerve, closer to the right fovea, at the P_{RR} point (**Figure 3**). In the left eye, the P_{RL} retinal point is the closest point of the fovea, obtained by the interception of the temporal anatomical horizontal meridian with the neural corresponding of communication periphery of the contralateral optic disc (projection of the contralateral blind spot periphery). If the P_{RR} and P_{RL} retinal points are the neurologically corresponding signals to the P_R screen point retinal projections, the image fusion is perfect. In this case, retinal points are not the neurologically corresponding signals to the P_R screen point retinal projections; therefore, there is no fusion of images, and there is binocular diplopia. The projection on the left temporal anatomical horizontal meridian, containing the P_{RL} point, sends the visual signals to the ipsilateral cerebral hemisphere in the L_T line (left temporal side) shown in **Figure 3** diagram. The projection on the right nasal anatomical horizontal meridian, containing the P_{RR} point, sends the visual signals to the contralateral cerebral hemisphere in the R_N line (right nasal side) shown in **Figure 3** diagram. In the R_N line, there is a small segment for the optic disc representation. Arrow "2" locates in the brain at the intersection with the R_N line and the neural point P_{RRB} (right horizontal nasal anatomical meridian) corresponding to the signal received from P_{RR} retinal point and reaches the L_T line at the neural point P_{RLB} (left horizontal temporal anatomical meridian) corresponding to the signal received from P_{RL} retinal point. If the P_{RRB} and P_{RLB} neural points are the neurologically corresponding signals to the P_R screen point retinal projections, the image fusion is perfect. The image fusion follows the neural correspondence shown by the "3" arrow, which does not correspond to the respective P_R screen point retinal projections; thus, there is binocular diplopia. The right superior oblique muscle action can accommodate the cornea to perform the angular displacement of "2" arrow until reaching "3" arrow (make the Z_L point coincide with P_{RL} point corresponding to P_{RLB} point in brain). That is, intersect "a" line (**Figure 3**) with the "b" line on the screen, or move the Z_R point (**Figure 3**), projected on the optic disc of the right eye, to overlap the P_{RR} point or P_{RRB} in brain. As the control is contralateral, the right superior oblique muscle action moves the Z_L point until it coincides with the P_{RL} point, that is, the horizontal diameter of the contralateral blind spot is projected on the LT line white highlight, indicated by "3" arrow.

5. Conclusion

As is well known, the brain is "cross-wired" with body movement control and superior oblique muscle but is ipsilateral to the other oculomotor muscles. For the reception of visual signals, the brain is ipsilateral to the projection in the temporal retina and contralateral to the projection in the nasal retina. In the binocular limit of lateral vision, the nose contralateral shadow is the contralateral temporal projection, so that the ipsilateral nasal projection is the only contralateral control signal of the third and sixth cranial nerve functions. Therefore, contralateral ocular movement occurs only under the influence of the projections in the ipsilateral eye. The image fusion influences only the contralateral movement of the superior oblique muscle to avoid binocular diplopia. In summary, the ipsilateral and contralateral nasal projections form the contralateral oculomotor control signals, and the ipsilateral temporal projection transmits, for the brain, the reference signal in motor control of the contralateral superior oblique muscle. In addition, the inferior oblique muscle can correct some angular deviation of ipsilateral temporal projection, without any influence of control of the superior oblique ipsilateral muscle (it does not have a reference image for motor control). In this way, it is easy to understand the contralateral influence resulting from a monocular stimulus.

Rectus muscles: Its main function is to maintain the designed fixation point in the fovea centralis. The superior and inferior rectus muscles avoid and stabilize the vertical displacement of the ipsilateral retinal projection, and the lateral and medial rectus muscles avoid and stabilize the horizontal displacement of the ipsilateral retinal projection. Maintaining eyesight at a fixation point is extremely important for proper accommodation of the crystalline lens and cornea. The fixation point can be a light source or not, and it can be fixed or movable and can be in an ambience with or without changing the lighting level. Vision may be with or without ocular occlusion, may be with or without corrective lenses and may or may not be through a mesh. The head may have a rotating, extension and flexing motion, or it may

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remain motionless. These are possible combinations that depend on the goal to be achieved. Exercise can cause itching in the sclera nasal region.

Ciliary muscle: It has the main function of maintaining and stabilizing the projection in the ipsilateral temporal fovea and giving it the same dimension as in the contralateral nasal fovea image. These muscles also have the ability to correct the distance from the fixation point, which may be invisible to the eye and act as a mass transfer mechanism by forced convection in the lens.

Superior oblique muscle: It has the main function of enlarging or reducing the projection in the horizontal nasal anatomical meridian, so that the same projected image in the periphery of the optical disc is the same projected image in the corresponding neural region of the periphery of this optic disc, in the contralateral temporal retina. The deviation in the ipsilateral temporal projection causes a force antagonistic to the superior obliquus muscle movement.

Inferior oblique muscle: It has the main function of correcting the angular deviation of the projection in the temporal retina in relation to the projected image in the contralateral nasal retina. The torsional accommodation of the cornea is a joint action of the oculomotor muscles to obtain fusion of the temporal and contralateral nasal images, in addition to varying the intraocular pressure. This accommodation is the mechanism of forced convective mass transfer on the cornea and retina, and it may be inferior, cylindrical or superior, but the difficulty in twisting the cornea may cause twisting of the eyes. Because of the cornea torsional accommodation, a circle in the binocular view can project with the same radius in the retinas of the eyes, with duplication of the monocular vision information, adjustable, and able to obtain a much greater mathematical precision than the accuracy of monocular vision, in accordance with human perception.

Iris: It is a thin circular structure with the main function of reducing incident light when this brightness interferes with the sharpness of the temporal retinal projection as well as diaphragmatic action, to avoid the aqueous humor return, when the pressure in the anterior chamber is greater than the pressure in the posterior chamber due to corneal accommodation.

Eyelid movement: It has the main function of mechanical transport of nutrients and metabolic residues, in addition to being able to reduce the ocular opening voluntarily or involuntarily, when the iris reaches the minimum limit of its opening. The eyelid, on a regular basis, spreads tears, for rehydration and entrainment of the metabolic residue throughout the anterior ocular surface. Tears and metabolic residues are drawn into the puncta (an opening near the nasal bridge) by capillary action and conducted to lacrimal sac through the lacrimal canaliculi and then to the nasal cavity through the nasolacrimal duct. In the nasal cavity, the tear goes out through the nose or the metabolic residue can dehydrate; the resulting mucus accumulates in the nasal cavity; or the viscous residue passes through the throat and is eliminated orally or through the digestive tract. Elimination of the metabolic residue during sleep can cause a very inflamed throat, which may be accompanied by hoarseness for a few days. Cough and sneezing may occur with the expulsion of metabolic residue. Shedding of tears (or eye discharge) of one or both eyes may occur in response to the elimination of metabolic residue from the corneal epithelium, and it can last more than a day. The elimination of metabolic residue in the cornea can be accompanied by the sensation of foreign body in the eye.

Because of the personal habits, the mobile intraocular mass may remain stagnant for a long time, so the metabolic secretions of this medium can dehydrate by decantation, increasing its viscosity and, consequently, increasing the absorption and refraction of light penetrating the eyes. This is the process of accumulation of metabolic residues in the cornea, the trabecular meshwork, the lens and the retina, causing the most known intraocular problems such as refractive errors, keratoconus, glaucoma, cataract, retinal detachment, retinitis pigmentosa and macular degeneration among other problems, which may be added with other factors. Involuntary oculomotor movement exists to reduce the refractive error of the projected image in the temporal retina. However, this involuntary movement can add other problems such as change in the volume and shape of the eyeball, cornea and lens. However, this same involuntary movement can be used to rehydrate and remove the intraocular metabolic residue, in the form of solution or suspension.

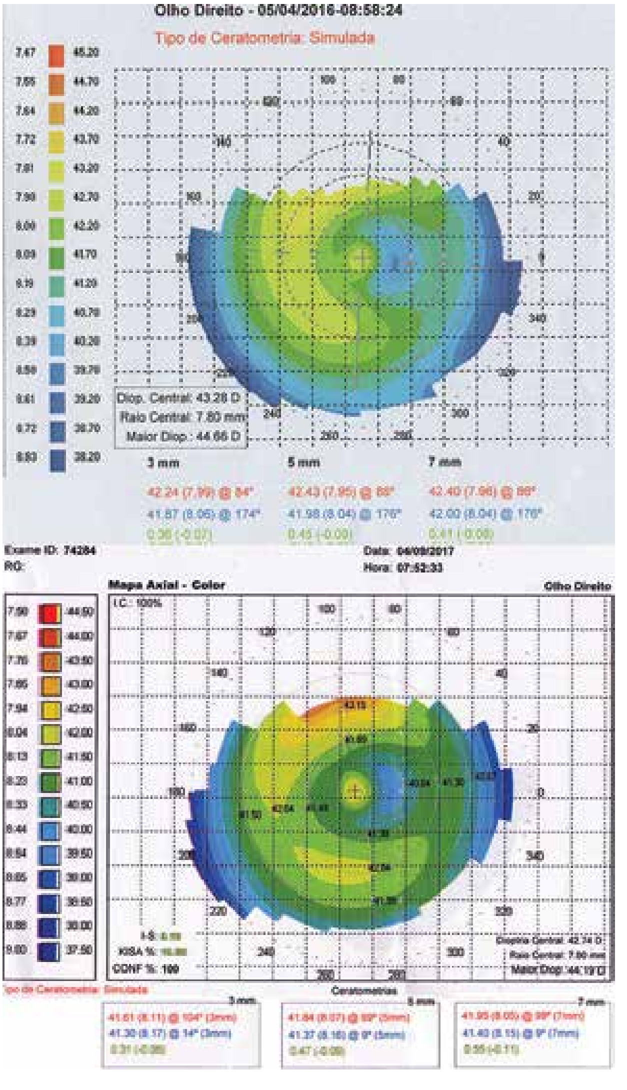

Figure 4. Corneal topography of the right eye performed on April 04, 2016, and September 05, 2017.

From the examinations performed on the patient, only a computerized corneal topography could provide some information to evaluate the progress of the treatment. For each eye and in both, it was necessary to add, on examination, the complementary volume, surplus volume and volume to be distributed, to obtain a uniform corneal lens. At the end of the work, these volumes will be null. **Figure 4** shows the corneal topography of the right eye performed on April 04, 2016, and September 05, 2017, and **Figure 5** shows the result of the same exam for the left eye. Visually, it is possible to verify the progress of the work performed, but there is no measure that can evaluate the volume of metabolic mass moved in the cornea, during 17 months. The region of the left cornea, with the most dehydrated metabolic mass, is indicated in the last examination, shown in **Figure 5**. This region has lower diopter and higher viscosity. Its rehydration causes a foreign body sensation in the cornea, but because of cataract, it can cause foreign body sensation intraocular.

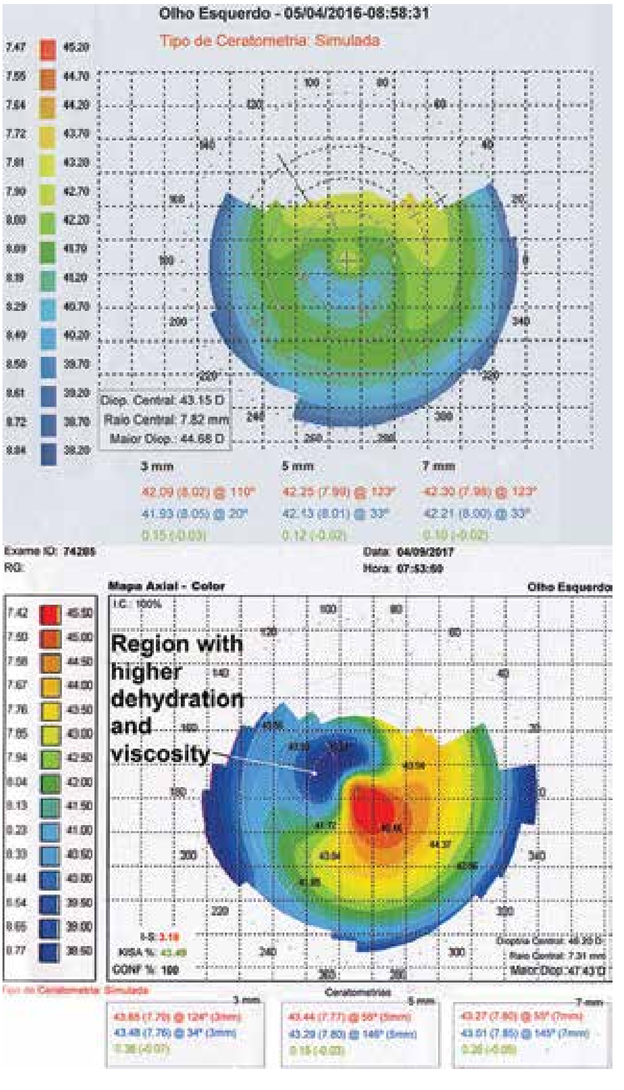

Figure 5. Corneal topography of the left eye performed on April 04, 2016, and September 05, 2017.

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To God for having helped the first author, in troubles during many years of suffering that led him to become an analytical observer of events in his own body, because of his mother, under the doctor's permission, 15 days before the birth of the first author, traveled by plane. In addition, by helping us to coexist, long ago, with the harms of internal political and economic decisions. For Marcos, brother of the first two authors, who showed in 1999, in a self-help book, the importance of oculomotor relaxation for the eyesight treatment. To colleagues, of the first two authors, ANDES-SN Sindicato Nacional members, and its Seção Sindicato ADUFEPE members, who, during the intervals of some of the societies' meetings, provided with important scientific information for the study. To those who were interviewed to friends, colleagues and family members who directly or indirectly have contributed to this work. There was no public or private financial participation for publication of this work. The authors agree with the individual mentions.

A. Appendix

A.1. Dynamic comparison of the agility of change of state among different activities of the body, eyesight adaptation to dark and movements of the limbs and superior eyelids

In Ref. [5], it was shown that in a first-order system, the percentage change of the final state from an initial state is given by Eq. (1) (see the graphic in **Figure 6**), where $e = 2.71828$, t is the time and τ is the time constant. In the human body, the eye movement has less constant time than the arm movement, that is, the eye movement is faster than the arm movement.

$$f(t) = 100 \cdot (1 - e^{-t/\tau}) \tag{1}$$

In this appendix, a first-order linear mathematical model is used to determine the time constant (numerical value of agility evaluation of a system) to find the maximum displacement time of the upper limbs in personal defense, considering concepts exposed and the maximum time with eyes closed, due to the movement of the eyelid with 287 winks per minute [5]. The result is compared to the value obtained, considering the adaptation to dark with 20 min. With the data obtained, it is verified that the time of 20 min for the adaptation to the dark is unacceptable, because it would have to admit the agility of the superior members much greater than the one of the vision.

The verification of the speed between two systems is performed through the percentage execution of the activity for multiple values of the time constant. If two systems named "A" and "B" with τ_A and τ_B their respective time constants and have the relation $\tau_A = 2\tau_B$, then, when time is equal to τ_A, "A" system performed 63.2% of its final state; however, "B" system has

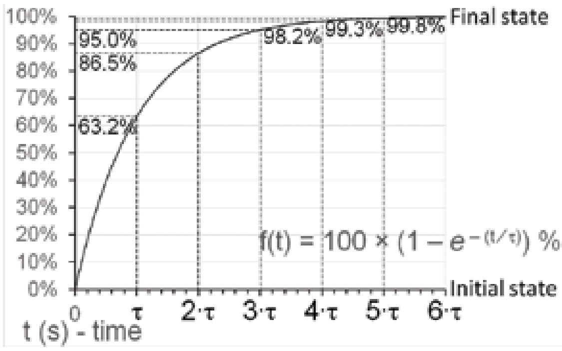

Figure 6. Graph of the function $f(t) = 100 \cdot (1 - e - t/\tau)$.

already achieved 86.5%. Therefore, the system with the shortest time constant is the fastest, in this case the "B" system.

a. Eyelid—287 flashes per min [5]

To simulate the movement of the eyelid, you should consider the maximum distance traveled by the eyelid should be considered as 100%. In the initial state, the eyelid is closed (or open) when the instantaneous time is equal to zero and, in the final state, the eyelid is open (or closed) when the instantaneous time is equal to $\tau_e, 2\tau_e, 3\tau_e, 4\tau_e, 5\tau_e, 6\tau_e$ or more, depending on the accuracy.

When t is equal to τ, the system executes 63% of the activity. When t is equal to 2τ, the system executes 86% of the activity. When t is equal to 3τ, 4τ or 5τ, the system executes 95, 98 or 99% of the activity, respectively.

Eq. (2) gives the time t_{oc} that the eyelid passes to open or close the eye, in seconds.

$$t_{oc} = 60/(2 \cdot 287) = 0.10453 \text{ s} \tag{2}$$

If **0.10453** represents 99% of the opened or closed eyelid, then the minimum time constant is $\tau_i = 0.10453/5 = 0.02091 \text{ s}$ and, if 95% of the maximum time constant is $\tau_a = 0.10453/3 = 0.03484 \text{ s}$, then the eyelid time constant τ_e is in the range $0.02091 \text{ s} \le \tau_e \le 0.03484 \text{ s}$. Eq. (3) gives the eyelid mean time constant τ_{em}.

$$\tau_{em} = (0.02091 + 0.03484)/2 = 0.02788 \text{ s} \tag{3}$$

Thus, the eyelid system completes its activity between $3\tau_{em}$ and $5\tau_{em}$, so its average time is $4\tau_{em}$, and the eyelid opens or closes the eye with time t_e given by Eq. (4), which is considered the transition time for the state change (from opened or closed eye to closed or opened eye or from light to dark).

$$t_e = 4 \cdot 0.02788 = 0.1115 \text{ s} \tag{4}$$

The neural system of reception and comprehension of the retinal image spends the same eyelid time t_e, to complete the whole process, after the conclusion of the eyelid movement, so that the total processing time t_{na} is given by Eq. (5), for the situation **a** (eyelid—287 flashes per minute).

$$t_{na} = (1 + 1) \cdot t_e = 2 \cdot 0.1115 = 0.223\,\text{s} \tag{5}$$

If the neural system has the completion time t_{na}, its time constant varies between $\tau_{nia} = 0.223/5 = 0.0446\ s$ and $\tau_{naa} = 0.223/3 = 0.07433\ \text{s}$ and then the neural time constant τ_{na} is in the range $0.0446\,\text{s} \le \tau_{na} \le 0.07433\,\text{s}$. Eq. (6) gives the neural mean time constant τ_{nma}, for the situation **a** (eyelid—287 flashes per minute).

$$\tau_{nma} = (0.0446 + 0.07433)/2 = 0.05947\,\text{s} \tag{6}$$

The neural system completes its activity between $3\tau_{nma}$ and $5\tau_{nma}$, so its average time is $4\tau_{nma}$, and the image interpretation occurs with time t_{na} given by Eq. (7), which is considered the transition time for the state change (the time of interpretation of the retinal image).

$$t_{na} = 4 \cdot 0.05947 = 0.23786\ \text{s} \tag{7}$$

The superior limb movement system, to reach the maximum displacement, takes twice the time t_{na} of the reception and comprehension of the retinal image process, after its completion, so that Eq. 8 gives the total processing time t_{sa}, that is, slightly less than one second for superior limb maximal displacement.

$$t_{sa} = (2 + 1) \cdot t_{na} = 3 \cdot 0.23786 = 0.71359\ \text{s} \tag{8}$$

b. Dark adaptation—30 min [9]

If the neural system has the completion time $t_{nb} = 20.0\ \text{min}$ (in Ref. [9] cites 30 min), its time constant varies between $\tau_{nib} = 20/5 = 4.0\ \text{min}$ and $\tau_{nab} = 20/3 = 6.66667\ \text{min}$, that is, $4.0\ \text{min} \le \tau_{nb} \le 6.66667\ \text{min}$. Eq. 9 gives the neural mean time constant τ_{nmb}, for the situation **b** (dark adaptation—30 min [9]).

$$\tau_{nmb} = (4.0 + 6.666)/2 = 5.33333\ \text{min} \tag{9}$$

The neural system completes its activity between $3\tau_{nmb}$ and $5\tau_{nmb}$, so its average time is $4\tau_{nmb}$, and the image interpretation occurs with time Eq. (10), which is considered the transition time for the state change (the time of interpretation of the retinal image).

$$t_{nb} = 4 \cdot 5.33333 = 21.33333\ \text{min} \tag{10}$$

The movement system of the superior limbs takes twice the time, t_{nb}, to reach the maximum displacement of the reception and comprehension of the retinal image process, after its completion, so that Eq. 11 gives the total processing time t_{sb}, that is, slightly more than an hour for superior limb maximal displacement.

$$t_{sb} = (2+1) \cdot t_{nb} = 3 \cdot 21.33333 = 64.0 \text{ min} \quad (11)$$

Thus, the mathematical model and its parameters have shown that if the measured eyelid movement, 287 flashes per minute [5], is considered as a reference, it obtains, for the displacement of the upper limbs, the time $t_{sa} = 0.71359$ s, compatible with the reality. However, if the time of 20 min (30 min [9]) is considered as a reference for adaptation to the dark, it obtains, for the displacement of the upper limbs, the time $t_{sb} = 64$ min, incompatible with reality.

The exposed model does not consider dead time (the time lag between the beginning of stimulus given to a system and the beginning of resulting response); however, it is possible to adopt $t_{na} = 0.23786$ s and $t_{nb} = 21.33333$ min as the dead time in the respective simulations. In this case, the dead time, considering the eyelid movement, is compatible with reality and confirms the simplified representation of the event, whereas for the second case, the waiting time is incompatible for the defense of the body, therefore, or the parameter adopted is incompatible or the model chosen is not applicable. This work adopted the first alternative.

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Section 3

Combine Cataract and Glaucoma Surgery

Chapter 4

Combined Glaucoma and Cataract: An Overview

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Additional information is available at the end of the chapter

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Abstract

Glaucoma and cataract frequently coexist in our elderly population regardless of geographical location or ethnicity. Cataract extraction alone has demonstrated to reduce intraocular pressure in eyes either with or without glaucoma. However, this chapter focuses on how cataract surgery might be combined with different glaucoma surgical procedures, such as trabeculectomy, non-penetrating procedures and minimally invasive procedures (MIGS), as well as implantation of drainage devices like the Trabectome® and the iStent®, both used for trabecular flow increase; the CyPass® implant, which acts by increasing the uveoscleral flow; the XEN® implant that facilitates the drainage of the aqueous humor from the anterior chamber to the subconjunctival space and finally the endocyclophotocoagulation that decreases the aqueous humor production. Current surgical options will be discussed, focusing on recently reported studies, analyzing the clinical aspects that influence the choice for each surgical treatment.

Keywords: MIGS, glaucoma, cataract, IOP, combined surgery, novel glaucoma procedures

1. Introduction

Cataract and glaucoma are ranked as the leading causes of blindness worldwide (51 and 8%, respectively). Cataract and glaucoma frequently coexist in our patient population. Phacoemulsification combined with trabeculectomy has historically been the preferred surgical approach for concurrently managing cataract and glaucoma. The severity of glaucoma must be taken into account for all cases of cataract surgery in glaucoma patients. In case of a refractory glaucoma; when more than three types of medication are required, with associated early stage cataract; it is advisable to postpone any phacoemulsification procedure until after glaucoma surgery. However, all cases most be evaluated individually, and cataractogenous effect of the procedure should be considered in this situation. Moreover, cataract extraction performed after a filtering surgery may lead to a reduction of the bleb function.

2. When to combine surgeries and how to minimize complications

In the last few years, glaucoma surgery has undergone great advances when we are talking about surgical treatment of the glaucoma, one of the main points about this is combining cataract and glaucoma surgery [1].

We can combine cataract surgery with different glaucoma surgeries, such as trabeculectomy, implantation of drainage devices, non-penetrating procedures and minimally invasive procedures (MIGS) to mention a few [1].

The success of them depends on several factors among which they can mention:

- Type of glaucoma
- Severity of damage
- Amount and time of use of topical medicine
- Previous surgery/s
- Type of surgery to be performed

Within this last group of surgeries are procedures and devices that seek to derive the aqueous humor toward the Schlemm's channel, the suprachoroidal space, to the subconjunctival space and that reduce the aqueous humor production [1].

This opens a range of possibilities for the treatment of glaucoma, mainly in early stages of the disease, which turns it into a useful resource for the control of glaucoma and making it an option with fewer risks and complications than the classic procedures [1].

2.1. Newer surgical alternatives

Among the methods that can be used, FDA-approved, are Trabectome® and iStent® for use since 2006 and 2012, respectively, both used for trabecular flow increase, the recently approved CyPass® implant in 2016, acts by increasing the uveoscleral flow, the XEN® implant that facilitates the drainage of the aqueous humor from the anterior chamber to the subconjunctival space and finally the endocyclophotocoagulation that decreases the aqueous humor production [2].

It has now been established that the MIGS techniques are prepared for a decrease in intraocular pressure (IOP) at least 20% to be considered effective. In addition to being considered as safe, this means a very low incidence of adverse effects and complications, especially those that affect the patient's vision.

The efficacy and safety of some devices have been demonstrated by many multicenter studies [2].

The hypotensive effect of these techniques may be additional if combined with cataract surgery, phacoemulsification specifically, with this combination is reporting the IOP description up to 40% [4]. The fact that those are techniques with a lower IOP decrease should not be seen as a problem and it is a mistake to compare these techniques with the standard surgery of glaucoma, trabeculectomy with mitomycin C, since they are not designed to replace the latter to fill the gap between medical treatment and more aggressive surgeries [3].

Any patient who undergo phacoemulsification of the lens gives us an opportunity to combine the surgery with a minimally invasive procedure of glaucoma. Due to the efficacy and safety profile, these procedures should be used in cases of mild-to-moderate glaucoma. Regarding the type of glaucoma, they are performed in open-angle primary and secondary to pseudoexfoliation and pigment, except for endocyclophotocoagulation that can be used in other types of glaucoma. With all this, MIGS would help us gain time and delay, as far as possible, more aggressive surgery [3].

In situations in which we combine cataract surgery with some minimally invasive procedure, it is not easy to differentiate what proportion of the hypotensive effect is due to cataract surgery and how much is due to the MIGS procedure. We can say that the hypotensive effect of cataract surgery alone reported by different authors is 2–4 mmHg in a variable period of time (1–7 years) [2, 3].

Some recommendations to facilitate the procedure or implantation of devices and to reduce the rate of intra and postoperative complications are: familiarization with the technique and/or device to be implanted, use of the surgical microscope with different viewing angles, correct use of surgical goniolens and previous experience in procedures or surgeries involving surgical manipulation of the angle [2].

According to a meta-analysis, comparing the efficacy of iStent combined with cataract surgery versus phacoemulsification alone in patients with glaucoma and cataract, the decrease in IOP was greater in the group in whom iStent was placed and this effect is even greater if more implantation is performed of a device [4].

2.2. Combined phacoemulsification and canaloplasty

Mention will be made of some of the minimally invasive procedures currently performed, beginning with canaloplasty. This procedure consists in the creation of two overlapping scleral flaps, the probing of the Schlemm's canal with a catheter designed for that effect and the introduction of a suture with the aid of the same catheter and then knotted at its free ends to achieve a canal distension and a tension in the tissues of the trabecular meshwork with the consequent opening of the trabecular meshwork, ending with a watertight suture of the superficial flap. Better results are obtained when this procedure is combined with phacoemulsification of the lens. The reduction obtained is approximately 40% to 3 years with a success of up to 65–82% [5, 6].

2.3. Combined phacoemulsification and iStent®

Another available procedure is the iStent implant, which consists of a metal device that is implanted at the level of the trabecular meshwork to create a bypass between the anterior chamber and the Schlemm's canal. It is the smallest device that is implanted throughout the body as depicted in **Figure 1**. The method may be done in isolation or in combination with phacoemulsification of the lens; if implanted in conjunction with surgery of the lens, the moment in which it is implanted is variable, being able to be before or after the extraction of the lens, taking into account that it must be done with the pupil in miosis and under the direct visualization of the angle through a goniolens. The hypotensive effect of this device increases when it is associated with cataract surgery in the same surgical act, as well as with the number of implanted devices [4].

If we compare the IOP results, between cataract surgery and cataract surgery plus iStent implantation in PAOG patients with at least one medication and IOP ≥ 19 mmHg, at 15 months the IOP reduction was 17.3% and a 80% medication reduction in the iStent group, compared to 9% IOP reduction and 32% medication reduction (cataract surgery alone) [8].

Almost all of the randomized controlled trials show a mild IOP reduction (between 10 and 20%). But when multiple iStents are implanted with cataract extraction, the IOP reduction is up to 40% with three stents, attention has turned toward using multiple iStents [7].

For multiple iStents alone (without cataract surgery), using the second-generation iStent inject among phakic and pseudophakic subjects, the results show a 29–48% IOP reduction from medicated baseline. At 1 year after implantation of two stents, 66% had IOP ≤18 mmHg off of medication, and the mean IOP reduction among all was 40% [8].

2.4. Combined phacoemulsification and CyPass®

One device used to increase drainage through the uveoscleral pathway is the CyPass Micro-stent, which creates a communication between the suprachoroidal space and the anterior chamber. The CyPass Micro-stent is a fenestrated micro-stent made with a biocompatible

Figure 1. iStent implant at the level of the trabecular meshwork to create a bypass between the anterior chamber and the Schlemm's canal.

polyamide, 6.35 mm in length and an external diameter of 510 μm. It is introduced under gonioscopic visualization at the level of the union of the scleral spur with the band of the ciliary body by a curved guide to follow the contour of the sclera along the supraciliar space. Trough physical and mechanical properties and a series of retaining rings at the proximal end of the device, the stability of the device is ensured in the supraciliar space. Different studies have shown that the implantation of this device decreases IOP both in isolation and in combination with cataract surgery, with an IOP decrease of approximately 30–35%, and this effect is maintained over time, as well as in the use of hypotensive medication from 1.4 drugs to 0.2 on average. The complications that can be observed after the implantation of this device are few and include loss of visual acuity, corneal edema, iris inflammation, cyclodialysis, hypotonia, migration or obstruction of the device and increase of IOP [9, 10].

CyPass with cataract extraction demonstrate a favorable safety profile. The mean IOP reduction was 5.5 mmHg (from 21.1 ± 5.91 to 15.6 ± 0.53 mmHg) which means a 37% decrease from baseline IOP and a 50% reduction in glaucoma medications [11].

This are the results at one-year follow-up from CyPass implantation alone in a recent multicenter interventional study. Baseline IOP was reduced from 24.5 ± 2.8 mmHg with 2.2 ± 1.1 medications to 16.4 ± 5.5 mmHg with 1.4 ± 1.3 medications at 12 months. This was a 34.7% reduction in IOP. About 83% of eyes avoided conventional incisional glaucoma surgery [11].

2.5. Combined phacoemulsification and endocyclophotocoagulation

Cyclophotocoagulation, initially with a transscleral probe, typically used in refractory glaucoma. Recent reports demonstrate the safety and efficacy of endocyclophotocoagulation (ECP) in the treatment of mild-to-moderate glaucoma. Similar to other MIGS, it is conjunctival-sparing, blebless, and can be combined with cataract surgery. The laser endoscope probe can be inserted through a temporal 2.4 mm clear corneal wound into the anterior chamber and sulcus (filled with OVD). With direct visualization of the ciliary processes, the visible portion of the ciliary process are treated with the diode laser (Iridex Oculight, Mountain View) at 200 mW mean power and continuous duration. Approximately 270° of ciliary processes must be treated to the point of blanching and shrinking of the tissue. Overtreatment is defined by extreme blanching and a popping sound, which indicates an air-bubble explosion [12].

A 3-year outcomes of a prospective nonrandomized matched-control study comparing ECP with cataract extraction versus cataract extraction alone in medically controlled OAG, showed a 10.1% IOP reduction and a 73% medication reduction at 2 years in the treatment group. The control group (cataract surgery alone) showed a 0.8% IOP reduction and a 17% medication reduction at 2 years [12].

Another author reported retrospective results of endocyclophotocoagulation and cataract extraction versus cataract extraction alone in mild-to-moderate glaucoma patients, the combined group had a 14.5% IOP reduction with 85% medication reduction at 36 months. The control group (phacoemulsification alone) 12.4% IOP reduction and a 13.3% medication reduction at 36 months. While there was no significant difference in the IOP reduction between groups, there was a significant difference in medication reduction. At 36 months, the 61.4% of the combined group versus 23.3% of the control group achieved an outcome of 20% IOP reduction with a decrease of at least one ocular hypotensive medication [13].

2.6 Combined phacoemulsification and Ex-PRESS®

The Ex-PRESS Glaucoma Filtration Device (Alcon Laboratories Inc., Fort Worth, TX) is a biocompatible [14], non-valved stainless steel device, designed to offer a fast an simple glaucoma filtering device [15] and to provide a lower complication rate with a more stable early postoperative course [16]. Initially it was implanted through full-thickness sclera, directly under the conjunctiva, allowing aqueous drainage into the subconjunctival space [17], alone or in a combined procedure including phacoemulsification, as depicted in **Figure 2**. This technique however, was associated with a higher rate of complications: persistent hypotony, flat anterior chamber, choroidal detachment, suprachoroidal hemorrhage, conjunctival scarring and implant extrusion [18–21]. In 2005, Dahan and Carmichael [15] described an alternative device to be implanted under a scleral flap; these modifications provided satisfactory IOP control and reduced postoperative complications rates.

In a retrospective study by Lan et al. [22] that described the long-term outcomes of the Ex-Press Device combined with phacoemulsification in patients with primary open-angle glaucoma (POAG) and primary angle-closure glaucoma (PACG) and founded a lower postoperative IOP on the POAG group, in addition to more hypotony when compared to the PACG group. Three years after surgery the cumulative complete and qualified success rates were 63.3 and 83.3% (POAG) and 53.3 and 73.3% (POAG), respectively.

Huerva et al. [23] evaluated the efficacy and safety of the Ex-Press device in combination with cataract surgery. After 1-year follow-up, 59.5% of patients had IOP control without medications and 10.8% with one medication. Complications in the early period included ocular hypotony and uveal effusion in 5%, as well as one case of re-intervention after 1-year due to uncontrolled IOP.

Figure 2. The Ex-PRESS Glaucoma Filtration Device implanted through full-thickness sclera in to the anterior chamber.

3. Impact of cataract surgery on intraocular pressure

The leading cause of age-related, reversible blindness is cataract and the leading cause of irreversible blindness worldwide is glaucoma, the incidence of both cataract and elevated intraocular pressure, with or without glaucoma, increases with age [24]. There have been various reports of the effect of cataract surgery on intraocular pressure (IOP) in glaucomatous and non-glaucomatous eyes, however, the magnitude and clinical significance of these changes continues to be debated. Some studies found a significant IOP reduction whereas others reported no significant change [25], depending on the type of glaucoma.

Intraocular pressure is the only known modifiable risk factor for the development and progression of glaucoma and intraocular pressure-lowering therapy delays its progression [26]. In glaucoma patients, the indication of cataract surgery differs from other patients, depending on various factors such as disease stage, preoperative IOP, number of medications, gonioscopy appearance, age and the experience and skills of the surgeon. Therefore every surgeon should recognize the influence of cataract surgery on IOP control in each type of glaucoma [27].

Previous reports of the effect of cataract surgery in IOP have reflected great variability in IOP reduction, related to angle anatomy, preoperative IOP and anterior chamber depth [28–30]. Identify which patient would experience an IOP-lowering response with cataract surgery alone could modify surgical decision-making.

3.1. Cataract surgery and open-angle glaucoma

In glaucomatous and normal eyes, cataract surgery produces a reduction in IOP, although these effects are more pronounced in patients with primary angle-closure glaucoma (PACG), there has been noticed a reduction in IOP also in POAG.

In a prospective study, Elgin et al. [31] compared the effect of cataract surgery on anterior segment parameters measured by optical biometry in patients with primary open-angle glaucoma (POAG) and pseudoexfoliation glaucoma (PSX), IOP decreased postoperatively 1.9 mmHg and 3.1 mmHg in each group, they also observed a significant increase in anterior chamber depth in both groups with a greater increase in PSX patients probably related to ciliary zonular laxity.

In a retrospective study of the Swedish National Cataract Register Data, Charlotta Zetterström et al. [24] found that after cataract surgery, patients with glaucoma had a larger reduction in IOP than the group of patients who did not have glaucoma and patients with glaucoma and PSX had significantly greater IOP reduction than patients without these diagnoses. They also found that when high IOP was given as an indication for surgery, the IOP reduction after cataract surgery was greater.

Shingleton et al. [32] retrospectively evaluated the change in IOP and glaucoma medications after cataract surgery in glaucoma patients, glaucoma suspects and normal patients. At 3 years follow-up IOP decreased 1.4 mmHg in glaucoma patients and glaucoma suspects and 1.7 mmHg in normal patients, the number of glaucoma medications in the glaucoma group did not show any significant change at follow-up and they found that after 3 years, 85% of the glaucoma patients had IOP less than or equal to their preoperative IOP, with the same number of glaucoma medications or less. Despite being a retrospective study it demonstrated a sustained reduction in IOP after cataract removal.

Slabaugh et al. [33] in a retrospective study of 157 patients with POAG found a decrease in IOP by a mean of 1.8 mmHg after phacoemulsification at 1 year follow-up but 38% had worsening of IOP control including 24% that needed additional medications or laser trabeculoplasty and 0.6% that required trabeculectomy. Among patients that did not have any change in medications, higher preoperative IOP, older age and deeper anterior chamber depth were associated with lower postoperative IOP.

The American Academy of Ophthalmology in a recent assessment investigated the long-term effect of phacoemulsification on IOP in patients with POAG, PSX and PACG [34]. They found that higher IOP before phacoemulsification is the single most common significant factor associated with a greater drop in IOP after phacoemulsification and concluded that for patients with POAG controlled with 1 or 2 medications, phacoemulsification alone results in a decrease in IOP (−13%) and medication requirement (−12%) although 26% of patients experience worse IOP control after phacoemulsification and may require additional medications, laser treatment or both.

3.2. Cataract surgery and angle-closure glaucoma

The prevalence of primary angle-closure glaucoma is highest in Asia (1.09%) and there is an estimated of 23.4 million cases worldwide for 2020 [35].

Patients with chronic primary angle-closure glaucoma (PACG) have an altered trabecular meshwork architecture with fewer spaces and fused trabecular beams, these changes are the result of mild, recurrent subacute attacks of angle closure that lead to chronic angle-closure glaucoma [36].

In a large percent of patients, there are multiple mechanisms for angle-closure glaucoma as pupillary blocking and plateau iris, in those patents residual angle-closure post iridotomy would result in poor control of IOP, in those patients lens extraction may resolve residual angle closure [37]. Previous studies demonstrated that lens extraction has the ability to lower IOP, lens extraction would widen the angle even without structural alterations of plateau iris because the lens plays a central role in the pathogenesis of PACG, its increased thickness, relative anterior positioning and progression of its thickness result in narrowing of the anterior chamber.

Lens extraction reduces diurnal IOP fluctuations, IOP levels and the number of anti glaucoma medication in PACG with previous laser iridotomy, the change in IOP fluctuation values correlates positively with the change in anterior chamber deep an preoperative IOP fluctuation [38]. Thus patients with narrowest angles might experience a greater benefit from cataract surgery alone depending on the proportion of the angle that has been permanently closed by peripheral anterior synechiae.

In 1998, Gunning and Greve [39] retrospectively evaluated the long-term effects of extraction of incipient cataracts or clear lenses in patients with subacute or chronic angle-closure glaucoma, after a mean follow-up of 52.6 months glaucoma control was achieved in 68% of patients, they concluded that the choice of first a cataract procedure with the option of a future trabeculectomy may be a more attractive approach in patients with subacute or chronic angle-closure glaucoma than trabeculectomy followed by an optional cataract procedure.

In the EAGLE trial, they assessed the efficacy and of clear lens extraction versus laser peripheral iridotomy and topical medical treatment as first-line therapy in people with newly diagnosed primary angle closure and intraocular hypertension or primary angle-closure glaucoma. After a mean follow-up of 36 months, clear lens extraction showed greater efficacy and was more cost-effective than laser peripheral iridotomy, they concluded that clear lens extraction should be considered as an option for first-line treatment [40].

In a prospective study, Tham et al. [41] compared phacoemulsification alone versus combined phacotrabeculectomy in patients with PACG medically controlled, after 2 years follow-up combined surgery resulted in less topical glaucoma drugs but there were no differences in glaucomatous progression, also combined surgery was associated with more postoperative complications.

In another prospective study, Tham et al. [42] also compared phacoemulsification versus trabeculectomy in patients with PACG medically uncontrolled, alter 1 year follow-up, there was a significant and comparable reduction in IOP in both groups but trabeculectomy was more effective in reducing dependence on glaucoma drugs also with more postoperative complications. In the phacoemulsification group, only 27% did not require IOP-lowering medications or further surgery after 24 months.

The decision of a cataract surgery alone versus a combined surgery should be made taking account of the type of glaucoma, the severity of the disease and the IOP. Patients with a mild damage and a controlled IOP with topical medications are good candidates for cataract surgery alone.

4. Surgical complications in combined surgery

Patients after glaucoma surgery have an increased risk of cataract formation or progression, approximately 50% of patients will require cataract surgery within the first years after trabeculectomy surgery [43].

Phacoemulsification in presence of a functioning filtration bleb increases the risk of bleb failure in 33%, there are changes in bleb morphology that results in elevations in intraocular pressure (IOP), increased glaucoma medications or additional surgical treatment [44, 45].

The coexistence of cataract and glaucoma in the same patient can follow different strategies such as glaucoma surgery first, cataract surgery first or combined surgery, it depends of the type of glaucoma, the severity of the disease, target intraocular pressure, patients age and the preference of the surgeon.

4.1. Phacotrabeculectomy

Although a staged approach of trabeculectomy followed by cataract surgery has demonstrated successful refractive results, with the last improvements in phacoemulsification and trabeculectomy, phacotrabeculectomy stills a surgical option for some patients with cataract and glaucoma. The indications for phacotrabeculectomy are the simultaneous presence of a visually significant cataract and medically uncontrolled glaucoma, advanced glaucomatous optic nerve damage or visual field loss. A combined approach has the advantages of reduced overall cost, reduced anesthesia and surgery time and less recovery time.

In a retrospective study, Jin et al. [46] evaluated the outcomes after phacotrabeculectomy in consecutive patients. Over 60 patients included in the study, hyphema and hypotony developed in three eyes in the early postoperative period. Bleb hemorrhage occurred in two eyes and cleared within 2 weeks without incident, one eye had a bleb leak that resolved after conservative treatment. The most frequent late complication was posterior capsule opacification requiring capsulotomy in six eyes. Bleb revision was performed in two eyes for dysesthetic bleb 2–3 years after surgery. A second trabeculectomy and an injection of 5-fluorouracil were performed each in one eye, for poor filtration. In this study, the rate of complications was remarkable lower compared with other reports.

In another retrospective study in Singapore [47], the complications after phacotrabeculectomy with Mitomycin C were evaluated, the mean follow-up was 47 months. Most of the postoperative complications occurred within the first month: hypotony in 25.6%, hyphema and shallow anterior chamber in 10% each one. About 11.3% of patients required surgical intervention: bleb needling with antimetabolite use in 4.4%, implant of glaucoma drainage device 1.3%, anterior chamber reformation 1.3% and lens repositioning 0.6%, the majority of complications were transient and self-limiting. They concluded that close and active monitoring is critical in the early postoperative period to prevent complications and surgical failure.

There are reports of tilt and decentration of intraocular lens (IOLs) after phacoemulsification in patients with glaucoma; those are more common in eyes with pseudoexfoliation syndrome or closed-angle glaucoma.

In combined surgery, the changes in anterior chamber depth, axial length, changes in corneal curvature, iridectomy and fluctuations of IOP could affect the accuracy of the IOL power calculation and its position. Ong et al. [48] in a retrospective study investigated the refractive outcome of phacotrabeculectomy compared with a sequential approach, they found a greater myopic refractive prediction error and mean absolute error in the combined group. They advocate the surgeon aim for a slightly more hyperopic result for the combined approach to achieve results closer to emmetropia.

4.2. Combined phacoemulsification and glaucoma drainage implant

In the case of phacoemulsification combined with a glaucoma drainage device operative complications include anterior and/or posterior capsule tears, vitreous loss and IOL-capsular bag subluxation. Cataract extraction combined with implant insertion produce a moderate to severe reduction in IOP (hypotony) lasting for 1–14 days or more, after which the IOP return to safe levels. Other complications include hyphema, anterior chamber shallowing, choroidal detachment associated with varying degrees of hypotony and IOP spikes [49]. Distended and symptomatic blebs could be seen in these patients and, most infrequently, diplopia.

Corneal decompensation after insertion of drainage devices and cataract extraction was likely to be due to pre-existing endothelial loss caused by previously uncontrolled IOP, but it is possible that endothelial injury may also be aggravated during phacoemulsification [39]. The hypertensive phase defined as elevated IOP in the presence of a functioning bleb and a patent tube and occurring up to 9 months after surgery was found to occur in similar rate than in the isolated drainage implant surgery (22–50%) [49–51]. Tube erosion and occlusion show no difference between tube implant alone and when it is combined with cataract extraction [49–51].

4.3. Phacoemulsification and non-penetrating surgeries

There are several options to manage patients with both cataract and open-angle glaucoma and the rates of complications are different in non-penetrating surgeries compared with trabeculectomy. One of the advantages of phacoemulsification with non-penetrating surgeries versus phacotrabeculectomy is a lower incidence of postoperative inflammation and other immediate complications like hyphema and shallow anterior chamber.

In a retrospective study, Schoenberg et al. [52] compared the surgical outcomes between phaco canaloplasty and phacotrabeculectomy. There were no differences in overall failure rates between the two groups, in the phacotrabeculectomy group two patients had a decrease in vision but only one was related to the surgery. Five patients in each group required revision of the surgical site at the slit lamp for management of elevated IOP.

The most common complication in the phacocanaloplasty group was hyphema (27.7%) and resolved over a 2 week period in all patients. There were some serious complications during follow-up, one patient in each group developed choroidal effusion, one patient had a suprachoroidal hemorrhage and two developed hypotony maculopathy in the phacotrabeculectomy group. They concluded than phacocanaloplasty is an excellent option in patients with mild-to-moderate open-angle glaucoma but despite the higher risks of serious complications phacotrabeculectomy may be a good choice in patients with advanced glaucoma requiring greater IOP reduction.

A retrospective study [53] compared the outcomes of phacotrabeculectomy versus phacoemulsification-deep sclerectomy, there were no cases of bleb infections or endophthalmitis, hypotony occurred in only two patients who underwent laser goniopuncture after phacoemulsification-deep sclerectomy. The frequency of late bleb leaks was significantly higher in the phacotrabeculectomy group, there was a low incidence of immediate side effects in both groups but there was a high incidence of intraoperative perforations (15.7%) in the phacoemulsification-deep sclerectomy group.

A recent survey of the American Glaucoma Society [54] assessed the surgical practice patterns among their members in various clinical settings. In the case of a patient without prior incisional surgery and with a visually significant cataract, 24% of surgeons performed phacotrabeculectomy with mitomycin C, 22% phacoemulsification with minimally invasive glaucoma surgery and 9% phacoemulsification with a glaucoma drainage device versus 44% of surgeons that preferred phacoemulsification alone.

The surgical approach for a patient with cataract and glaucoma has evolved over the years, improvements in previous surgical techniques and new available surgical options with less rates of complications has changed practice patterns among glaucoma surgeons.

5. Novel surgical approaches in cataract surgery

Cataract and glaucoma are ranked as the leading causes of blindness worldwide (51 and 8%, respectively) [55]. Both the cataract and glaucoma can coexist in elderly patient population. An estimate of 20% of cataract procedures performed annually in the USA has glaucoma or ocular hypertension. A combined cataract extraction with trabeculectomy has been the preferred surgical approach for managing cataract and glaucoma [56].

In developed countries, glaucoma is the second leading cause of irreversible blindness and this burden tends to increase as the population ages [57]. Similarly, for cataract, whose prevalence is also age-related the global prevalence of 15.5% increases to 45.9% in those over 75 years and is expected to duplicate by 2020 [58].

Cataract surgery has been demonstrated to reduce IOP in glaucoma patients as well as in non-glaucomatous eyes, with variable magnitude depending on anterior chamber depth, angle configuration or the presence of concomitant pathology as pseudoexfoliation syndrome [34]. Additionally, several series have demonstrated a greater IOP reduction postoperatively in elderly patients, females, eyes with an axial length ≤21 mm, and PXF patients [59]. Also, another beneficial effect of cataract removal can be observed in the capacity to increase the accuracy of functional and structural analyses currently used for diagnosing and evaluating glaucoma and its progression, since a visually significant cataract may act as an obstacle to these tests. Therefore, we can presume that combined treatment could be established, with cataract surgery being part of glaucoma treating standardized procedures.

5.1. Simultaneous or sequential cataract and glaucoma surgery

Currently, a variety of surgical procedures are available: first, phacoemulsification cataract extraction alone. Second, sequential glaucoma surgery and cataract extraction, and finally combined surgery. Phacoemulsification alone is suggested for controlled glaucoma patients with moderate and non-progressive visual field defect [59].

The severity of glaucoma must be taken into account for all cases of cataract surgery in glaucoma patients'. In case of a refractory glaucoma, when more than three types of medication are required, with associated early stage cataract, it is advisable to postpone any phacoemulsification procedure until after glaucoma surgery [61]. Moreover, when phacoemulsification cataract extraction is performed after glaucoma surgery, it is advisable to verify bleb function, which could be reduced. For these cases, combined surgery is more beneficial due to an improvement on intraocular pressure decrease when compared to phacoemulsification alone [60, 61].

5.2. Femtosecond-assisted cataract surgery in glaucoma

Femtosecond laser-assisted cataract surgery (FLACS), a new technology that was firstly introduced in 2008 has shown promising treatment outcomes, has realized increasing popularity [62]. Non-inferiority has been established relative to manual cataract surgery, and some reports have suggested superiority relative to manual methods [63]. Potential advantages include customized corneal incisions and capsulotomy position, precision in shape and size of capsulotomy, custom lens fragmentation patterns, endothelial cell loss reduction and better refractive stability and predictability [63].

To date, many studies have attempted to compare the outcome and complications of FLACS and conventional phacoemulsification cataract surgery. Some studies have shown better visual acuity recovery and lower endothelial cell loss after FLACS when compared with conventional phacoemulsification, in non-glaucoma patients [64, 65]. However, in glaucoma patients, the use of FLACS alone or in combination to filtering glaucoma surgery have been optimal, when taking into account postoperative visual recovery, corneal cell integrity and functionality [65].

With femtosecond laser technology and intraoperative image guidance, options for overcoming major challenges in otherwise difficult cataract cases are now available [66]. Preoperative assessment of pupil dilation (4.0 mm or greater) and presence of iridocorneal or iridolenticular adhesions is important in determining whether a patient with Peters anomaly is a candidate for femtosecond laser-assisted cataract extraction. Iridocorneal or iridolenticular adhesions that encroach on the central 4.0 mm of the visual axis may interrupt the laser capsulotomy and may necessitate decentration of the capsulotomy or exclusion of the patient [62].

During femtosecond laser pretreatment in cataract surgery, suction is applied to stabilize the eye before laser anterior capsulotomy, main incision construction and lens fragmentation [67]. Recently reported data from femtosecond pretreatment in cataract surgery suggest that the above-mentioned vacuum application transiently increases intraocular pressure (IOP) [62, 67]. Moreover, large increases in IOP can cause vascular or rhegmatogenous events; however, Schultz et al., reported recently that during femtosecond pretreatment, the IOP increase in healthy eyes is small (mean peak increase 18.5 mmHg from baseline) and appears to be well tolerated [68]. Currently, it is not known whether glaucoma patients are more predisposed to the acute complications or whether their response to vacuum applied during femtosecond laser pretreatment differs from that of patients without glaucoma [69]. Furthermore, a significant increase in IOP during laser pretreatment could result in nerve fiber damage and glaucoma progression.

5.3. Combined FLACS and glaucoma

5.3.1. Preoperative assessment

Laser-assisted cataract surgery patients should be evaluated for glaucoma. Therefore, a number of factors should be taken into account.

1. Glaucoma family history: it has been shown that people with familiar predisposition for glaucoma have increased risk of developing ocular hypertension and glaucoma. In

addition, these patients can develop glaucoma/OHT at a younger age. Therefore, glaucoma and visual field assessment is mandatory for patient's undergoing cataract surgery [70].

2. Elevated IOP remains the most important, modifiable, risk factor for developing glaucoma. However, a single IOP measurement is not sufficient to assess the actual risk of glaucoma, especially when there are other coexisting risk factors, taking into account that transient increase on intraocular pressure is going to be induced by the docking procedure during laser pretreatment [71].

3. Other ophthalmic diseases: pigment dispersion as well as pseudoexfoliation syndrome have been associated to secondary open-angle glaucoma [72, 73]. Previous reports have demonstrated that the presence of pigment dispersion syndrome does not affect the results of refractive surgery; however, topical antiglaucoma medication before surgery can modify the healing process thus the corneal wound can last longer [74].

4. Hypermetropia: hypermetropes are more likely to have narrow anterior chamber angles and a case of acute angle closure after LASIK in a hypermetropic patient has been reported. Preoperative gonioscopy will help the surgeon to recognize patients with narrow angles [75].

5.4. Toric IOL in glaucoma patients

Cataract surgery has gradually changed from vision rehabilitation to refractive surgery, which aims to achieve the best visual quality with minimal surgical trauma. With improvements of surgical techniques, postoperative corneal astigmatism has become a key factor affecting postoperative visual quality. Surgical astigmatism is caused by many factors, of which surgical incision is the main factor. The application of phacoemulsification on a clear corneal incision can cause slight reverse astigmatism, suggesting that the healing process of clear corneal incision directly affects changes of corneal astigmatism. This astigmatism is caused by the structure of the corneal incision, and corneal biomechanical changes.

Femtosecond laser-assisted cataract surgery (FLACS), which includes lens fragmentation, clear corneal incisions, and limbal relaxing incisions, was first reported by Nagy et al. [64]. The clinical application of the femtosecond laser has led to new developments for cataract surgery. The femtosecond laser system can make ladder-like multi-plane incisions in which the inner surface is enclosed. That is, the ladder between the corneal surface and matrix is made first to improve the impermeability of the incision, maintain intraocular pressure (IOP) and anterior chamber stability and prevent leakage of aqueous humor, thus reducing the incidence of endophthalmitis. The femtosecond laser system was first used to complete the phacoemulsification steps including capsulorhexis, nucleus fragmentation and clear corneal incision. The patients were then subjected to phacoemulsification to complete the entire cut along the tunnel made in former steps using a puncture knife [65].

Pseudoexfoliation is related to both glaucoma and cataract. Particularly, these patients have a tendency to achieve a poor pupil dilation; in addition to weak zonules, iridodonesis, phacodonesis or lens subluxation [75, 76]. In addition, patients with PXF may have higher pressures in the postoperative phase [76].

Toric IOLs might also not be successful in patients with an unstable capsular bag, or pseudoexfoliation and/or weak zonules, as the lens and bag may rotate or tilt once implanted, altering the patients' vision. There is a potential error if a toric IOL is implanted at the same time a glaucoma procedure is done, since a glaucoma surgery might induce keratometric changes depending on sutures and their tension, and further changes may occur if those sutures are removed or lysed, negating any benefit from the toric implant [77].

5.5. Multifocal IOLs

Multifocal intraocular lenses platforms are indeed valid options for glaucoma patients; however some considerations should be noted regarding its selection. Several lenses affect the monitoring of visual fields, recent reports by Inoue et al., revealed that multifocal IOLs can reduce contrast sensitivity and may alter raw values, gray scale and mean deviation values. Further, increased glare may reduce the sensitivity [77]. In addition, multifocal IOL implants cause significant nonspecific reduction in mean deviation (MD) values in automated perimetry in healthy eyes with multifocal compared to monofocal intraocular lens (IOL) implants on Humphrey Visual Field 10-2 testing that does not improve with time or neuroadaptation [77, 78]. Multifocal IOL implants may be inadvisable in patients where central visual field reduction may not be tolerated, such as macular degeneration, retinal pigment epithelium changes and glaucoma.

Long-term medical therapy used for several glaucoma patients can induce some degree of pupil rigidity, and in these cases, it is advisable to avoid multifocal IOLs if pupil diameter is less than 3.5 mm. Nevertheless, diffractive multifocal IOLs, which are not pupil-size dependent, can be considered for these patients. Irregular-shaped pupils, however, may increase the photopic symptoms and glare [77–79].

It is important to emphasize that multifocal platforms can be safely used in glaucoma suspects and ocular hypertensive patients with no disk or visual field damage who have been stable. In addition, glaucoma patients with early or mild visual field damage that has been controlled and stable, as well as glaucoma patients with a level of glaucoma in the fellow eye that is similar, and not severe, advanced or progressive.

Large trials providing scientific evidence-based data on the impact of multifocal IOL's in glaucoma patients, decisions regarding the implantation in a glaucoma patient should be individualized, taking into account patients' motivation and the rate of progression of glaucoma.

6. Conclusions

Cataract surgery is one of the most performed surgeries in the developed world. In addition to its significant impact on visual acuity, it has a proven potential effect on IOP decrease, but does not reduce IOP peaks [55]. More than 20 million Americans over 40 have cataract symptoms and more than 3 million cataract surgeries are performed in this country each year [80]. On the other hand, cataracts and glaucoma are the main causes of blindness in the world (51 and 8%, respectively). Glaucoma is the second cause of irreversible blindness, which increases with age [56]. Having both the same trend factor (age), they often coexist. Cataract has an overall prevalence of 15.5%, which increases to 45.9% in subjects older than 75 years and is estimated to be doubling by 2020 [58].

Does cataract and glaucoma coexistence represent a natural key to the management to both conditions? The answer to this question is under discussion, but it is important to note that 30% of patients who underwent cataract surgeries in the United States in the Medicare program had concomitant glaucoma [80, 81]. In addition, another study revealed that 9.1% of patients diagnosed with cataract coexist with the diagnosis of glaucoma [82].

Combined surgery seems to be the most understandable approach in the management of these two conditions. Cataract surgery in conjunction with conventional filtering procedures, such as trabeculectomy and valve implants, is indicated in patients with moderate to severe damage, although there is not real consensus [83, 84].

An important aspect of combined surgery is IOP peaks reduction. Traditional combined surgery produces a significant reduction on IOP, but with a higher risk of complications.

It is at this point that MIGS represents a revolution in combined surgery for glaucoma patients, certainly the IOP reduction is moderate (20%), but the complications number is reduced, it is an additional option to mild glaucoma or topical drug intolerance.

With the advent of these devices, a new vision is established in the glaucoma management, in earlier stages, leaving behind the traditional concept of glaucoma surgery in moderate or severe damage, even more the combination of these procedures with phacoemulsification, defines a new paradigm not only in the IOP control, also in a more audacious and timely visual rehabilitation, inclusive some cases premium lens implant.

On the other hand, the implementation of these novel techniques, require a prominent knowledge of the angular anatomy and be a surgeon experienced in glaucoma surgery, moreover, provides the opportunity to experts in phacoemulsification, to perform minimally invasive techniques and to do appropriate management in glaucomatous patients with mild damage. Cataract surgery with MIGS is an alternative in scrupulously selected patients (mild and moderate). There is insufficient evidence of the long-term intraocular pressure with these devices and techniques (MIGS) may become the most popular surgery in the glaucoma management and with a greater cost-benefit compared to topical treatment; however, there is not enough evidence on this, so it is advisable to consult it constantly and be cautious in the patient selection. Moreover, it is essential to recognize the inherent benefit of the combined procedure and the impact on the visual health and quality of life of our patients.

Conflict of interest

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership or other equity interest; and expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Section 4

Advance Methods in Cataract Surgery

Phacoemulsification Cataract Surgery without Viscoelastic Substance: Bianchi's Method

Germán R. Bianchi

Additional information is available at the end of the chapter

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Abstract

Life expectancy of the population increase and cataract development will affect all the people with aging. Cataract surgery, a worldwide performed procedure, evolves and progresses. However, different techniques exist, which could be selected for different cases. Any ideal technique should be safe, simple, fast, and easy to learn with good clinical outcome. This chapter will describe one technique to operate cataracts with those characteristics and to perform phacoemulsification cataract surgery without viscoelastic substance. Some advantages of this technique are related to avoiding viscoelastic potential problems, as postoperative intraocular pressure elevation or anterior chamber inflammation associated with viscoelastic. Moreover, a fundamental factor to remark is the difference between work into the anterior chamber with negative pressure or positive pressure. Because the anterior chamber is maintained by the balanced salt solution with the continuous irrigation without viscoelastic. Performing the capsulorhexis is easier. Other advantages are shorten surgical time, fewer economical cost, and potentially fewer complications. Some limitations are as follows: intraocular lens must be one piece foldable, and principally, patients with corneal endothelial pathology must be excluded. Tips, step-by-step surgery, recommendations, and evolution of the technique will be described, with the wish that many surgeons will try to perform Bianchi's method (bimanual, microincision phacoemulsification cataract surgery without viscoelastic substance) for your next patient.

Keywords: phacoemulsification, cataract surgery, viscoelastic, technique, cataract surgery complications

1. Introduction

The life expectancy is increasing every decade, and the lens of the eye decreases their optical quality over the years [1]. If we could live the number of years what is expected, everybody will have cataracts and will need a cataract surgery. That is a fact. Cataracts are still a leading cause of moderate to severe visual impairment, even blindness worldwide [2–4]. Visual impairment caused by cataract leads to not only an economic loss but also the impaired quality of life [5]. However, cataract is easily treatable by surgery [6]. On the other hand, there are different studies trying to find how cataracts could be prevented [7–9]. In the future, cataractogenesis could be totally elucidated, and maybe cataract surgery will not be necessary. However, until today, the only way to resolve this problem is by a surgical procedure.

Science and technology improve ophthalmology performance to protect the sight. Today, a cataract surgery takes only a few minutes, with topical anesthesia, with sutureless, and with a very fast visual recovery. Moreover, cataract surgery research in this field progresses continuously. And it always is possible to improve for tomorrow what we are doing now. The chapter which I want to share with you is exactly about that: how we could improve cataract surgery technique, with the same surgical equipment usually employed.

I have begun performing cataract surgery since 22 years ago. When I learned to operate cataracts, extracapsular was the surgical technique of choice, without the aid of viscoelastic substance. Their use at those years was not extended widely. And surgeries went well. After that, phacoemulsification technology produces a revolution, improving surgical outcome. At the same time, the intraocular lens (IOL) industry grew up, as well as viscoelastic substances spread worldwide and were included as one necessary medical supply for the surgery. Viscoelastic substance appears to resolve a lot of problems, which could arise when the anterior chamber is opened [10, 11].

The anterior chamber space preservation is relevant to avoid endothelial complications [12]. If anterior chamber space is flattened, the iris could be damaged, the corneal endothelium could suffer, and all of the work inside the eye are riskier. New surgeon generation from developed countries learns to operate cataracts with phacoemulsification equipment using viscoelastic substance as the gold standard technique. And today, femtosecond laser technology is growing and possibly in a close future takes the place of phacoemulsification technique completely. However, more machines, more devices, and more medical supplies are increasing their final cost and not necessarily increasing their visual and refractive results over other techniques. Moreover, there are many surgeons around the world, in developing countries, where that sophisticated technology is not accessible. They help people without an expensive medical device and without viscoelastic substance and still perform cataract surgery by extracapsular technique [13]. The Blumenthal technique of manual small-incision cataract surgery (MSICS), with the help of anterior chamber maintainer, has been proven safe and effective, preventing endothelial cell loss during surgery [14, 15].

Why have I developed this technique to perform phacoemulsification cataract surgery without the aid of viscoelastic substance? After one scientific meeting in Vienna, Austria (European Society of Ophthalmology 2015), I was thinking about the way to decrease my surgery time, simplify the technique without increasing risk, and if possible improve my personal surgery outcome. There are published descriptions to avoid the use of viscoelastic substance during IOL implantation [16, 17] with good results. First, I began doing that and it was fine. However, I want to avoid the use of viscoelastic substance at all. Could capsulorhexis and hydrodissection have been performed without viscoelastic substance safely during phacoemulsification technique? The answer is yes, and also, avoiding completely the use of viscoelastic substance, it could have relevant advantages, as I will describe in this chapter. I propose to myself to perform and develop phacoemulsification cataract surgery without viscoelastic substance. I will share my experience, my technique tips, indications, contraindications, and why today this is my first choice technique to perform cataract surgery.

2. Viscoelastic substance: advantages and problems

Since the 1970s, viscoelastic substance begins to progress, and today they are popular and indispensable for integral parts of intraocular surgery [18]. The main purpose for using viscoelastic substance in cataract surgery is to maintain a stable anterior chamber depth and protect the corneal endothelial cells from being damaged [11]. That decreases surgical complications and makes challenging cases easier. For example, there are cases called "intraoperative floppy iris syndrome," which was associated with tamsulosin, a systemic α-1 blocker used to treat benign prostatic hypertrophy [19]. The clinical intraoperative triad of the syndrome consists of fluttering and billowing of the iris stroma caused by ordinary intraocular fluid currents, a propensity for iris prolapse through the phacoemulsification and/or side-port incisions, and progressive constriction of the pupil during surgery [19]. Also, viscoelastic substance is sometimes helpful to tamponade a posterior capsule rupture for subsequent IOL implantation [20] or to inject viscoelastic substance through a pars plana incision to elevate the nuclear pieces into the anterior chamber [21].

However, there are studies which describe problems related with viscoelastic substance. The IOP elevation by viscoelastic substances is caused by a reduction of aqueous outflow due to blockage of the trabecular meshwork where the fluids exit the eye, which was first published in 1990 [18] and later confirmed by other authors in vivo and in vitro [10, 22, 23]. Therefore, complete removal of viscoelastic substance is recommended after IOL implantation. The IOP elevation is usually transient, peaking at 4–7 h postoperatively and returning to baseline within several days, but the maximum IOP may exceed 30 mmHg. Therefore, careful monitoring of IOP and IOP-lowering therapy may be necessary, especially in patients with glaucoma who have a compromised outflow facility.

Flare or Tyndall effect could be postoperatively detected after cataract surgery, which in part is frequent, but in excess that could be the manifestation of "toxic anterior segment syndrome" (TASS) after cataract surgery, and viscoelastic substance could be associated with this [23, 24]. Also, an extra surgery time is necessary to introduce viscoelastic substance and to completely remove them from the anterior chamber, trying to avoid the problems previously described. Moreover, viscoelastic substance increases the final cost of the surgery. In conclusion, viscoelastic substances could help to perform a more secure surgery, especially in some cases, but also could be the cause of other problems, sometimes serious. Because of that, this work emphasizes and proposes a special technique to perform phacoemulsification cataract surgery without viscoelastic substance.

3. Bianchi's method: patient selection

As any surgical technique, specific indications and contraindications (inclusion/exclusion criteria) will be described, to choose the appropriate case or to exclude patients with high risk:

1. Include patients with cataracts classified as NO1–NC1 to NO4–NC4 according to the LOCS III classification (avoid NO5–NC5, NO6–NC6).
2. Exclude patients with less than 2000 endothelial cell count preoperative. Endothelial cells count evaluation is necessary to be included as a standard preoperative test, and it is advisable to perform as postoperative standard follow-up test.
3. Exclude patients with endothelial defects, *pseudoexfoliation*, posttraumatic cataracts, pupil synechiae or small pupil, uveitis, and/or previous vitreoretinal surgeries.
4. Include only patients programmed to implant foldable one-piece intraocular lens (IOL) models with injector.
5. Exclude patients when three-piece IOL models are programmed to implant. I do not recommend those kinds of IOLs for this procedure because their haptics are hard and the capsule could be broken.

4. Bianchi's method: technique description step by step

When a new surgical technique is presented, there are many questions to be answered. I will try to describe all of the details because I hope many surgeons worldwide probe it with success. One first question: will it be necessary to acquire new equipment, devices, and/or machines? The answer is no. The technique could be correctly performed with different standard phacoemulsification equipment, and any surgeon who perform phacoemulsification with viscoelastic technique could perform the Bianchi's method without viscoelastic substance. Hand positions and movements are similar to "microincision cataract surgery" (MICS). It is just necessary to get a micro-capsulorhexis forceps of 1.1 mm diameter, which must have the same diameter of the irrigation cannula. From standard surgical instruments usually employed to perform phacoemulsification, you will only need the irrigation cannula, but the aspiration cannula is not necessary. **Figure 1** shows the specific surgical tools.

Topical anesthesia must be performed as usual *and then*:

1. Two clear corneal incisions of 1.1 mm were performed with v-lance near the limbus. The first was at "2" o'clock and the second at "10" o'clock.
2. Immediately after the first incision was performed, the irrigation cannula (1.1 mm diameter) was introduced, the second incision was performed, and the micro-capsulorhexis forceps of 1.1 mm diameter was introduced. The size of the v-lance and the irrigation cannula must be the same to avoid leakage through the corneal incision.

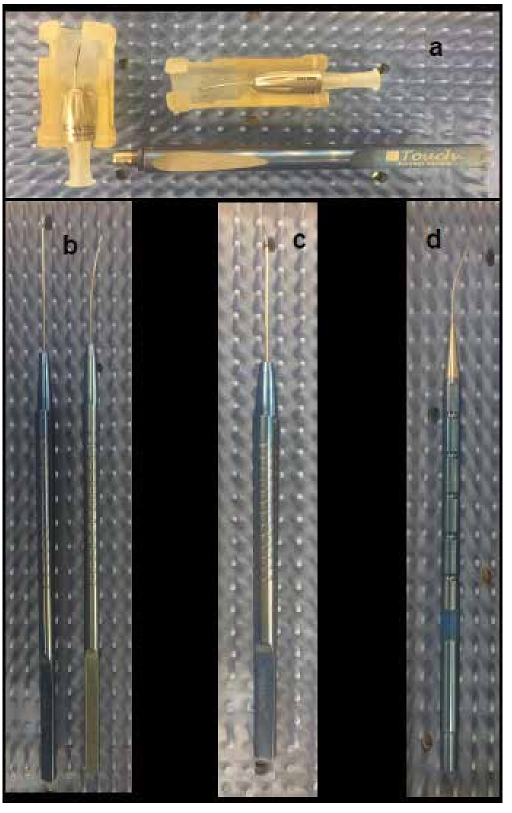

Figure 1. Surgical instruments necessary to perform Bianchi's method. (a) MST Touch Handle and 23g Micro-Holding Forceps for capsulorrhexis; (b) Curve and straight Micro-Scissors; (c) capsulorrhexis micro-forceps and (d) I/A irrigation cannula.

3. The irrigation bottle with balanced salt solution (BSS) must be elevated usually at 80–100 cm above the patient's head level, under continuous irrigation (no more, to avoid IOP increase), to obtain a deep and stable space in the anterior chamber. The irrigation cannula has two lateral vents, which let the BSS leave and move in a centripetal way, toward the equator. That means the liquid circulation is not against the endothelium; therefore, the endothelium is protected. For the learning curve, in the first case, it is recommended to put in the automatic or continuous way the irrigation mode of the phaco. This lets to maintain stable the anterior chamber automatically. With more experience, the surgeon can manage them with the phaco pedal.

This bimanual technique is suitable for right- or left-handed surgeons. The previous description is for right-handed surgeons. For left-handed surgeons, "2" o'clock incision is for micro-capsulorhexis and the cannula must be located at "10" o'clock incision.

4. Capsulorhexis was performed (**Figure 2**), while the liquid (BSS) circulation in the anterior chamber produces a positive pressure, which determines a stable and safe space to work. This is one of the most important points of the technique. It is easier to perform the

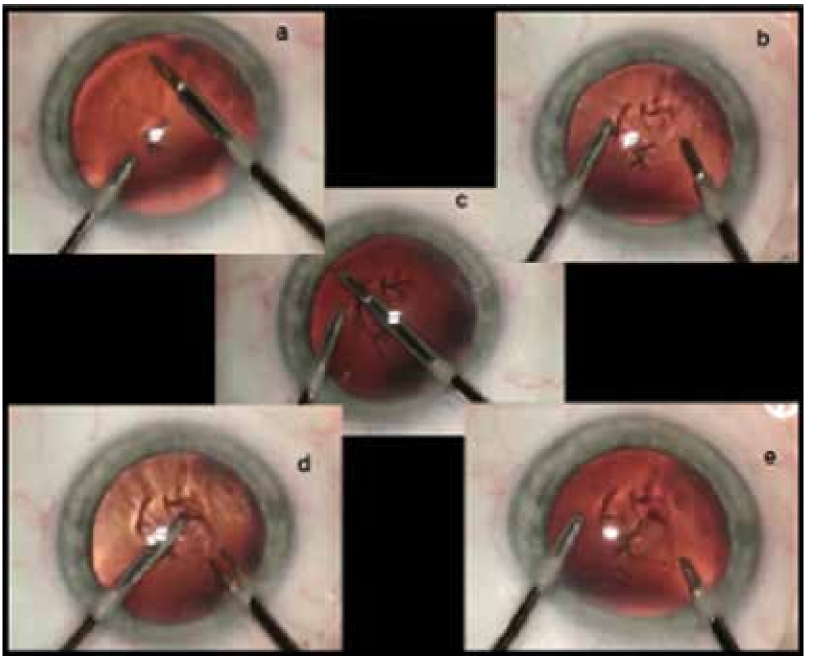

Figure 2. This figure shows from "a" to "e" the capsulorhexis procedure with continuous liquid circulation into the anterior chamber.

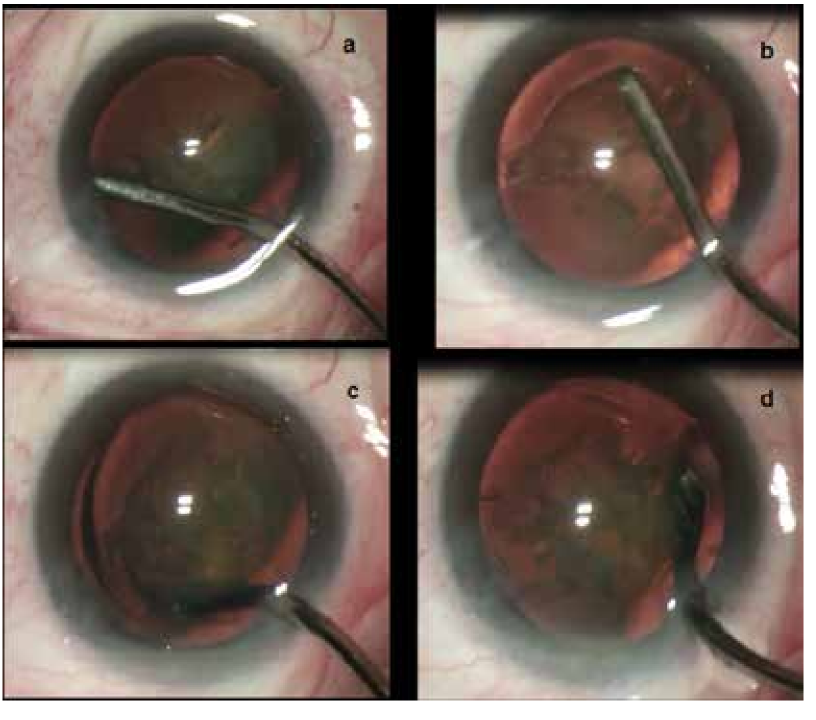

Figure 3. Hydrodissection step performed with the irrigation cannula and from "a" to "d" is possible to see the nucleus rotation.

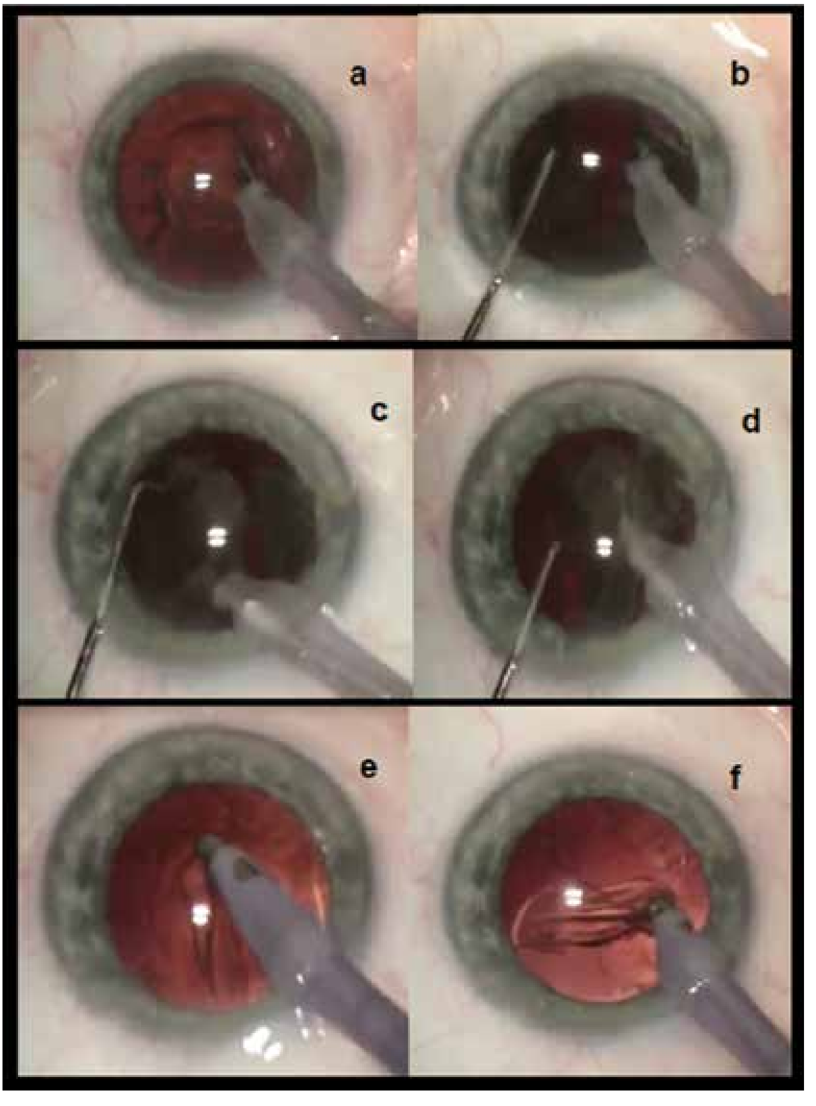

Figure 4. Phacoemulsification, aspiration, and mass extraction were performed as usual.

capsulorhexis under positive pressure than under negative pressure (as what happens with viscoelastic substance), because continuous irrigation flattens the anterior face of the lens. When you are working under positive pressure into the anterior chamber, it is very rare to have the problem of capsulorhexis rupture. In my experience, capsulorhexis failure was more frequent with viscoelastic substance than those cases performed without viscoelastic substance.

5. After that, hydrodissection was performed with the same irrigation cannula until a complete rotation of the nucleus was observed (**Figure 3**). Perform this step carefully, because if you push too much the nucleus, the zonnula could be broken. However, it is not difficult to perform the hydrodissection: simply, let the irrigation cannula position below capsulorhexis, and the liquid diffuses around the nucleus to release it. Or sometimes, a

circular movement of the cannula could be performed to facilitate that the nucleus will be released from the epinucleus. Then, the rotation of the nucleus will easily occur.

6. Phacoemulsification, aspiration, and mass extractions: it will be performed without any difference from a standard procedure (**Figure 4**).

7. Next step: without removing the cannula, the second corneal incision must be increased (**Figure 5**) according to the phaco tip, for the IOL implantation (1.8 mm, 2.2 mm up to 2.8 mm or what the surgeon need) (**Figure 6**). Only foldable one-piece IOL models with injector could be used. Three pieces IOL models are not recommended for this procedure. When the intraocular lens cartridge was introduced through the incision, the anterior chamber could suffer a space reduction due to BSS outflow, but immediately after the IOL injection begins, liquid leakage stops, and the anterior chamber space is restored. The positive pressure expands the capsular bag, and then the IOL is placed with the cannula to help during the unfolding process to obtain the correct IOL position. Also, this procedure let the toric IOLs be easily rotated, if it was necessary. This is another advantage of this technique against standard technique with viscoelastic substance, because sometimes, after removing viscoelastics, toric IOLs could be displaced and are necessary to correct their position again, to obtain the exact location for astigmatism correction.

Finally, I usually inject an intracameral antibiotic (cefuroxime) and the surgery concludes. Most of the surgeries were performed between 4 and 5 min or 6 and 7 min for harder cataracts.

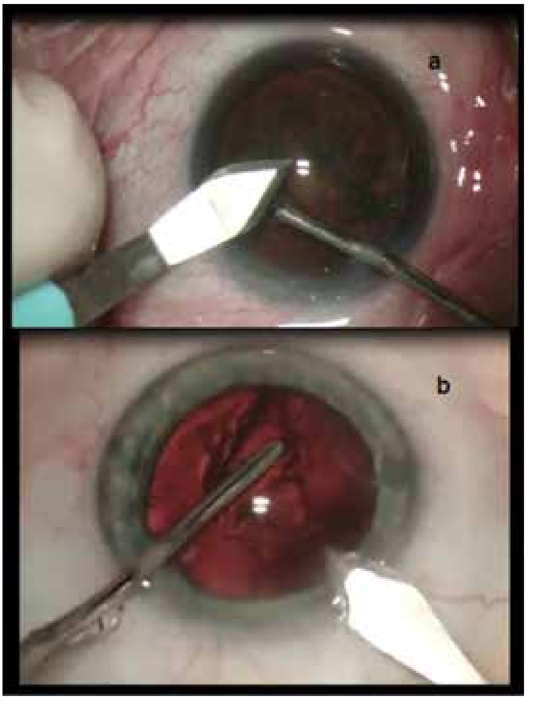

Figure 5. This figure shows the second corneal incision enlargement.

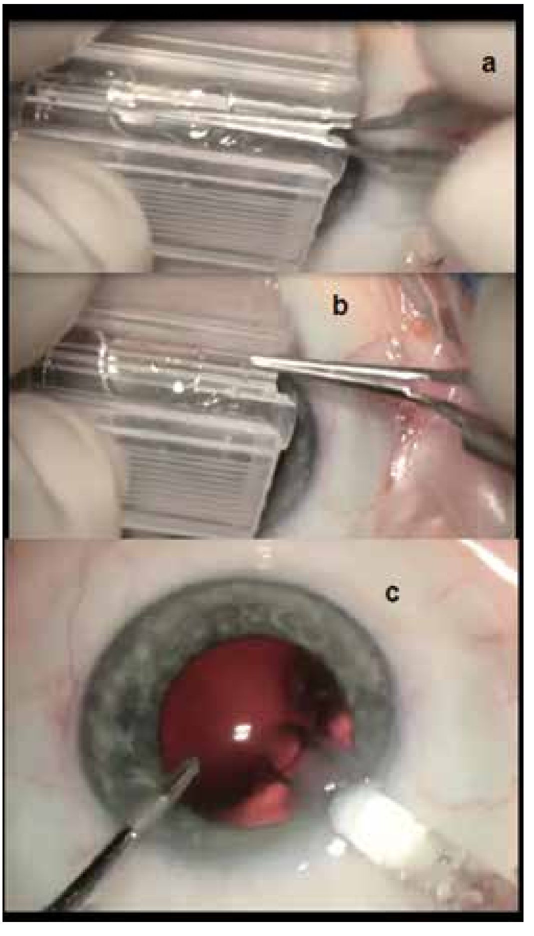

Figure 6. One-piece intraocular lens is placed in an injected.

5. Is this technique secure?

Performing cataract surgery without viscoelastic substances seems to be dangerous for the corneal endothelial tissue. However, with the surgical steps previously described, it is true? To evaluate and control this matter, since my beginning with this technique (July 2015) and after 1500 operated cases, all of the patients are still followed with endothelial cell count and central corneal thickness evaluation (always at the preoperative time and, then, at least 6 months post-op with endothelial cell count follow-up).

A prospective comparative study is ongoing, to evaluate clinical outcomes and complications between both techniques: phacoemulsification with and without viscoelastic substance by Bianchi's method. I can advance some data from this study, as a brief preliminary report. The patient's age was 45–91 years old; none of them has suffered intraoperative or postoperative complications as capsular bag rupture, IOL implantation problems, expulsive hemorrhage, IOP elevation, TASS, and/or endophthalmitis. All of the patients improve their visual acuity. Endothelial cell count and central corneal thickness were compared between patients operated with and without viscoelastic substance, and nonstatistical significant difference was found between both groups. The surgical time with Bianchi's method is between 4 and 5 min (7 min maximum) and for standard phacoemulsification with viscoelastic is 8–10 min (for this study, the surgeon was *German Bianchi MD* for all of the procedures). Why is the surgical time shorter? Because an extra time is needed to insert and completely remove the injected viscoelastic substance. Besides a prolonged operation time, which per se increases overall operation risks and complications, viscoelastic substance removal can immediately affect safety issues. Also, an increased irrigation-aspiration time might also be responsible for endothelial cell loss due to the aspiration trauma. The use of a viscoelastic substance can have side effects and may cause endothelial damage as well.

Even though it is an ongoing study, preliminary data plus the experience of 2 years doing this technique with good outcomes let me confirm that it is secure, fast, and simple. Now, it is my first choice to perform cataract surgery.

I have started to teach this technique to the ophthalmic residents of the clinic where I work, and they told me "it is not difficult" and also the learning curve is fast. However, some colleagues previously told me: "well, is easy for you… but not for everybody!." No, today I can confirm that the Bianchi's method to perform cataract surgery without viscoelastic substances is easy, for any ophthalmic surgeon who used to perform phacoemulsification technique or MICS.

6. Is there another experience where surgeons try to avoid the use of viscoelastic substance?

Schulze et al. [25] avoid their use, only during IOL implantation, without finding difference in endothelial cell loss. Oksuz et al. [26] described a technique without VS to perform capsulorhexis, but they use it after hydrodissection and for the IOL implantation. Finally, they aspirated it from the anterior chamber.

In the past, Wright et al. [13] compare their results of small-incision extracapsular cataract surgery using the anterior chamber maintainer without viscoelastic substance, and they finally show that the magnitude and range of the endothelial cell losses associated with this technique are significantly greater than those described following phacoemulsification. Because of that, these authors finally recommend the use of VS for this extracapsular procedure.

But in 2008, Sallet [27] described a phacoemulsification cataract surgery technique completely performed without VS, where he found no difference in their clinical outcome comparing it with 50 patients operated with VS. However, Galan [28] previously performed a similar technique with 1.6 mm corneal incision and enlargement to 3.0 mm for IOL implantation with less success rate than Sallet G, which Sallet considered could be due to the narrower incisions performed by him of 1.2 and 2.6 mm for IOL implantation. The technique described in this work proposes two corneal microincision, which is 1.1 wide and the enlargement of one of those to 2.2–2.8 mm according to the phacoemulsification tip (Sallet G open 2.6 mm). Small corneal incisions could be in part the key to obtain better surgical results. Another difference with the technique described by Sallet G is about hydrodissection: in the present technique, it is performed by the irrigation cannula.

7. Economical surgery cost

This new technique is not more expensive. In fact, it is more economic, because it is not necessary to buy viscoelastic substances. In the country where I live, the final cost of the surgery increases US$75 per procedure when viscoelastic substance (I use DisCoVisc®) is necessary.

However, as in this chapter was described, there are many patients where viscoelastic substances are not necessary: not only because it increases the surgery cost but moreover because they could be a potential problem, which disrupts the surgical outcome.

8. Final recommendations

As it was mentioned at the beginning of this chapter, lifetime expectancy increases as well as ocular tissues grow older. Our eyes are not prepared for the last years that we are living. Cataracts appear and the possibility to replace them with an IOL let many people stay able to keep their sight and quality of life. Moreover, the improvements in the surgical techniques, device, equipment, and tools let today to resolve high orders of refractive problems with the IOL implantation (with or without removing the lens). The procedure to implant an IOL into the eye is short, simple, and secure. But it is always possible to improve and adequate techniques to different environments.

The technique described in this work was presented in the XXXV Congress of the European Society of Cataract & Refractive Surgeons (ESCRS Lisbon 2017) at the Video Awards Session. There is a mini-review published in September 2017 [29]. Also, the video of the technique could be showed in https://vimeo.com/212631783. If you are a cataract ophthalmic surgeon, try this technique, and you will decrease complications, surgery time, and surgery cost with a better postoperative recovery. Remember the indication and contraindication, choose the right patient, and go ahead.

Below is the list of advantages and limitation.

Advantages:

1. Avoid complications related with viscoelastic (IOP elevation, TASS) and corneal endothelial damage during the viscoelastic substance aspiration.

2. Perform a fast surgery (4–5 min usually, 6–7 min at maximum).

3. Work all the time under positive pressure in the anterior chamber; this let the capsulorhexis becomes easily performed.

4. Short learning curve: usually new cataract surgeons only learn to operate phacoemulsification cataract surgery with viscoelastic substances. I'm not against viscoelastic substance, which is really useful for some cases, although, for other cases, it could be possible to perform a safe procedure without viscoelastic substance, moreover, with "extra" advantages!
5. Surgery cost: the final cost of the surgery decreases for the patient, because you do not need an extra medical supply (you do not need to buy viscoelastic substance for each surgery). And as my scrub nurses happily told me, they also prefer it. Why? Microcapsulorhexis forceps cleaning and maintenance are more easy when I use BSS than viscoelastic substances. And also, that increases the lifespan of my surgical tool. For all of those reasons, it decreases the total surgical economical cost.
6. One more advantage: you do not need a third-hand incision.

What are the limitations or contraindications?

1. Avoid "hard" cataracts.
2. Avoid three-piece IOL.
3. The technique is not recommended for patients with endothelial corneal pathology, pseudoexfoliation syndrome, traumatic cataracts, and/or history of previous vitreoretinal surgery. However, in those cases, the standard phacoemulsification procedure will also increase the surgical risk. Endothelial corneal transplantation or complete perforated corneal transplant could be necessary at the end because of bullous pseudophakic keratopathy and the consequent corneal edema.
4. Endothelial cell count is a mandatory preoperative study, and I recommend follow-up 6 months after surgery. I know that some places do not have an endothelial cell counter analyzer, but it is a study which I think is relevant to perform not only the Bianchi's method, moreover, for every patient who will need a cataract surgery. Today the people have great expectative about their refractive surgical outcome after cataract surgery, and if a patient has an endothelial problem and if it was possible to have an objective data about it, the surgeon could decrease patient's expectative and explain to him which could be his specific surgical risk, before performing the surgery. I emphasize this point. It is a really important issue to prevent legal problems.
5. If capsulorhexis goes wrong, always convert to viscoelastic standard technique.
6. Hydrodissection must be performed without pressing over the posterior capsule to avoid rupture.
7. Doing the IOL implantation should be obtained in a well expanded anterior chamber, but if not, use viscoelastic substance.

In summary, a bimanual phacoemulsification microincision cataract surgery could be performed without the aid of viscoelastic substance, decreasing their economical cost during 5–7 min. The technique is easy to learn and potentially with fewer complications, which must be scientifically demonstrated in a prospective study (which is an ongoing study), and even better in a multicentric study to confirm that this technique is efficient and reproducible for different ophthalmic surgeons.

And finally, to end this chapter, I want to share with you a little story.

My professor was Dr. Hugo Dionisio Nano, one of the most important ophthalmologists in Argentina, with international recognition around the world. Dr. Nano, with his age of 88 years old, usually goes to his clinics, goes to scientific meetings, and still is an active "ophthalmology teacher" for many colleagues. In 2016, he needed a cataract surgery and chose me as his surgeon, a great honor and a great challenge for me. For his first eye, I have performed the standard phacoemulsification cataract surgery, with viscoelastic substance. Surgery went fine with no complications. However, he had a moderate postoperative inflammation and intraocular pressure rise, which resolved a few days later. One week after, I chose to operate his second eye without viscoelastic substance (Bianchi's method), and he did not have any postoperative problem. This is one anecdote I know, but I hope with this chapter, I could give you enough scientific information and technical tips to encourage you and try "Bianchi's method" in your next cataract surgery.

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Optimizing Outcome of Cataract Surgery in Resource Scarce Sub-Saharan Africa

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Additional information is available at the end of the chapter

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Abstract

Background: Sub-Saharan Africa disproportionately accounts for high number of avoidably blind largely caused by cataracts.

The blindness burden: Limitation in human and material resource for delivery of cataract surgical services, cost, gender, distance to hospital, time off for the care giver, fear of surgery, uncultured behavior of eye care personal, poor visual outcome, general governments neglect of health care, lack of health insurance for vast majority of the population, healthcare funded by individuals as out of pocket despite grinding poverty, reliance on poorly coordinated and unsustainable outreach program, malpractices of quacks and traditional eye healers amongst other reasons.

More than just a cataract: Cataract services require systematic evaluation of the patients' general condition as well as the eye. Appropriate counseling is required to understand the goal and expectation of treatment. Adequate planning of surgery includes ocular biometry and provision of the appropriate intra ocular lens. The management protocol must ensure adequate measures are taken to prevent/ manage critical incidents whenever such a need arises.

Conclusion: Cataract surgical services need to be patient centered with the goal of optimizing resources for quality outcome without compromising safety.

Keywords: cataract, surgery, resource, outcome, patients, safety

1. Introduction

Age-related cataract is the leading cause of avoidable blindness [1–4]. While Africa hosts 11.9% of the World population, it also disproportionately accounts for about 15% of those avoidably blind. Sub-Saharan Africa carries the worse burden with 4.8 million blind partly due to 66% population growth [5]. Other factors accounting for this include scarcity of eye care personnel, limitation in technology and training for eye care, lack of local production of eye medicine, and other consumables leading to dependency on importation in the presence of limited foreign exchange availability, unrestrained and unregulated malpractices of quacks, and traditional eye care providers. It is not unusual for such unregistered practitioners to be patronized by the political class resulting in wide-scale eye couching with all the related complications. In Sub-Saharan African region where human and material resources are scarce, health care is on a free fall as health insurance is largely inaccessible to the vast majority of the population [6].

Unfavorable health indicators such as high maternal mortality, high infant and under five mortality [7], high morbidity and mortality from both communicable [8] and noncommunicable diseases [9], and reduced life expectancy are the norm [10]. The poor people pay for health care as out-of-pocket expenses. Whenever health personnel knock on their door to administer vaccines, they become suspicious, considering the fact that they have to wait long hours to be attended to at government hospitals and clinics and most times they buy drugs from unprofessional vendors in pharmacy shops. Clerics and community leaders who should have been carried along are uninformed and often unsupportive of such programs. As such "free" healthcare programs are shunned by some communities who are made to believe they are aimed at subtly curtailing their population.

Local eye care advocacy groups can spend months to years hoping to see government officials to suggest ways forward to no avail. Expatriate eye care teams who surface once or twice in a year to do a few hundred cataract surgeries are received almost immediately by the local authorities. Such teams are treated with care and concern providing a photo opportunity for the politicians and giving the impression that all the eye problems of the community have been solved. Dependence on inconsistent external outreach services by authorities lead to further complacency and neglect.

Inappropriate appointment of members into district, state and national blindness prevention committees is such that technocrats hardly have a say in decision making. Such committees hardly meet, and when they do, decisions are hardly transformed into action. Often there is no time scale for implementation, no mechanism for self-audit, and no follow-up on programs, and the roles of members are hardly clearly stated. Most eye care teams are bedeviled with lingering rivalry and leadership crisis, which tend to be prolonged and incapacitating causing inability to achieve the goal of the team. There is need for models of leadership capacity building to address the need for core technical and management competencies [11].

There are unlimited barriers to eye care, which include distance to facility, transportation cost, time off for the care giver to accompany the patient, gender, cost of cataract surgery, rude behavior of some eye care workers, cost of investigations (blood sugar level, hepatitis, HIV, etc.), multiple visits, long bookings for surgery, and poor outcome as perceived by those who preceded the index patient [12–18]. The need to optimally use available materials and human resource to ensure that patients get the best outcome of surgery despite the existing limitations is of paramount importance.

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2. More than just a cataract

Cataract surgery is considered one of the most rewarding medical interventions. Suffice it to say that sight is restored almost immediately thus improving the patients' quality of life [19, 20]. This observation may result in considering the procedure so casually without taking meticulous steps that ensure that there is quality in terms of postoperative visual acuity and patient's safety. Removing the cataractous lens and inserting an intraocular lens no matter how fast and quick this is achieved are not synonymous with obtaining good postoperative vision and ensuring patient's safety.

Good clinical practice starts with obtaining reliable history. The ophthalmologist should be courteous and willing to listen to the patients' complaints. There should be no indication, behavior, or action to make the client feel he is in a police station facing interrogation or a courtroom on trial for what he did or should have done about his eye condition. Rural folks constitute majority of the population in the region and often tend to fear such formal interactions with unfamiliar personalities in an unusual environment. When the patient becomes fearful and suspicious, reliable history may not be obtained, thus heralding the first step toward not obtaining quality outcome.

Ordinarily, patients present with painless progressive loss of vision over a time frame often in months to years. Additional information related to pain could arise from a number of factors including secondary glaucoma from intumescent cataract, inflammation, and/or panophthalmitis due to infection from attempted couching. A positive history of application of (harmful) traditional eye medication (TEM) could be obtained by gentle probing. TEM use is not unusual despite its harmful effect [21, 22]. This may require making a suggestive comment such as "losing one's sight is quite disturbing, please were you able to obtain traditional medicine that someone has tried in your community in the hope that your eye will open?" Compare this statement with "did you apply damaging traditional eye medication instead of coming to see us here in the eye clinic where we can offer you the best treatment?" Some TEMs are potentially contaminated and may contain substances that can damage the cornea.

In other instances, patients could have had surgery elsewhere with improper guidance on follow-up or the postoperative medication has finished and nowhere/no means to buy. Postoperative inflammation tends to last more than 6 weeks perhaps due to environmental and genetic factors. Complain of pain should warrant careful probing of possible preexisting ocular and systemic diseases. There is need to ask for presence of discharge from orifices, skin, and other body parts. This is relevant to treat any source of infection before surgery. This will reduce the risk of transmission of microbes to the raw eye postsurgery.

The clinician needs to enquire whether the patient is a known hypertensive, diabetic, or living with HIV. This is necessary in order to ensure control of the preexisting medical conditions for the safety of the patient, the staff, and other clients. Patients with hypertension or cardiac disease could have exacerbations with adrenaline-containing local anesthetic injection. Centers must have dedicated instruments set for those with hepatitis virus infection and HIV as these diseases are found among patients undergoing eye surgery [23]. Fore knowledge of these diseases will ensure taking measures to safe guard the health of all those attended to in the facility. A positive history of previous drug reactions and the type of medication must be solicited. Reaction can occur with both orthodox and traditional medications [24].

Knowledge of musculoskeletal diseases is important to ascertain that the patient can lie down properly in the supine position during the procedure. It is unforgiving to miss such crucial information from the history and/or during general clinical examination and make such discoveries while the patient is on the table.

History of urinary frequency must be obtained in older male patients to exercise caution in administration of carbonic anhydrase inhibitors pre-op as this may push them into acute retention. Similarly, patients with bladder outlet obstruction tend to have urinary frequency and may go into urge incontinence while on the operating bed. Thus, appropriate measures are taken to limit such distress during surgery.

2.1. Ocular examination

Visual acuity is measured at 6 m with good illumination. Illuminated charts are more helpful; where electricity supply is irregular, vision could be tested in the open. Snellen chart is for literate patients and Landolt C or "E" chart is for the nonliterate ones. Vision can be as low as perception of light (PL). Cataract no matter how dense should not lead to no perception of (NPL) vision. Presence of NPL vision should make the clinician curios to search for additional cause of ocular morbidity co-existing with the cataract. The lids are examined for position and alignment as cicatricial trachoma is still prevalent leading to entropion/trichiasis [25]. Periocular vascular congestion is a pointer of intraocular inflammation and/or infection. The superior limbus should be examined for tale-tell scar from possible previous surgery. A bleb indicates the patient had previous glaucoma surgery [26]. This knowledge is important in counseling the patient on visual outcome before surgery for cataract.

The cornea should be clear. Dot opacity may indicate transcorneal couching [27]. Couching is associated with worse vision outcome [28]. Cornea should be examined for climatic droplet keratopathy or calcific band keratopathy in patients with prolonged ocular surface disease. Pseudophakic bullous keratopathy could be seen in cases of previous cataract surgery that had endothelial damage. If present in one eye, this should warrant additional precaution in operating the index eye by limiting unnecessary entry of instruments into the open eye, cushioning the endothelium with viscoelastic material, and reducing operating time. Such surgery should not be performed by a trainee on the learning curve. Similar advice is advocated for patients with an only eye. The anterior chamber (A/C) should be deep and quite even with pen light inspection. Shallow a/c with corneal edema may result from a swollen cataractous lens; in this instance, the intraocular pressure (IOP) is elevated. It is not unusual to observe cortical matter or nucleus in the A/C from previous couching. Fresh keratic precipitates (KPs) are indicative of active anterior uveitis and thus such cataract could be secondary to the inflammation that requires treatment before any surgical intervention is considered.

The pupillary reaction should be brisk. Abnormal pupillary reaction should lead the clinician to evaluate for signs of gross retinal or optic nerve disease such as retinal detachment or optic atrophy from glaucoma or other causes. Direct fundal examination may not reveal even a red reflex with fully matured cataracts. Immature cataracts could allow examination of the posterior pole particularly with the binocular indirect ophthalmoscope (BIO). A normal optic disk and retina are expected in age-related cataract in the absence ocular comorbidity. Gross retinal function could be assessed by using four-quadrant like projection. In the light projection test, the patient should be able to point in the direction of the light accurately when presented from above, below, and to the left and right sides of the index eye. Other techniques include shining two bright light spots on the index eye after occluding the contra lateral eye. The patient should be able to discern the 2 light sources apart at 5, 7, and 12 cm for visual acuity of counting finger, hand motion, and light perception, respectively. B mode ocular ultrasound scan can be used to rule out retinal detachments or intraocular mass particularly where there are equivocal clinical findings.

The intraocular pressure (IOP) is measured with Goldman's (or other tonometer where available) and should be within the normal limits. A normal IOP measurement does not rule out glaucoma. Noncontact and minimal contact tonometer such as Pulse air and Rebound are more tolerated albeit available in few eye centers. They are more expensive in the presence of lean health budget in the region. Low IOP may indicate retinal detachment warranting further investigation. Slit lamp bio-microscopy is done to inspect the cornea, anterior chamber (a/c), lens and iris, this may be with associated with pupillary dilatation to detect presence of synaechia, to determine morphologic appearance and grading of the cataract. Specular microscopy is performed to assess the endothelial cell density; low density is associated with the risk of corneal decompensation after surgery, although measures are always taken to prevent such occurrence. Less expensive handheld slit lamps could serve the same purpose.

2.2. Preparing the patient for cataract surgery

Eye care teams in the region must ensure that there is appropriate preoperative assessment of patients, proper counseling, and informed consent administration. Basic eye and general examination is essential in planning for good outcome of surgery. This does not necessarily have to be expensive. Preparation includes measurement of the pre operative visual acuity, the state of the corneal clarity, pupillary reaction and intra ocular pressure measurement. The anterior segment is assessed with slit lamp to identify age related degenerative changes, other ocular co-morbidity, presence of posterior synaechia, dislocated lens from possible attempted couching, and anterior uveitis. Four quadrant light projection test is performed to grossly assess state of the retina.

Systemic examination is necessitated to ensure the safety of the patient. It includes blood pressure measurement and fasting blood glucose level estimation. The packed cell volume should be no less than 10 mg/dl. Patients with diabetes mellitus must have adequate control where necessary and available 3-month sugar level pattern can be ascertained by determining the glycosylated hemoglobin (HbA_1c level 7.2% or less is considered normal) [29]. Diabetic eye complications are potentially blinding and can coexist with the cataract [30]. Cataract surgery is also known to exacerbate diabetic retinopathy, making proper counseling on projected visual expectation and the need for further treatment related to the underlying disease important. Cataract surgery is known to improve vision and vision-related quality of life in patients with diabetes [31, 32].

At this stage, it is worthy to ascertain clinically clear respiratory system, a normal cardiac examination consisting of blood pressure, regular normal volume peripheral pulse, undisplaced cardiac apex position, and first and second heart sounds. An electrocardiogram maybe requested for when needed and a cardiologist can be asked to review and stabilize the patient. The central nervous system is examined to rule out obvious cranial nerve palsy and motor dysfunction, and the patient should be in a stable mental state to understand and cooperate during the procedure.

An abdominal examination is needed to detect suprapubic distension caused by a full bladder in patients with suspected urinary outflow obstruction. The general physical examination protocol will determine the presence of any musculoskeletal anomalies that can interfere with positioning of the patient on the operating table.

Other investigations include screening for hepatitis and HIV for the safety of the patient, the eye care team, and other patients. Trimming of bushy lashes will make the eye neater intraoperatively and during postoperative dressing. Oral carbonic anhydrase inhibitor such as acetazolamide is administered the night before and on the morning of surgery. Tropicamide is used to dilate the eye. Consent to undergo surgery is obtained from the patient in the presence of the care giver. As much as can be allowed, day-case surgery should be encouraged. The advantages include reduced/abolished cost of admission to the patient and circumventing the issue of limited bed space, which will otherwise reduce the number of surgeries performed in a session. Perhaps, this is even more desirable particularly in hospitals where ophthalmic and other potentially septic surgical patients share common ward space.

2.3. Ocular biometry

This consists of A-mode ultrasound scan to determine the axial length of the eye and keratometry to obtain corneal power in the two principal meridians. IOL Master gives error message and is not useful in patients with fully matured cataract. The two values are factored into calculating the intraocular lens power. Various formulae are incorporated into determining the IOL power. To prevent obtaining postoperative refractive deficits, there is a need to obtain accurate IOL power [33]. The practice of using standard power IOL perhaps based on experiences on most frequently used power in parts of the region can be adopted out of necessity. Such patients depending on their visual needs may turn out to need further spectacle correction, an unnecessary additional out-of-pocket expense that could have been avoided. Ideally, all patients should and must have the best, as residual refractive errors may manifest later. Manual keratometry will suffice where automated ones are unavailable though these are not as user-friendly.

2.4. The operating room (OR)

Standard requirement includes wall, floor, and ceiling that will not retain dirt and germs. There should be wall and floor tiling that can easily be washed and mopped. The windows need to be kept closed and ventilation provided by room air conditioning. Floor, wall, or ceiling fan will sprinkle dirt and other contaminants into the opened eye. Where grid energy is unavailable, a portable generator can be used. There should be no thoroughfare in the operation room. There should be a red line beyond which unauthorized persons are not allowed. Bidirectional swing doors are preferred to enable the surgical team move in and out of the operating suite without the need to handle the door. Patients have to substitute their clothes with the theater gown before going into the operating room (OR). The scrubbing area should be in an adjacent room. Where such an arrangement is not possible, moveable wash pans can be used on a stand. The changing room is adjacent to the theater. Windows should be cleaned regularly and kept closed. Open floor drains should as much as possible be avoided. Staff must not bring food items into the OR as this may encourage pests. Regular fumigation is advocated to improve sterility.

A simple examination couch can serve as operating bed. Where space allows, two couches can be placed. This will reduce transit time wasting in between cases. Two surgeons can man each station or one surgeon can alternatively switch between the stations. There should be a minimum of four cataract sets, whereby two can be sterilized alternating for patients with no identifiable communicable disease, in addition to one set dedicated for patients with HIV and the other for those with hepatitis. Boilers are ineffective in sterilization. Hot air oven does not blunt sharp instruments and is preferred to steam autoclave. A minimal of two trolleys is required to set the instruments. Trolleys are routinely washed and cleaned with appropriate disinfectant solution. Aluminum drip stands with tray are used to hang irrigation fluid and cannula. Cannula needs to be washed, flushed, and sterilized with activated glutaraldehyde solution not forgetting to flush again with saline before use on the patient. Plastic microscope handles and other control covers should be similarly treated. To ensure safety, a separate cannula should be used for each patient and sterilized in between cases. At the end of the session, unused fluids must be discarded.

A sharp box is required to dispose of used needles, whereas other used items can be thrown into the kick about bucket for conveyance to the incinerator later. There should be separate drape for each patient. Bilateral simultaneous cataract extraction must be avoided to limit morbidity in the event of postoperative endophthalmitis. There are low-cost ophthalmic microscopes from Far East countries, which despite having less versatility (stereopsis/zoom/camera attachment, etc.) can serve adequately.

The surgeon and assistant (ideally a trained ophthalmic nurse) should be properly scrubbed and gowned. Separate pair of gloves is to be used for each patient. An idle team should consist of the surgeon(s) and two assistants, one to stay with the surgeon and the other to circulate ensuring used instruments are promptly removed and replaced by sterilized ones. An attendant should serve the role of bringing in the patients with their folder and appropriate power IOL. The surgeon can dictate critical incident to be recorded by the circulating assistant before full documentation in the patient's record note at the end of the session. The notes could be designed with tick boxes that the attendant can fill easily as dictated by the surgeon during the procedure.

2.5. Regional anesthesia

Cataract surgery is performed under local anesthesia unless there are indications to do otherwise. More often, lignocaine with adrenaline 1:100,000 dilutions is administered. This may be mixed with hyaluronidase to improve local spread with less amount of anesthetic. Retro bulbar block is preferred to periocular and topical anesthesia as patients tend to have a low pain threshold. Facial block is administered around the neck of the mandible (O'Brien), under the periosteum of the lateral orbital rim (Van Lint), or in between these two locations (Atkinson). Systemic absorption could result in tachycardia and elevation of blood pressure. Retro bulbar bleeding could give rise to instant proptosis, if significant it may be wiser to postpone and reschedule the surgery. Where possible, periocular regional anesthetic block should be administered outside the OR.

Extra capsular cataract extraction (ECCE) is widely practiced as transition to manual small incision (MSICS) and to phaco surgery spread gradually in the region. Trainers guide trainees to acquire surgical skills in that order. Sutures contribute significantly to the overall cost of surgery, thus MSICS provides some relief in cost [34]. Proper suture placement is essential with ECCE to reduce postoperative astigmatism, thus avoiding the use of high-power cylindrical correction on the pseudophakic eye. However, MSICS requires the use of keratome, crescent blades, and side port lance. These maybe used once and discarded in developed countries, and in resource-scarce regions, they are resterilized up to five times such that six patients can benefit from each one. Phaco services are available in few centers perhaps due to high cost of the equipment and limited training opportunity. Some studies have shown no statistically insignificant difference in visual outcome between phaco and ECCE in the long term. Patients who can afford should have a choice. Public-private partnership could be a solution to obtaining expensive equipment and training in this part of the world.

2.6. Extra capsular cataract extraction

The periocular skin is cleaned with 10% povidone iodine and a head towel is placed under and tied around the patient's head. A drape with appropriate widow is applied covering the rest of the face excluding the index eye. A speculum wire is placed to part the lids open. Povidone iodine 5% is applied onto the conjunctiva and a cotton tip applicator is used to clean as saline irrigation is performed simultaneously. A toothed forceps is used to pick the superior rectus muscle and bridle silk suture is passed under it. This is then stabilized by fixing the suture with artery forceps to the face drape. The surgeon has numerous options of accessing the anterior chamber. A stab limbal incision can be made before filling the A/C with viscoelastic material and subsequent anterior capsulotomy. A superior corneal incision with razor fragment can be performed and extended with scissors. Alternatively, a keratome can be used to make a bevel stab corneal incision, which is later extended with scissors. There are various techniques of capsulotomy; can opener or continuous curvilinear capsulorhexis is appropriate. The nucleus is manipulated into the A/C and delivered with vectis while applying counter pressure with a muscle hook. The A/C is cleared of cortical matter using irrigation aspiration cannula. More viscoelastic material is injected into the eye, thus deepening the posterior capsule. The IOL is removed from the package, flushed with normal saline inserted, rotated, and dialed into position. When properly placed, the pupil appears round, regular, and central. Depending on the surgeon's choice, interrupted or continuous monofilament silk sutures are applied to close the wound. Sutures have to be well aligned to reduce/limit/ prevent postoperative astigmatism. The bite length should be a third on the corneal and two-thirds on the sclera sides and the bite depth is two third of the cornea/scleral thickness. Burying the suture on either of the two ends is advised as this limits irritation. Any remaining viscoelastic material is aspirated. Intracameral and subconjunctiva antibiotic is administered. In addition, subconjunctival steroid is administered and an eye shield is placed over the eye. Some studies obtained good visual outcome of ECCE in 47.5, 78.8, and 94.3%, respectively [35–37]. Biometric IOL power determination partly accounts for those with better outcome.

2.7. Manual small incision cataract surgery

Preliminary cleaning, draping, and bridle suture placement are similar to that in ECCE. The superior rectus muscle insertion ends about 7.5 millimeters from the limbus. A fornix-based conjunctiva flap is raised, and the underlying sclera is exposed. Limited bipolar wet field cautery may be applied to close bleeders. A horizontal incision of 6.5 to 7.0 millimeters is made 3 millimeters away from the limbus. A frown-shaped sclera incision produces less astigmatism. The proximal sclera lip is gently lifted to allow using the crescent blade to construct a tunnel into the A/C. Thin tunnel roof can lead to button hole and a thick roof may lead to premature entry into the A/C. The tunnel is widened with a keratome as it enters the A/C. The internal opening should be 30% wider than the entrance wound. After administering viscoelastic material into the A/C, a lance is used to make a side port. Anterior capsulotomy is then performed. Nucleus is separated from the cortex by hydrodissection and maneuvered into the A/C by gentle rotation and subsequent delivery with vectis. In some instance, the surgeon may prefer to break the nucleus into halves using a pair of forceps before delivery. Viscoelastic material is used to cushion the endothelium and allow insertion, rotation, and dialing of the lens into position. The side port can be used toward this aim. With the IOL in position, any residual cortical matter and viscoelastic material are aspirated. Lens matter at the sclera tunnel entrance into the A/C is approached via the side port. Any residual viscoelastic material is aspirated. Antibiotic and steroid administration is similar to that of ECCE. MSICS was demonstrated to show better uncorrected postoperative vision when compared to ECCE [38]. Even when final visual recovery is similar in MSICS and ECCE, eyes in the small incision group tend to have significantly faster recovery [39].

2.8. Phaco surgery

After routine cleaning and draping, a superior rectus bridle suture is applied and the globe stabilized. A 3.2 mm keratome is used to make a stab bevel incision into the anterior chamber followed by viscoelastic material administration and side port stab incision. An A/C maintainer is placed to maintain stability of the intraocular pressure during the procedure. Continuous curvilinear capsulotomy is done minding that a well-delineated margin is required. Femto second laser for making corneal incision, capsulotomy, and lens fragmentation is largely unavailable in the region. A 25G cannula mounted on a syringe is used for hydrodissection by gently injecting saline in each quadrant with the aim of separating and lifting the nucleus away from the cortex. The surgeon has the option of cracking the nucleus into two halves at this stage. It appears easier to completely displace the nucleus into the anterior chamber. For those on the continuous learning process, this limits the risk of posterior capsular tear and drop nucleus. When the nucleus is fully in the A/C, a golden ring sign appears around it. The nucleus can be cracked in half with a fragmenter. The A/C is deepened to keep the postcapsule away during fragmentation/aspiration and to protect the corneal endothelium. The phaco tip is inserted through the keratome incision and a phaco spatula through the side port to stabilize the nucleus as it is fragmented and aspirated. Any remaining cortical matter is aspirated with simcoe double cannula. The A/C is further deepened with viscoelastic material in preparation for foldable IOL insertion. Preloaded lens tend to be more expensive when unavailable. Where such is unavailable, the lens is loaded onto the syringe, which contains viscoelastic material. The tip is inserted into the eye and with gentle pressure on the stylus the IOL glides into the posterior capsular sac (in the bag). Dialing maybe required infrequently. A miotic agent is administered to narrow the pupil. Any residual viscoelastic material is aspirated. Saline is injected to swell off the stab corneal wound site as suturing is not required. Phaco surgery has been demonstrated to give good postoperative visual acuity in the immediate and intermediate postoperative period [40].

2.9. Intraoperative challenges

Each procedure is unique and every patient is special and deserves to get the best. Despite adequate training and experience, challenges could arise during surgery that require diligence in decision making and appropriate action to ensure that the goal of safety and quality outcome is realized. Posterior capsular rent could occur with any of the three procedures described earlier. Minimal tears may not require derailment from completing the surgery as planned. Larger tears could interfere with the placement and stability of the IOL. Often times, such big tears are associated with vitreous in the A/C. This will require manual and where available phacovitrectomy. This may necessitate the need to use an anterior chamber or iris claw IOL instead.

The other disturbing scenario is when the nucleus drops into the vitreous. Where combined phacovitrectomy machine is available, this is used to clear lens remnants from the vitreous. Manual attempt to do so could lead to retinal detachment. Where material and human resource to assure appropriate intervention is lacking, it is imperative to immediately refer the patient to the few centers where such services are available.

2.10. Care after surgery

Patients are advised to lie on their back or on the side of the nonoperated eye perhaps to limit undue position-related pressure on the raw eye. Postoperative medications include topical antibiotic-steroid combination eye drops, a mydriatic agent with moderate cycloplegic effect, oral broad-spectrum antibiotic, and nonsteroidal anti-inflammatory agent. It is of importance to obtain drugs from a reliable source due to preponderance of fake and substandard makes.

Admitted and day-case patients are reviewed a day after surgery. The routine should start from asking the patient if there are any complaints. The visual acuity is then determined unaided and with pin hole, followed by careful inspection of the wound site for any leakages/iris prolapse. The IOP should be within limits. The cornea is examined for clarity. Presence of corneal edema and/or striate keratopathy is noted and these usually improve with medication. The pupil should be regular, central, and round. Any peaking is a sign of iris entrapment in the wound edge or improper IOL placement. Open wound will give rise to shallow A/C with low IOP and a positive Seidel's test may require secondary suturing. Cortical remnants may be observed with slit lamp in the A/C or behind the IOL and may require aspiration. Tilted or decentered IOL is to be redialed into position.

2.11. Postoperative infective endophthalmitis

Postoperative bacterial endophthalmitis is arguably the most dreaded complications of intraocular surgery, although relatively rare with some reports indicating an incidence of 0.6% [40], 0.13–0.7% [41]. The commonest agents are conjunctival commensals like Staph epidermidis 70%, Staph aureus 10%, Strep species 2%, and occasionally the devastating *Pseudomonas aeruginosa* [42]. This can arise within 48–72 hours after surgery. Typically, the patient develops ocular pain and drop in vision after initial postoperative improvement. On examination, the lids appear tense and tender, with periocular congestion. The cornea is cloudy and there are signs of intraocular inflammation, a hypopyon may be seen in the anterior chamber. Inflammatory reaction in the anterior vitreous is noticed with slit lamp examination. The posterior segment is poorly visible. This is an emergency and the patient requires admission. Appropriate intraoperative intracameral antibiotic administration has been demonstrated to reduce the incidence [43, 44].

Endophthalmitis management protocol involves preparing intravitreal injection of vancomycin 2 mg and ceftazidime 2 mg (or 0.5 mg amikacin). A vitreous tap is performed and aspirate is sent to the laboratory for gram staining, microscopy, culture, and sensitivity. The prepared intravitreal antibiotic is administered. In addition, subconjunctival ivancomycin 50 mg and ceftazidime 125 mg (or amikacin 50 mg in those with penicillin allergy) is administered. Topical ceftazidime 5% and vancomycin 5% eye drops are to be instilled hourly. Topical 1% atropine drop is used six hourly to relieve ciliary spasm. The patient's clinical condition is monitored. A reduction in ocular pain/inflammation is indicative of improvement. Treatment is continued as the patient is monitored. If there is no improvement, repeat vitreous tap and antibiotics. The choice of antibiotics maybe modified based on the culture results/clinical improvement. Topical or systemic steroids can be administered when there is indication that the infection is under control based on clinical parameters such as pain reduction, fibrin contracting, and hypopyon reducing. The treatment is tapered based on the patient's response and culture results [45].

Posterior capsular opacity: This is a cause of intermediate and long-term reduction in postoperative visual acuity. Nd:Yag capsulotomy is performed to restore vision. Open capsulotomy may be considered where laser services are unavailable.

2.12. Identifying recording and limiting critical incident

Critical incidents are events or incidents that cause harm to the patient [46]. There is hardly any documentation on prevalence of such events in sub-Saharan African countries. Such incidents may include failing to make the right diagnosis, faulty assessment and preparation of the patient, mislabeling of the index eye, theater-related mishaps comprising defective sterilization, contaminated irrigation fluids, intraoperative and postoperative complications, use of substandard medications, etc. Documenting such incidents and reviewing the patient's management protocol in order to forestall future occurrence is very important. Linking such events to individual is counterproductive as isolated blame game does not solve systemic failures [47].

2.13. Steps toward preventing critical incidents, obtaining successful visual outcome, and ensuring the patient's safety

Gaining trust of the patient and care giver by creating an enabling environment to make them believe they're not in a court under cross examination is essential in obtaining a reliable ocular and systemic history. The ophthalmologist must perform careful and purposeful ocular and systemic assessment to determine the correct diagnosis and identify any ocular co-morbidity. Prompt and appropriate management of underlining ocular and or systemic diseases will ensure the patient condition is optimal for obtaining a predictable favorable cataract surgical outcome. Patient should be counseled on the cause of vision loss (cataract), the preparations for surgery, the cost, logistics, the need to buy and use prescribed medications, the visual expectations after surgery and the symptoms that should alert the patient of potential complications. Ocular biometry must be done routinely to determine the correct IOL power is available and used for each patient. Similarly, consumables and post operative medications are to be obtained from a certified and reliable source. Obtaining and maintaining a conducive and safe operating environment is essential in securing favorable surgical outcome. Basic minimum eye clinic and theater equipments have to be provided as well as purpose built operating room. The clinician must ensure that correct medication in appropriate dose is given to the patient. Obtaining and maintaining the basic minimum eye clinic and theater equipments necessary to getting good surgical outcome. Use of appropriate not necessarily purpose built operating space.

While in the operating room: Ensure the patient has bathed/is clean before coming to the O.R. The patient must exchange personal clothes with theater gown. Ensure that the correct eye is labeled by double checking and comparing with the patient's notes. Ensure all instruments are cleaned and sterilized. Ensure all drapings are washed and sterilized. Ensure separate and sterilized instruments are used for each patient. Use separate irrigation/aspiration cannula for each case. Resterilize all reusable instruments in between cases. The surgeon and assistant are to be properly gowned. Install purpose made water taps with long handle that are elbow controlled in the scrubbing area. Where unavailable, an assistant can pour water with a bowel for the person scrubbing. Appropriate scrubbing of the surgical team with antiseptic lotion. Trim dirty nails before surgery and ensure wrist watches, rings, and bangles are removed before scrubbing. Take meticulous and purposeful steps toward successful completion of the procedure. Avoid impulsive and erratic moves that can cause tissue damage leading to critical incident. Record all critical incidents for the purpose of internal audit and rectification of any short comings while avoiding individual blame. Provide dedicated instrument sets for patients with hepatitis and/or HIV. Ensure correct and appropriate eye medications are applied as the eye is padded. A perforated eye shield is better than a gauze pad. Provide dedicated instrument set for patients living with HIV/hepatitis.

Maintaining a committed and motivated eye care team. Timely and strategic training of the eye care team. Provision of refraction services. Ensuring staff and patient's safety in the operating room and at all times. Prompt documentation of procedure including critical incidents. Arranging follow-up visits till postoperative ocular status is stable.

2.14. Good visual outcome and safety-centered cataract outreach service

Cataract outreach entails an eye care team leaving the base hospital to provide services in locations within or even outside national boundaries. Often times, there is inadequate and improper planning of such programs with suboptimal preparation for the conduct of the camp services and patient monitoring till full recuperation. There is need to change from appearing, operating, and disappearing without proper arrangement on who cares for the patient when the outreach team is gone.

Guide toward successful cataract surgical outreach:

- There should be an advance team to evaluate the facility were the outreach will be conducted ensuring that basic minimal infrastructure is available without compromising patient safety.
- The advance team should liaise with and co-opt local eye care team in order to ensure joint participation in the conduct of the program.
- Any prior advocacy visit must include the local eye care team and their relevance highlighted to ensure continuity and success of the program.

- Proper screening and documentation of the selected patients are conducted by the joint advance and local team. This should include appropriate tests to detect communicable diseases such as hepatitis and HIV.
- Venue and date are agreed upon with the approval of relevant local health authorities.
- Biometry is performed on all the patients so that the correct power of IOL is determined and provided.
- Where possible, counselors are involved in discussing all issues related to the cause of the patient's blindness, the proposed intervention, the expected visual recovery, the use of medications, and postoperative follow-up. Patients must be given opportunity to ask questions.
- There has to be informed individual consent administration.
- The correct eye is labeled appropriately.
- Staggered scheduling is advised to reduce overcrowding, thus ensuring that the patients arrive and are operated and dispatched in manageable batches.
- Patient records must be kept at the facility used for reference whenever required and not be carried away by the outreach team.
- The local team is to continue the patients' care when the outreach team is gone.
- The philosophy is quality visual outcome based on integrated eye care team without compromising the patient's safety. The care is patient centered not client's eye.
- Collaborative long-term partnership, strengthening of local eye care teams, and sustained intervention program appear to yield better cataract prevention services in sub-Saharan African setting [48].

2.15. The big question and the final answer

Ophthalmologist and other eye care personnel need to ask themselves if they are willing to have cataract surgery in the centers they work. If the answer is not an affirmative "Yes," such institutions are not good enough to provide cataract surgery with favorable outcome and may not be safe for patients to patronize!

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Section 5

New Methods of Cataract Treatment

Chapter 7

Presbyopia Correction During Cataract Surgery with Multifocal Intraocular Lenses

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Additional information is available at the end of the chapter

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Abstract

Introduction: The first generations of multifocal intraocular lenses (MFIOLs) were designed to provide patients good distance and near vision, but intermediate was not satisfactory. Trifocal, a bifocal of low-add and quadrifocal MFIOLs were invented, offering possibility to correct vision for distance, near, and intermediate tasks. The novel IOL, extended range of vision (EROV), is covering mostly intermediate and distance vision, with lower level of photic phenomena.

Patients and methods: We have evaluated visual results in 4408 eyes implanted with different MFIOLs in 12 years period (2004–2016). Postoperative uncorrected visual acuity for far, intermediate, and near was evaluated. Postoperative satisfaction and complication rate and management of complications are presented.

Results: In the first generation MFIOLs, almost 70% of eyes gained uncorrected distance visual acuity of 1.0. Uncorrected near visual acuity was J1–J2 in 95% of eyes with diffractive IOLs. Modern MFIOL designs enabled improvement of vision at intermediate distance, without compromising vision at far and near.

Conclusion: With the first generations of MFIOLs, good distance and near uncorrected vision was achieved. With novel MFIOLs a very good uncorrected vision was achieved at far, intermediate and near, while with EROV lens, near vision was less satisfactory, but patients had less photic phenomena.

Keywords: multifocal, presbyopia, cataract surgery, refractive lens exchange, bifocal diffractive lens, intraocular lenses, refractive lens, trifocal lens, quadrifocal lens, extended range of vision lens

1. Introduction

The main cause for cataract or opacification of the lens is age, although it can also be a congenital disease or a consequence of ocular and systemic diseases (uveitis and diabetes), systemic medication (steroids), trauma, and inherited abnormalities (Marfan syndrome, Lowe syndrome). According to WHO data, it accounts for 48% of world blindness, and surgical removal of cataract is the only available treatment for a patient with developed cataract. The prevalence of cataract surgery increases with age, from 16% in the 65–69 age group up to 71% in more than 85 years age group [1]. Removal of cataract by phacoemulsification of the lens, followed by intraocular lens implantation, is in fact one of the most common surgical procedures. According to estimates, 20 million cataract surgeries are performed annually worldwide, but despite this impressive statistic, the number of patients visually handicapped by cataract still globally increases every year. Modern cataract surgery had tremendous development during the past 10–15 years. Improved surgical technique and modern materials have enlarged indication profile for cataract surgery. This also created higher postoperative expectations from patients. Although it is often expected that patient will not need spectacle correction after cataract surgery (at least for far vision), more than 50% of operated eyes need spectacles after surgery to achieve optimal vision. This is due to the fact that with the standard monofocal intraocular lenses (IOL), first of which had been implanted in 1950 by Sir Harold Ridley, only a spherical component of the refractive error can be corrected, without taking care of the astigmatism. In order to determine accurate IOL power for each patient's eye, it is essential to determine keratometric values and axial length readings. Based on such readings, a calculation of the spherical power of the monofocal IOL is made with specially designed formulas adapted for each refractive error. Monofocal IOLs are readily available in different optical powers in every operating theater and thus can be implanted during a standard cataract case, correcting patient's spherical error and providing good distance vision. However, full visual recovery in patients with corneal astigmatism and presbyopia will be limited by the fact that both corneal astigmatism and presbyopia were not corrected with the implantation of standard monofocal lens. Every patient with such IOL will lose its ability to focus near objects and will need spectacle correction of approximately +2.5 diopters for near vision. With the increasing patient's expectations regarding their vision after the surgery, newer generations of intraocular lenses had to be provided.

First, IOLs successfully dealing with presbyopia, named multifocal lenses (MFIOLs) or "premium lenses," were launched on the market in the early 1980s and were represented with diffractive and refractive design [2]. They were the first step toward full vision correction after cataract surgery. Bifocal diffractive IOL with +4.00D near addition is designed along the principles of diffractive optics and was available in a silicone or hydrophobic acrylic model. This lens consists of a three-piece or single-piece, square-edged 6.0 mm optic with a prolate anterior surface producing −0.27 spherical aberration. The posterior surface of the optic features a diffractive zone. The near addition is +4.00D translating to +3.00D at the spectacle plane. In the theory, the optical design redistributes incident light, 50% for near and 50% distance, independent of pupil size. Bifocal diffractive IOL with +3.00D near addition is aspheric one-piece hydrophobic IOL with central apodized diffractive structure and peripheral refractive zone. The near addition of +3.00D refers to +2.4D at spectacle plane. These lenses, due to their diffractive design, were able to provide patients with good near vision even without the use of spectacles, thus correcting presbyopia [3]. Refractive IOLs available at that time were multizonal IOLs with different areas for distant and near vision. They are a

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three-piece refractive acrylic lens with five concentric zones. Three zones, including the central one, are for far vision, and two zones are for near vision. An aspheric transition provides a balanced intermediate vision. The near add-power is +3.50D, translating to +2.50D at the spectacle plane. A unique edge design provides a 360° barrier aimed to offset the incidence of posterior capsular opacification (PCO) and minimizes edge glare. They gave good distant and intermediate visual acuity but poorer near vision with a significant problem with halos in night driving.

Disadvantages of MFIOLs caused by lens design were halo and glare (especially at night) in some patients, loss of contrast sensitivity, and the fact that patients needed some time for their brain to adapt to MFIOLs [4]. Moreover, the first multifocal IOLs were unable to correct vision at intermediate distance, which is mostly important for younger presbyopes who often use computers or other tasks at the distance of 60 cm to 1 m. Later on, newer, modern designs of MFIOLs were invented, trifocal, bifocal, and "low-add" lenses with different add-powers, extended range of vision, and quadrifocal IOLs, successfully correcting vision for all visual needs at distance, intermediate, and near [5–7]. Trifocal IOL is an aspheric, diffractive intraocular lens. The optical zone of trifocal lens had +3.33D near addition and a +1.66D intermediate addition (although different add-powers are also available). It has asymmetrical light distribution of 50, 20, and 30% for far, intermediate, and near foci, respectively. The IOL is fabricated from a hydrophilic acrylic material with a 25% water content and hydrophobic surface. This is a single-piece IOL with 6.0 mm optic diameter. Central 4.34 mm zone includes trifocal optic, and peripheral 1.66 mm zone has bifocal optic. It has a four-haptic design with an angulation of 0° and a 360° square edge to prevent posterior capsule opacification. Quadrifocal IOL is a non-apodized diffractive trifocal IOL with an intermediary 4.5 mm diffractive zone that distributes light to three focal points independent on pupil size. The IOL is a single-piece lens fabricated from a hydrophobic and ultraviolet- and blue light-filtering acrylate/methacrylate copolymer material. This novel diffractive structure has optimized light utilization, transmitting 88% of light at the simulated 3.0 mm pupil size to the retina. The light is split into two, with one half allocated to the distance focus and the other half split evenly between the near and intermediate focuses. The lens design is intended to improve the intermediate vision tasks and increase patient satisfaction, with a third focal point at an optimal intermediate distance of 60 cm, tending to provide more continuous vision. Bifocal diffractive "low-add" IOLs are provided with different add-powers (e.g., +2.75D, +3.25D, +4.00D add), and they have a full diffractive profile on the posterior surface of the optic. The relief height of the diffractive rings is equal in all three models; they have equal light distribution to distance and near regardless of pupil size or add-power. The focal point distance is controlled by the number and spacing of the diffractive rings, and patients have same contrast sensitivity and low-light visual acuity for all add-powers. Extended range of vision IOL delivers a continuous, full-range vision with reduced incidence of halos and glare. It merges two complementary technologies: echelette design which introduces a novel pattern of light diffraction that elongates the focus of the eye, resulting in an extended range of vision, and achromatic technology for the correction of longitudinal chromatic aberration which causes contrast enhancement. It is a diffractive, single-piece, aspheric IOL.

Although MFIOLs were able to fully correct vision in high percentage of patients, especially when modern lens designs are used, they were not applicable in eyes with the astigmatism, since such eyes have an individual need for correction of cylindrical power and axis which is different in each eye. In general population, 35% of eyes have the astigmatism of ≥1.25 diopter (D), 61% having with the rule astigmatism, 25% against the rule astigmatism, and 14% oblique astigmatism. Both the cataract itself and the astigmatism reduce patient's vision and thus the quality of life. The anterior corneal surface shifts from with-the-rule to against-the-rule astigmatism with aging, whereas posterior corneal astigmatism remains as against the rule in most cases. Total corneal astigmatism is calculated from anterior and posterior corneal curvature measurements [8]. The quantity and axis of the astigmatic refractive error are different in each patient's eye and can be corrected by spectacles with cylindrical power. If the eye scheduled for cataract surgery has a significant astigmatism, postoperative vision will be impaired by this refractive error, and patient will need spectacles to obtain adequate distance and near vision. For patients with significant astigmatism, solution was found with the invention of toric IOLs, which were designed for two functions: to restore visual acuity deteriorated by cataract and to correct corneal astigmatism [9–13]. Toric IOLs must be produced individually since each eye with the corneal astigmatism has a unique combination of spherical and astigmatic correction (regarding both the amount and the axis of astigmatism). Moreover, in a proper calculation of toric intraocular lens power, one should evaluate total corneal astigmatism as a better predictor than keratometric astigmatism [8, 14]. Since the prevalence of against-the-rule astigmatism significantly increases with age, such astigmatism should be treated more aggressively during cataract surgery [15]. The most recent advancement in IOL technology is a combination of multifocal and toric design, resulting in multifocal toric design of the lens which provides a complete visual recovery for patients with astigmatism and presbyopia [9, 16, 17].

Based on the positive visual outcome with the implantation of newer generation of lenses in a cataract surgery, modern IOLs have become treatment of choice for many patients with presbyopia and astigmatism even when their natural lens is still clear and has no cataract [18–20]. Namely, refractive errors such as hyperopia and myopia combined with presbyopia, and also plano-presbyopia, cannot be fully treated with refractive surgery on the cornea. Laser corneal ablation is highly effective in correction of refractive errors and may be the best option for younger population [21]. However, for patients aged 45 or more, only distance vision can be corrected by laser ablation, but the problem of presbyopia remains. With the surgery on the lens, called refractive lens exchange, and implantation of MFIOL full vision can be restored: distance, intermediate, and near vision. If MF toric IOL design is used, also the preexisting astigmatism can be fully corrected [9, 16, 17].

In this chapter, we have analyzed postoperative visual results in our patients operated for cataract and refractive lens exchange with implantation of different types of MFIOLs, used in our setting throughout the last 12 years.

2. Patients and methods

A total of 4408 eyes were implanted with different presbyopia-correcting intraocular lenses in our hospital throughout a period of 12 years (2004–2016). Exclusion criteria for MFIOL implantation were corneal disease, retinal or optic nerve disease, or sever dry eye syndrome. Preoperative assessment included precise biometry and IOL calculation (IOL Master 500, Zeiss, Germany), corneal topography (Pentacam, Oculus, USA), aberrometry (Wavefront Aberrometer, USA), pupillometry, endothelial cell analysis (Noncontact Specular Microscope, Topcon, USA), optical coherence tomography (OCT, Zeiss, Germany), ultrasound, and careful examination of the retinal status. Patient's selection and preoperative counseling were made by experienced cataract surgeons.

The first group of eyes included 2546 eyes implanted with bifocal diffractive MFIOLs (ReSTOR 4+, ReSTOR 3+, Tecnis, Acrylisa) and refractive design (ReZoom) MFIOLs, with a follow-up of 5 years. Most of the patients were implanted with same lens design in both eyes, while in 440 eyes, a technique so-called "mix and match" was used to enhance intermediate vision. In "mix and match" approach, a refractive IOL (ReZoom) was implanted in dominant eye and diffractive IOL (Tecnis or ReSTOR) in non-dominant eye. The second group of eyes included 1862 eyes implanted with MFIOLs of the following designs: (a) trifocal (Zeiss AT LISA tri), (b) quadrifocal (AcrySof IQ PanOptix), (c) combination of "low-add" bifocals with different add-powers (Tecnis ZKBOO +2.75D in dominant and Tecnis ZLBOO +3.25D add in non-dominant eye), and (d) extended range of vision (Symfony ZXR00) (see **Table 1**). Follow-up was at least 6 months (range 6–144 months). All eyes were operated under topical anesthesia, as a conventional phacoemulsification procedure on two phaco machines (Whitestar Signature, Abbott Medical Optics and Infinity Vision System, Alcon, USA). Special attention was made during the following surgical steps: small incision preferably on the steep axis, continuous curvilinear manual capsulorhexis with 5 mm diameter, careful polishing of the posterior and anterior capsule, and viscoelastic removal behind the IOL. Same MFIOL was implanted in both eyes simultaneously, except in case of "low-add" lenses where "low-add" with addition of +2.75 was implanted in dominant and "low-add" of +3.25 add in a non-dominant eye. Postoperative uncorrected visual acuity (UCVA) for far, intermediate, and near vision was evaluated for different types of MFIOL. For MF toric IOL implantation, the axis of astigmatism was marked on a patient's eye during preoperative preparation, in a seated position on a slit lamp, and toric IOL was aligned with this mark during the surgery. The amount of corrected astigmatism was evaluated. Postoperative satisfaction rate, complication rate, and management of complications are presented for all MFIOLs.

Type of multifocal IOL	Number of eyes
Diffractive +4.00 bifocal	1160
Diffractive +3.00 bifocal	826
Refractive	560
Trifocal	649
Low-add	550
Extended range of vision	663
Quadrifocal	30

Table 1. Number of eyes implanted with different types of multifocal intraocular lenses throughout a 12-year period.

3. Results

The number of eyes implanted with different types of multifocal intraocular lenses throughout a 12-year period in our hospital is represented in **Table 1**. In the first 5 years of MFIOL use, mainly lenses of diffractive bifocal and refractive design were implanted, while later on newer generations of MFIOL like trifocal, "low-add" combination, extended range of vision, and quadrifocal lenses were used.

Visual outcome after implantation of first-generation MFIOLs of diffractive and refractive design is represented in **Figure 1**. Close to 70% of eyes gained uncorrected distance visual acuity (UDVA) of 1.0, while <10% of eyes had UDVA of less than 0.8. Uncorrected near visual acuity (UNVA) was J1–J2 in 95% of eyes with diffractive IOLs and in 84% of eyes with refractive lens design. Overall, close to 90% of eyes was spectacle independent. "Mix and match" technique did not change visual outcome for distance vision and had slightly negative impact on near vision; however, it did increase percentage of spectacle-free time since it improved intermediate vision.

With the first generation of lenses, the optical design could not provide good vision at intermediate distance. Therefore, we have started to implant the first lenses designed to improve intermediate vision—lenses of trifocal design and compared the outcome of these lenses with bifocal ones (**Figure 2**). With trifocal design very good UDVA and UNVA were preserved, and there was a significant improvement in uncorrected intermediate vision (UIVA), with mean visual acuity of 0.8 for intermediate tasks. With even newer design of trifocal lens—so-called quadrifocal IOL—more continuous vision at intermediate distance was obtained due to superior visual outcome at 60 cm (arm length). Novel technology of extended range of vision (EROV) lenses became available, and a combination of two different add-on powers in "low-add" bifocal lenses aimed to improve intermediate vision of our patients. Visual outcome of UDVA, UIVA, and UNVA in patients implanted with four modern lens designs compared to older lens designs are represented in **Figure 3**. As shown, modern MFIOL designs enabled a significant improvement of vision at distance of 60–100 cm (intermediate) as compared to diffractive and refractive MFIOLs, without compromising very good visual results at far and near. Satisfaction rate after MFIOL implantation according to preoperative refractive error is presented in **Table 2**. In patients with the astigmatism of >1D, multifocal toric lenses were implanted to correct the astigmatic part of the refractive error. The axis of toric MFIOL implantation was always marked in a sitting position, to avoid misplacement of the lens due to cyclotorsion while the patient is lying down. After toric MFIOL implantation, the mean preoperative astigmatism of 2.25 D was reduced to a mean of 0.32 D (**Figure 4**). The appearance of a bilaterally implanted trifocal toric IOLs, in a primary position (left) and with a dilated pupil (right), correcting patient's vision in both eyes to 100% distance, intermediate, and near vision without any spectacles, is shown in **Figure 5**.

Complications related to MFIOL design like halo and glare were determined among our patients: 15% of patients with refractive lenses reported halos and glare during night driving. Due to

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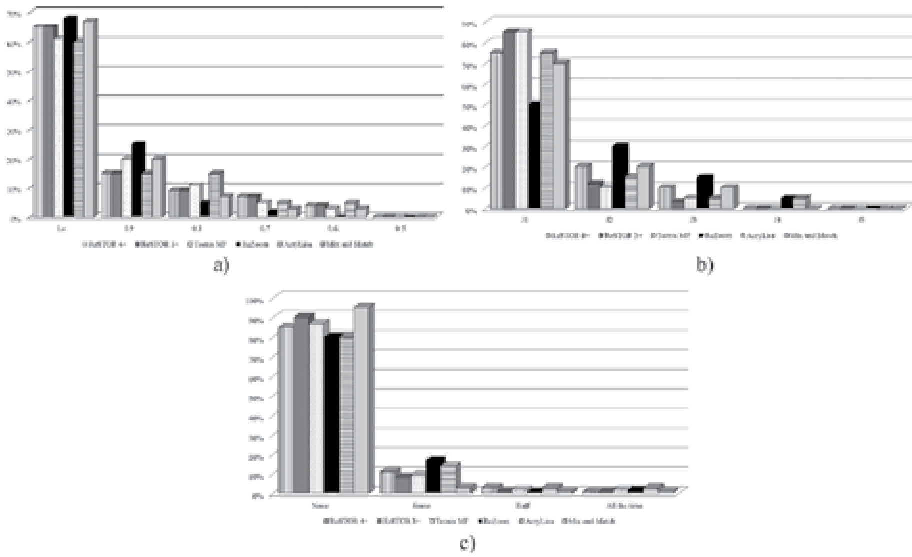

Figure 1. Percentage of eyes achieving (a) uncorrected distance visual acuity of >0.5, (b) uncorrected near visual acuity of >J5, and (c) a portion of time wearing glasses in eyes implanted with different types of multifocal intraocular lenses, in a 5-year follow-up.

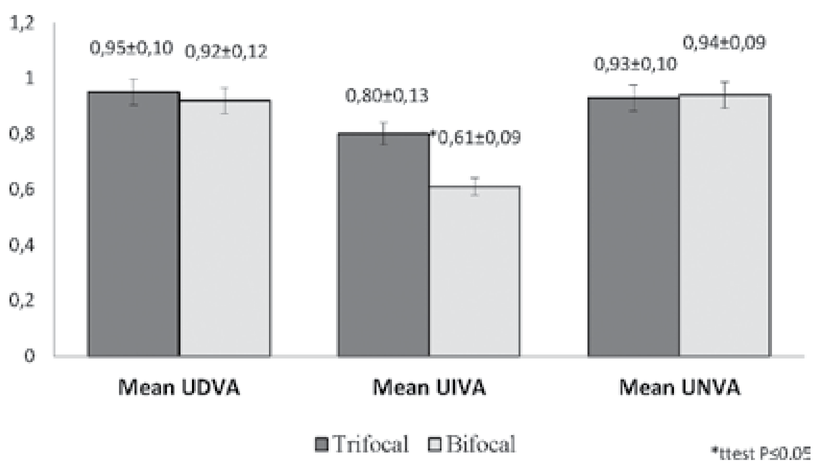

Figure 2. Comparison of mean uncorrected distance visual acuity (UDVA), uncorrected intermediate visual acuity (UIVA), and uncorrected near visual acuity (UNVA) between eyes implanted with trifocal and bifocal multifocal intraocular lenses (expressed in decimal values).

severe halo and glare, we had to explant 12 out of 560 (2.1%) refractive IOLs and replace them with bifocal diffractive IOLs. In modern lens designs, the percentage of halo and glare ranged from 4 to 9%, being lowest in EROV IOL (**Table 3**). Postoperative residual refractive errors were solved with laser refractive surgery. Laser surgery was needed in 6.1% of patients with diffractive bifocal IOLs, while in another groups, enhancement rate was between 1 and 3% (**Table 3**).

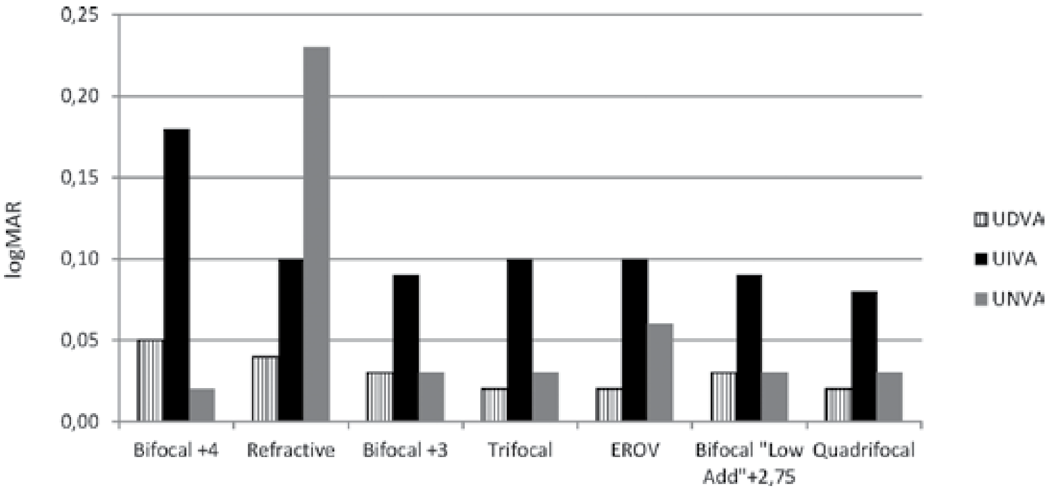

Figure 3. Comparison of uncorrected distance visual acuity (UDVA), uncorrected intermediate visual acuity (UIVA), and uncorrected near visual acuity (UNVA) between eyes implanted with diffractive (bifocal +4 and bifocal +3), refractive, trifocal, extended range of vision (EROV), "low-add," and quadrifocal multifocal intraocular lenses.

Patient refraction	Satisfaction after surgery; average mark [1–10]
High hyperopia	9.6
Low hyperopia	9.1
Plano-presbyopia	8.7
High myopia	8.2
Low myopia	8.1

Table 2. Satisfaction rate after bilateral multifocal intraocular lens implantation, according to preoperative refractive error.

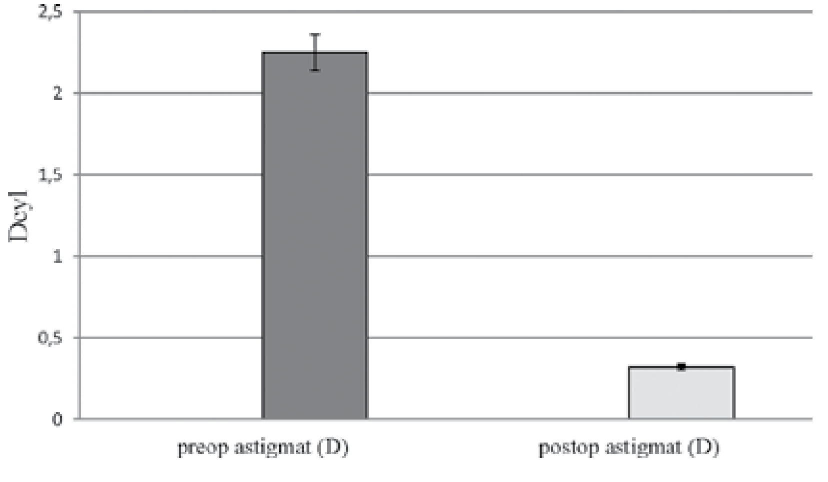

Figure 4. Change in the amount of astigmatism in eyes implanted with toric multifocal intraocular lens.

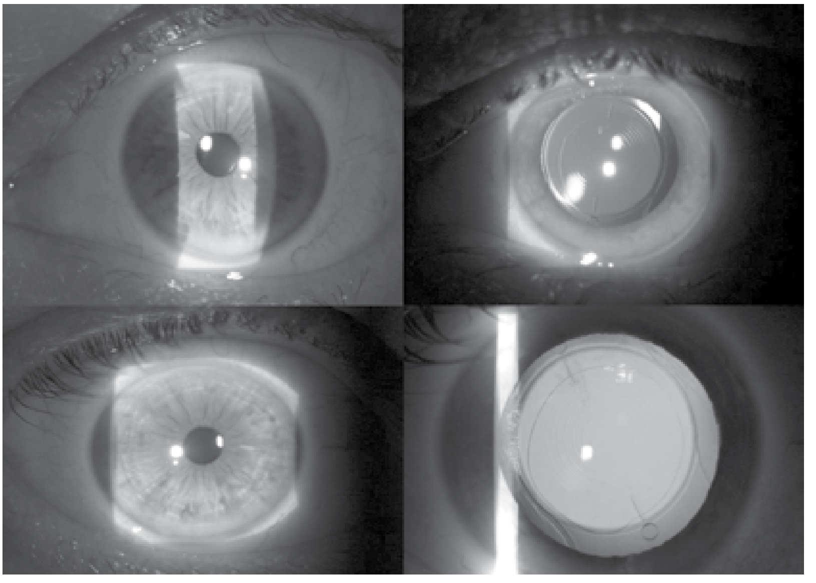

Figure 5. Patient aged 56, after bilaterally implanted trifocal toric IOLs, in a primary position (left) and with a dilated pupil (right). Visual acuity in both eyes is 100% for distance, intermediate (80 cm), and near, without any spectacles.

Lens design/complication rate (%)	Halo and glare	Laser enhancement for residual refractive error	Need for spectacle wear
Bifocal diffractive (Tecnis)	7.7	6.1	5.5
Bifocal diffractive (ReSTOR)	7.2	1.3	4
Refractive (ReZoom)	15	2.6	25.2
Trifocal	9	1.6	1.2
Extended range of vision	4	1.76	4.42
"Low-add" bifocal	8.6	2	1.3
Quadrifocal	5	0	1

Table 3. Complication rate after implantation of different types of multifocal intraocular lenses.

Almost one-third of patients reported symptoms of dry eye. Those patients were treated with artificial tears and punctal plugs when necessary. The need for spectacles was highest in refractive IOL group (25%), mostly for near reading. In bifocal diffractive group, 4–5% of patients had to wear glasses, mostly for computer or tasks at 60–100 cm. In EROV IOL group, 4.22% of patients needed glasses mainly for near vision. The best spectacle independence is achieved in patients with quadrifocal (although the number of implanted lenses is greatly smaller compared to other groups, so the data will most probably change with bigger numbers), trifocal, and bifocal diffractive IOL with "low-add" combination (**Table 3**). Posterior capsular opacification rate was very hard to compare because of a different follow-up (range 3–6%), but trifocal lens did have higher PCO rate compared to others, possibly due to hydrophilic material.

4. Discussion

Nowadays, cataract surgery is becoming a more and more refractive surgery at the same time. Patient's expectations are growing; but thanks to development of new technologies, surgery techniques, and intraocular lens designs, ophthalmologist can fulfill those demands. The aim of modern cataract surgery is to achieve good unaided vision at all distances together with high quality of vision in a safe manner and with a fast recovery. Presbyopia-correcting intraocular lenses are currently the most efficient and permanent treatment for presbyopia. First, IOLs successfully dealing with presbyopia, named multifocal intraocular lenses (MFIOLs), were launched on the market in the early 1980s. They were designed to have several foci in order to provide full vision correction after cataract surgery. These lenses, due to their design, were able to provide patients with good distance and near vision even without the use of spectacles [22]. However, due to their design, MFIOLs have also some disadvantages caused by the presence of several foci. Halo and glare (especially at night) are produced by defocused image and scattered light. Higher near additions at IOL optics increase halo and glare. Moreover, patients need some time for their brain to adapt to MFIOL (so-called neuroadaptation). Very often with neuroadaptation, symptoms of halo and glare tend to decrease. Another characteristic of MFIOL is loss of contrast sensitivity caused by separation of the light entering to the eye in two or three foci. Patients record this as slightly washed out or grayish image, especially in low-light conditions. MFIOLs are also very dependent on eventual residual refractive error, dryness of the eye, IOL centration, posterior capsule opacification, pupil size, and presence of vitreal opacities.

In eye hospital "Svjetlost," MFIOLs are in use since 2004, and currently around one-third of all implanted lenses are MFIOLs. For the first 5 years, we have used MFIOLs available at that time: bifocal diffractive lenses with +4.00D addition (later on also with +3.00D addition) and refractive IOLs. Bifocal diffractive IOLs enabled very good uncorrected far vision and near vision at 30–40 cm, with very good satisfaction rate among patients who did not perform many tasks at intermediate distance (60–100 cm). Refractive IOLs performed somewhat better at intermediate distance range, but near vision was significantly worse as compared to diffractive design. Visual outcome after implantation of the first diffractive and refractive lenses recorded among our patients was similar to other published data [23, 24]. However, lack of good intermediate vision was unacceptable for younger presbyopes performing many tasks at a distance of 60–100 cm. In an attempt to enhance intermediate vision, a technique called "mix and match" was invented aiming to ensure uncorrected vision at all distances. Refractive IOL was implanted in dominant eye (for far and intermediate) vision and diffractive IOL in non-dominant eye (for far and near). It worked well in majority of patients; however, in our hands around 25% of patients were complaining at different images in two eyes (because we used two different technologies) and/or photic phenomena. Some authors have reported very high satisfaction rate with "mix and match" approach, despite the fact that in a presented group of their patients also high percentage of halo and glare was reported [25]. These data show that despite some objective photic phenomena many patients still remain happy with the surgical outcome since they have gained spectacle independence. However, from physician's point of view, we were not satisfied enough with the outcome of "mix and match" method, so we stopped using this technique and switched to newer generations of lens designs emerging on the market: trifocal, combination of "low-add" bifocals with different add-powers, and extended range of vision (EROV) technology [25–27].

In our hands, all types of new-generation or "premium" MFIOLs (trifocal, quadrifocal, "low-add" combination, and EROV) provided similar and very good UDVA. The main improvement of modern lens designs is the quality of uncorrected intermediate vision, which is very satisfying with all lenses. Trifocal lenses provided excellent far, intermediate, and near vision, which seems to be more "continuous" with quadrifocal design mainly for tasks at 60 cm distance. The EROV provided excellent distance and intermediate vision, performing slightly worse at near if emmetropia was aimed in both eyes. Thus, to improve near vision with EROV lens, we are now implanting many patients with a planned myopic shift of −0.5% in a non-dominant eye ("mini-monovision"), and in this manner, better near vision was achieved. The advantage of EROV IOL is that it maintains a very similar level of visual quality as monofocal IOL, less visual disturbances compared to bi- and trifocals, and we have successfully implanted this lens also in amblyopic patients and those with the previous refractive surgery on the cornea. To conclude, both EROV and trifocal IOLs are good options for patients with intermediate distance requirements, while in patients having numerous near-vision tasks, EROV IOL should be aimed slightly myopic in a non-dominant eye, or trifocal/quadrifocal technology may be used. Comparing to other lens designs, PCO occurrence was higher in trifocal lens, but subsequent YAG capsulotomy did not affect long-term visual outcome. Implantation of two "low-add" lenses with different near add-powers provided good near, intermediate, and distance vision, comparable to the outcome with EROV and trifocal/quadrifocal IOLs.

In our patients with the astigmatism >1D, multifocal toric IOLs were implanted. These lenses are capable of correcting both presbyopia and astigmatism. Invention of multifocal toric IOLs was based on very good results in astigmatic correction with monofocal toric IOLs, which showed to be safe and effective in correcting astigmatism and improving vision even in cataract patients with very high astigmatism such as topographically stable keratoconus, pellucid marginal degeneration, and post-penetrating keratoplasty astigmatism [28–30]. The systematic literature review shows that spectacle independence for patients treated with four brands of monofocal toric IOLs increased from 15 to 85% of those who never wore spectacles [1]. There are several specific requirements for the IOLs aimed to treat the astigmatism; the lens has to be easy to manipulate in the capsular bag in order to achieve good alignment and needs good long-term positional stability, as low as possible induction of capsular shrinkage and posterior capsule opacification. Namely, toric IOL which has to be produced for each individual case is marked on its surface for proper alignment in the capsular bag. Axis of astigmatism has to be determined and marked in a seating position due to cyclotorsional movements of the eye while the patient is lying down for the surgery. Proper alignment of toric IOL during surgery is crucial since misalignment of only 10° leads to a loss of one-third of the astigmatic correction. Moreover, even a small decentration of IOL of less than 1 mm will induce aberrations and poorer visual result [31]. Shrinkage of the capsular bag may also lead to decentration of the lens and thus have negative impact on its proper alignment. Misaligned toric intraocular lens has to be repositioned into its proper position by surgical revision. If surgical correction is needed, the intervention should be performed as soon as possible after the primary surgery to avoid manipulation in the capsular bag with abundant fibrosis. Although it is recommended to re-center the lens in the first months after primary surgery, it has been reported that lens can be safely repositioned even 15 months after its implantation [32]. According to our results, with properly calculated and implanted toric MFIOL, both spherical and cylindrical errors can be successfully corrected.

In recent years, special medical equipment and centering systems were invented to minimize potential sources of errors during each step of the surgery (e.g., Verion Image Guided System or Zeiss Callisto). Both systems may improve precision, and size of the incisions enables perfect shape and size of the capsulorhexis and more precise alignment of the toric IOL or multifocal IOL along the optical axis. Such a computer-assisted cataract surgery will make premium IOL surgery even more precise, but it will take some time till all the cataract surgery units embrace this technology. All the results presented in this chapter are obtained without the use of advanced computerized systems. Therefore, the outcome and performance of different MFIOL designs implanted in our hospital in the last 12 years are in fact more objective to compare, since the methodology of surgery did not change significantly throughout this period. Once we add sophisticated computer-controlled systems into standard equipment used during cataract surgery with MFIOL implantation, the results should improve further.

Finally, very important or maybe the most important issue when we discuss about MFIOL use is the issue which cannot be presented by pure scientific data—preoperative counseling. Spectrum of lens design available nowadays on the market is quite large, and only careful discussion over patient lifestyle, everyday activities, job, and expectations may provide to write answer on which lens design to use. Patients who are looking for guaranties, "perfect" vision, or 100% spectacle independence are not good candidates for MFIOLs. The first step toward good results is that the surgeon working with MFIOL understand that there is no perfect lens for every patient, and then to transfer in a proper way this information to a patient. Looking at the preoperative refractive errors, hyperopic patients are the best candidates for such surgery. It is very wise to under-promise how it is going to be with implanted MFIOLs and then hopefully over-deliver. With such a proper preoperative counseling, and subsequent choice of the MFIOL best suited to individual patient needs, all currently available MFIOLs will provide a high level of both spectacle independence and patient satisfaction.

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For thousands of years, cataract surgery continues to be the "pearl" of ophthalmic surgery. It is explained by the fact that cataract removal always leads to an increase in visual acuity of patients. A new technology of cataract removal, phacoemulsification, was introduced by Charles Kelman in 1967. Despite this, it was difficult for the surgeons to transform from extracapsular cataract extraction to the new method—phacoemulsification. Recently, in the ophthalmological practice, the method of femtolaser cataract surgery (FLACS) has been introduced. This method allows you to automatically perform the basic stages of cataract surgery—corneal incisions, capsulorhexis, nucleus fracture. At the same time, to apply the various techniques of cataract surgery, the surgeon must possess virtually all the necessary techniques. This is dictated by the fact that, as a rule, cataract itself is rarely isolated—senile. Knowledge of the basic rules of cataract surgery, the use of pupillary rings and iris retractors in narrow pupils, the use of capsular rings in subluxations of the lens, the use of special modes of phaco in severe late cataracts, and a comprehensive clinical way of thinking can undoubtedly reduce the complications of cataract surgery.

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