Review Article

Cataract surgery in small pupils

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This paper presents the review of historical aspects and the current state-of-the-art in various pupil dilatation methods to be used in cataract surgery. The surgical algorithm in managing small pupil cases should include topical and intraocular mydriatics, appropriately selected viscosurgical device and mechanical dilatation with instruments, iris hooks, and/or pupil expanders.

Key words: Cataract surgery, Malyugin ring, pupil expansion devices, small pupils

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Small pupil is a well-known risk factor associated with numerous complications during and after cataract surgery. Inadequate preoperative mydriasis and/or intraoperative miosis might result in iris trauma and photophobia.[1-3] One of the most significant cataract surgery complications – vitreous loss in patients whose pupils failed to dilate increases by a factor of two,[4,5] anterior capsular tear, increased inflammation, irregular pupil shape, posterior capsular rupture, and retained lens material.

Small pupils are not a purely geometrical issue limiting the access to the surgical field. Keeping in mind that, there are numerous factors leading to poor pupil dilation including but not limited to the systemic diseases, intake of some pharmacological agents, local comorbidities (glaucoma, ocular trauma, previous ocular surgery, uveitis, etc.), these eyes are generally more prone to increased permeability of the blood-aqueous barrier, leading to postoperative inflammation.[6] Furthermore, the pathology of the lens zonular apparatus, loss of lens capsule elasticity, and increase of nucleus hardness should be considered as the factors aggravating cataract surgery through the small pupil.

Intraoperative floppy iris syndrome (IFIS) was described by Chang and Campbell in 2005 and proved to be associated with systemic administration of alpha-1a receptor antagonist Tamsulosin (Flomax). The main reason of that is atrophy of iris dilator muscle and decrease of iris tissue rigidity.[7] Complication rates in patients having that syndrome can be up to 12.5%.[8]

Advances in Pharmacological Pupil Expansion

Various pharmacological agents are used to dilate the pupil. The usual topical protocol consists of the combination of cycloplegic (tropicamide 1%) and adrenergic receptor agonist (phenylephrine 2.5%).[9] It is known that even with topical administration, drug absorption may cause some unwanted systemic side effects.[10,11]

The use of nonsteroidal anti-inflammatory drugs (NSAIDs) preoperatively has also been shown to support mydriasis and/or prevent miosis.[12-14] Various drugs of that class can be administered preoperatively in multiple daily doses with the aim to inhibit prostaglandin release during and after cataract procedure.

Intracameral administration of mydriatic drugs has several advantages over topical route including the absence of adverse systemic side effects and direct contact of the drug with the target tissue.[15,16] Combined intracameral use of mydriatic agent and local anesthetic showed to be very helpful to dilate the pupil at the start of the cataract procedure. This approach was pioneered by Sugar in 2006 suggesting mixing buffered lidocaine and epinephrine, the drug combination is known as Epi-Shugarcaine.[17] Furthermore, it was shown that intracameral injection of 1.5% intracameral phenylephrine proved to be very effective in relieving the IFIS.[18]

Currently, the drug with the commercial name Mydrane (Thea Pharmaceuticals; UK), which is a combination of tropicamide (0.02%), phenylephrine (0.31%), and lidocaine (1%), has been approved for use in some European countries.

However, washout by irrigation solution deliberately used in modern cataract procedures may limit the effectiveness

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and sustainability of the achieved effect. Constant irrigation is potentially more promising because the concentration of the drug within the eye is not lowering over the course of surgical procedure and the dose of the drug may be lower than that used for single injection at the beginning of the procedure.[19] Epinephrine alone can be added to irrigation solution for the intracameral administration to achieve sustainable mydriasis during cataract procedure.[20]

Recently, a combination of phenylephrine (1.0%) and ketorolac injection (0.3%) was approved for use in cataract surgery (Omidria; Omeros, USA). The drug is added to the irrigation solution and unlike the substance delivered through the topical route; it goes into direct contact with the iris tissue throughout the procedure. However, Omidria does not provide pupillary dilatation, but rather prevents the pupil from constricting and reduces postoperative ocular pain.[21,22] Currently, there is no evidence stating that constant irrigation with the combination of phenylephrine (1.0%) and ketorolac injection (0.3%) will help to maintain mydriasis in patients with known risk factors such as diabetes, glaucoma, and pseudoexfoliative syndrome.

Mechanical Pupil Enlargement Strategies

Since all currently available pharmacological approaches of dilating the pupil before or during cataract surgery cannot guarantee the result, the surgeon sometimes has to make the decision of whether or not to dilate the pupil mechanically at the time of the surgery.

If the pupil is moderately dilated, the experienced surgeon can perform phacoemulsification more or less easily yielding good clinical outcomes.[23] It is generally recommended to decrease the fluidic parameters of the phacoemulsification machine (vacuum and aspiration levels) to prevent inadvertent aspiration of the iris tissue in these cases. However, this type of strategy can be more successful if the patient's iris maintains rigidity compared to the patients whose irises are biomechanically unstable such as in cases with IFIS.

There is no consensus in the current literature on what size of the pupil is insufficient to proceed with cataract surgery. In some studies, the diameter of the pupil to be considered small may start from 6.0 mm.[22]

For the experienced surgeon, the threshold of pupil size to be able to perform phacoemulsification lies in the range of 4.5–5.0 mm. If the pupil is smaller, various pupil expansion strategies are strongly recommended. There is an algorithm to follow in small pupil cases.

First, the ophthalmic viscosurgical device (OVD) is injected into the anterior chamber. With OVD injection, the anterior chamber deepens, and the pupil becomes wider. In the technique known as viscomydriasis highly viscous OVD such as Healon5 (Abbott, Illinois, USA) is used.[24] However, OVDs typically do not provide the lasting effect needed throughout the entire procedure, because of the washout from the anterior chamber. That is, why in most cases it is necessary to perform repeated OVD injections during the course of the surgery.

Combining 2 OVDs with different rheological properties may help to maintain the pupil and prove to be helpful in IFIS cases. Lower viscosity OVD is injected in a doughnut-shape pattern covering the periphery of the anterior chamber and the iris while viscoadaptive OVD is injected into the center.[25] The surgeon is manipulating below the iris plane to avoid OVD forming a shell-like structure being aspirated.

When using deliberately high amounts of OVD with high viscosity, it is essential to completely remove it from the eye to prevent postoperative intraocular pressure spikes.[3]

There are four main surgical maneuvers to be considered when the pupil is not sufficiently dilated despite all the above-mentioned methods. They are synechiolysis, pupil stretching, iris cutting, and the use of mechanical pupil expanders.[26]

Adhesions in between the iris and the anterior lens capsule in most cases can be easily lysed with the spatula or similar instrument. Sometimes pupillary membranes that are strongly attached to the pupil and posterior iris surface can be identified. Gentle peeling of the membrane from the iris with the forceps releases contraction forces applied to the iris and helps to enlarge the pupil.[27]

Pupil stretching is done with the help of two instruments (spatulas, Kuglen hook or similar) introduced through paracentesis incisions located contralateral to each other or a special tripod instrument introduced through the main incision.[28,29] The main idea of this maneuver is to stretch the pupil in vertical and horizontal meridians to create small sphincter tears in the fibrotic iris tissue and to expand the pupil. Being relatively simple and effective in many cases, this manipulation may not provide sufficient mydriasis, cause iris bleeding and pupil atony postoperatively.[29]

Multiple microsphincterotomies performed with fine scissors share the same mechanism of action with pupil stretching technique. However, in many cases, it is much more controlled and helps to avoid extensive sphincter muscle tears.

Each of the above-mentioned pupil expansion methods come with their unique limitations and drawbacks. They may differ in the amount and length of surgical manipulations and possible intraoperative and postoperative complications. However, if used in properly selected cases both have the potential of providing good access to the lens with acceptable clinical outcomes.[30]

One of the most important inventions in the history of mechanical pupil expansion was introduction of the iris hooks. Since the very first reports, the technique gained wide popularity all over the world.[31,32] Classically, four evenly-spaced paracentesis are performed, and the hooks are introduced catching the iris edge. The sleeve of the hook is adjusted to expand the pupil to the desired size. Advantages of this technique include ease of manipulations and wide availability of the hooks manufactured in different sizes, materials, and designs.

When using iris retractors or hooks in IFIS cases, it is recommended to place them in a diamond configuration.[33] One of the hooks located adjacent to and below the main corneal tunnel retracts the iris downward and prevents it from being in the path of the ultrasonic needle.

The drawbacks of this technique include iris sphincter tears and risk of bleeding. It is generally recommended not to extend

the pupil over 5.0 mm in size to decrease the chances of iris tissue overstretching producing irregular and atonic pupils postoperatively.[34]

Recently introduced Asia Pupil Expander provides a square pupil very similar to the four iris hooks [Fig. 1]. It is a pair of scissor-like disposable devices with blunt, rounded tips, and an external spring mechanism. They are inserted through 1.1-mm side-port incisions located opposite to each other. Each device is introduced into the eye with the specially designed forceps. After releasing the forceps, the device expands hooking the iris with both curved tips. The resultant pupil shape is square or slightly trapezoidal; however, compared to the iris hooks, the number of incisions necessary to achieve pupil expansion is limited to two rather than four.

Pupil Expansion Rings

Over the years, the idea of designing the pupil expansion ring was very attractive. Several devices were proposed and used in the limited numbers including Graether silicon pupil expander, Siepser's hydrogel ring, Morcher PMMA ring, Milvella Perfect Pupil made of polyurethane, and some others.[35] These rings are relatively difficult to handle during the surgery, not very stable in the eye and may require significant time and efforts to implant and remove. These are the reasons why most of these devices are currently obsolete.

Currently, the most popular pupil expansion ring is the Malyugin ring (MicroSurgical Technology Inc.). It is a square foldable device made of polypropylene [Fig. 2]. The one-piece planar design features four circular curls located at equidistant points on the ring.[36] The profile is thinner as compared to preexisting rings, making it easier and safer to manipulate inside the eye. The device is injected into the anterior chamber and removed from the eye with the injection system.

The Malyugin ring, in contrast to iris retractors, creates a rounded rather than a square pupillary opening due to 8 iris-retaining points and expands the pupil without overly stretching or traumatizing it compared with the iris hooks.[37] The device is manufactured in two sizes – 6.25 mm and 7.0 mm in diameter, the latter being particularly useful for severe IFIS cases.[38]

There is a growing body of evidence related to the use of Malyugin Ring in various complicated cataract surgery scenarios not limited to the small pupil management. It has been shown that the Malyugin Ring can be utilized to clip the anterior capsulorhexis by two contralateral scrolls of the device to support weakened zonular apparatus and stabilize the capsular bag during small pupil phacoemulsification.[39] In patient having limited temporal suprachoroidal hemorrhage occurred during phacoemulsification, the Malyugin Ring safely remained in the eye for 7 days. It was then safely removed without negative consequences such as corneal endothelial cells damage or anterior segment inflammation, leading to visual recovery of the patient.[40]

Combined use of the iris hooks and the Malyugin ring in patient with corectopia can be justified in patient, for whom the femtosecond laser-assisted capsulotomy is justified.[41]

Inspired by the commercial success of the Malyugin Ring with over 1,000,000 devices sold worldwide within 7 years from the beginning of the production, several companies recently entered the field of pupil expanders.

The Visitec i-Ring Pupil Expander is a single-use device made of soft polyurethane [Fig. 3]. It creates a circular opening 6.3 mm in diameter. Four corners of the device create four channels that hold the iris in place and also adds to the stability of the device during the surgical procedure. The device is assembled with injector used to insert and remove it.

i-Ring maintains the circular contour of the pupil during the procedure and has a potential to preserve it from the mechanical impact.[42] However, the superiority over other pupil expansion devices in a head-to-head comparison has not yet been demonstrated.

Bhattacharjee Pupil Expansion Ring is made of 5-0 black monofilament polyamide (Nylon), available in square and Hexagon shapes in various sizes (6.0, 6.5, and 7.0 mm). It is a planar structure with inward facing notches located at the corners [Fig. 4]. These notches are used to fixate the pupillary margin. Planar structure makes the device extremely thin providing the advantage of implanting through the 0.9 mm incision.[43] However, planar fixation elements require additional manipulations and special instruments (forceps) to be securely engaged with the iris.

The new Xpand^{NT} iris speculum by Diamatrix Ltd is made from memory metal (titanium alloy). It is almost round having even number of alternating side elements connected by arches [Fig. 5]. The Xpand^{NT} is available in both single- and multiuse versions identical in form, function, and delivery method. The speculum can be inserted and removed through a special injector through a 2.4-mm incision, providing a

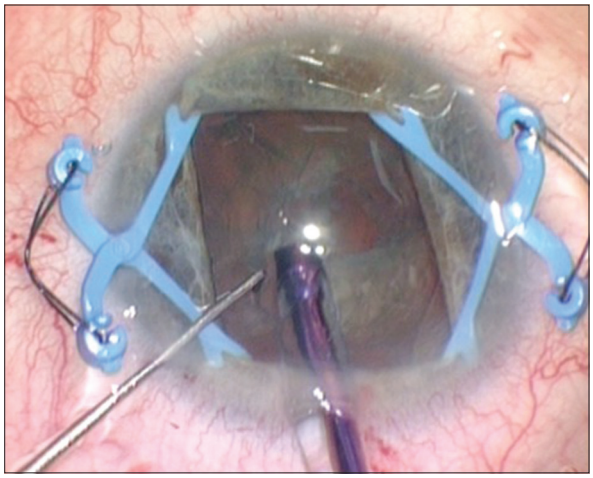

Figure 1: Asia Pupil Expander

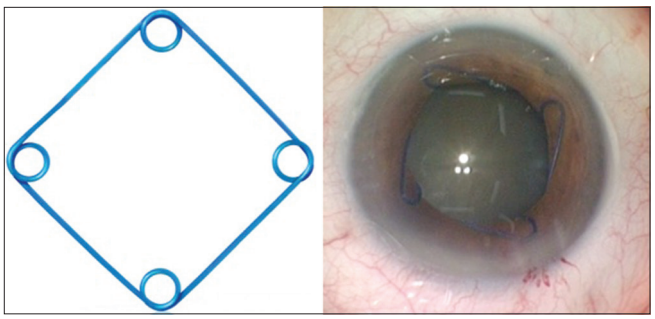

Figure 2: Malyugin ring

near-circular opening 6.7 mm in diameter. A manipulator is used to facilitate placement of the device feet that catches the iris edge and expand the pupil.

In 2016, the new version of the Malyugin Ring (2.0) was released. The new ring is made of 5-0 polypropylene. It is softer and more elastic than the previous model and comes with a redesigned inserter that can easily fit through a 2-mm clear corneal incision (The earlier version requires a 2.5 mm incision). Smaller diameter thread allows for the scrolls to be wider thus it is easier to engage with the iris and also gentler to the tissue.

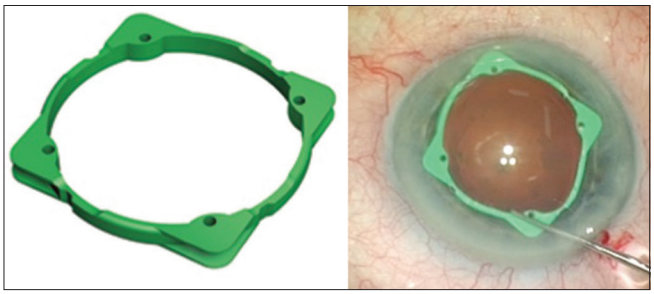

Figure 3: I-Ring Pupil Expander

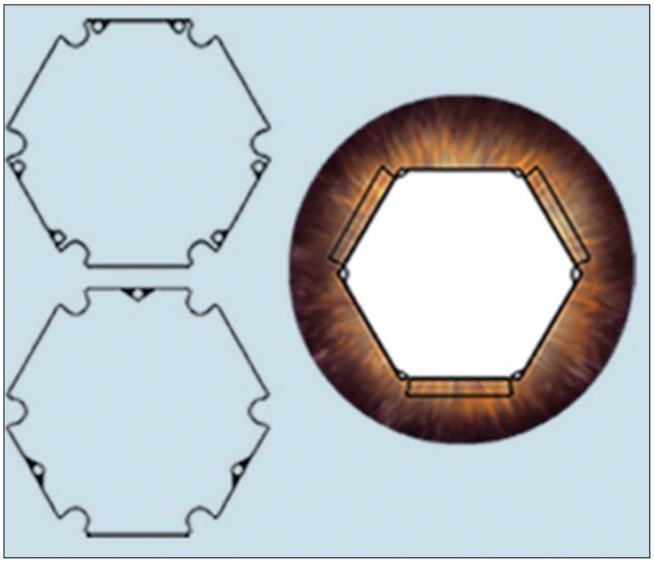

Figure 4: B-Hex Pupil Expander

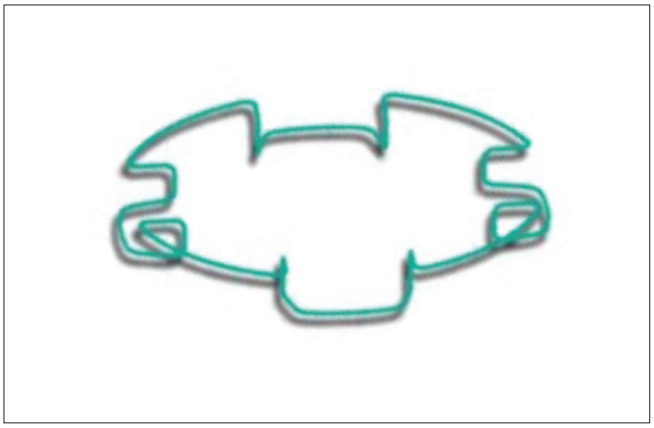

Figure 5: Xpand iris speculum

Femtosecond Laser-Assisted Cataract Surgery and Small Pupils

In 2008, femtosecond laser-assisted cataract surgery (FLACS) was introduced into clinical practice. It has a potential to be in the mainstream of clinical research and further improvements in the years to come yielding the improved clinical outcomes. However, this technology is not immune to complications, with intraoperative pupil constriction being one of them. During FLACS, photochemical photo disruptive process results in aqueous humor prostaglandins elevation. Subsequently, in some patients', prostaglandin-mediated intraoperative miosis occurs. The studies showed dramatically increased rates of intraoperative pupil instability and miosis varying from 1.65% to 64%.[44]

However, NSAIDs administered topically 1–3 days before FLACS significantly reduced the chances of pupil constriction following femtosecond laser delivery into the eye.[44-46]

Obviously, when the pupil is small from the very beginning, the use of FLACS may lead to smaller-sized capsulotomy. The latter increases the risk of capsular contraction and phimosis leading to progressive zonular weakness and intraocular lens-capsular bag complex dislocation in the delayed postoperative period. Several intraoperative pupil expansion strategies were developed for use in FLACS with the Malyugin Ring being one of the most successful.[47-50] If pupil expansion ring is used before FLACS, the surgeon should pay special attention to fill anterior chamber completely with OVD to keep the homogeneity of the optical path and to prevent air bubbles entrapped within OVD, as the latter may cause laser beam deviation and incomplete anterior capsulotomy.[42,51]

Conclusions

Significant variations in the ocular and systemic comorbidity require the whole spectrum of pharmacological and surgical strategies to be in the armamentarium of the modern cataract surgeon. Topical medications augmented with intraocular mydriatic injections appear to be the mainstream providing success in 90%–95% of all cases. However, mechanical pupil dilation is very helpful in achieving and maintaining the mydriasis when all other strategies failed. Pupil expansion devices may cause pupil trauma to some extent. Some of these methods are associated with bleeding, loss of iris sphincter function, and abnormal pupil shape postoperatively. This is specifically true for cases when the iris tissue loose its elasticity due to inflammation and fibrosis. The easiness of manipulations and the final results vary significantly with different devices. Iris hooks and Malyugin Ring are the current standard of care for intraoperative mechanical pupil expansion in patients not responding to the pharmacological protocols. However, a variety of different devices were introduced into the clinical practice over the past years, and some others were being currently under development. In general, latest innovations significantly reduced the chance of complications and increased the success rate of small pupil cataract surgery.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms.

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Conflicts of interest

There are no conflicts of interest.

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