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Improving the View in Vitreoretinal Surgery

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Abstract

Introduction

Great strides have been made since the advent of retinal surgery, including early scleral buckling dating as far back as the 1930s (1) to the beginning of pars plana vitrectomy in the 1970s.~~ ~~(2-5)~~.~~ These include enhanced instrumentation, viewing systems, and peri-operative tools and techniques to augment surgical efficacy and efficiency. Despite this, vitreoretinal surgery remains particularly dependent upon and sensitive to fluctuations in the intraoperative view, which can ~~remain~~ confound~~ing to~~ novice and experienced surgeons alike. This article will review recent advances in the viewing systems, illumination sources, and tools and techniques that have arisen to optimize the view in vitreoretinal surgery.

Viewing System

Rapid improvements in pars plana vitrectomy techniques that began in the 1970s were soon followed by the introduction and development of wide-angle viewing systems in the 1980s,~~ ~~(6-10) based on the principles of indirect ophthalmoscopy. A lens provides an inverted image that is then re-inverted by an optical system typically mounted on the surgical microscope, providing for an erect, stereoscopic image. (1, 6-9, 12)~~.~~ Such systems became readily adopted because they have permitted wider~~simultaneous~~ views of ~~wide areas of~~ the fundus, allowing for better recognition of pathology and facilitating safer and more efficient surgery. The era of small gauge vitrectomies~~y~~, in which rotation of the eye and scleral indentation with smaller, more flexible instruments is more challenging, has ~~only~~ accelerated the use of such systems.~~ ~~(10)~~.~~ In practice, there are two types of wide-angle viewing systems:~~,~~ non-contact lens~~-~~based and contact lens~~-~~based.~~ ~~(6, 11-14)~~.~~

The former consists of a smaller objective lens closer to the cornea, a larger condensing lens that is fixed higher in the microscope and~~,~~ typically~~,~~ an inverter. ~~(~~Table 1 compares the current, commercially-available surgical microscopes~~)~~. Advantages of this system include adjustable fields of view and ease of manipulation by the surgeon without the need for an assistant, while disadvantages include the need for continuous hydration to maintain corneal clarity and a propensity for fogging of the objective lens.

Table 1. Commercially available non-contact wide angle viewing systems

System	Manufacturer
Resight[1] 500 and 700	Carl Zeiss

OCULUS BIOM[2] 5	Oculus Surgical
OMS-800 OFFISS[3]	Topcon
MERLIN Surgical System	Volk Optical
P-W-L Upright Vitrectomy lens[4,5]	Ocular Instruments
EIBOS[5] 2	Haag-Streit
RUV800[5]	Leica

1 Equipped with 60D and 120 D lens
2 Binocular Indirect Ophthalmomicroscope
3 Optical Fiber Free Intravitreal Surgery System. Must be used with Topcon microscope. Illumination incorporated in the microscope permitting bimanual surgery.
4 Peyman-Wessels-Landers 132 Diopter Upright Vitrectomy Lens in Landers Wide Field Surgical Viewing System
5 Integrated inverter, shorter instrument

Contact lens-~~-~~based systems, in contrast, make use of plano lenses that are in direct approximation with the cornea, thereby shortening the working distance~~,~~ and eliminating corneal aberration, asphericity, and reflection, thereby providing greater resolution~~,~~ and improved stereopsis. ~~(~~Table 2 compares currently available contact-lens systems~~)~~. The main disadvantages of such systems are the requirements for sewing on a lens or for an experienced assistant ~~to~~ maintaining lens centration, and the propensity for air bubbles or blood to intervene and intermittently obscure the view (6-13). Variants of such contact lenses have also been developed to maximize magnification and resolution for macular work, with more focused fields of view (detailed in Table 3). Novel combinations of contact and non-contact based wide angle viewing systems have also been described. (15-18)~~.~~ Kita et al. recently published an update of a single use, plano-powered contact lens with a 0.26mm thick central meniscus made of polymethyl methacrylate (PMMA) used in conjunction with a wide angle viewing system. In a series of 82 vitrectomies and 6 scleral buckles, this lens maintained superior optical clarity compared to viscoelastic alone, better preserving corneal integrity. (18)~~.~~

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~~5 Integrated inverter, shorter instrument~~

Table 2. Selection of commercially available wide field contact lenses

System	Manufacturer	Magnification	Field of view (°)	
			Static	Dynamic
HRX	Volk Optical	0.43×	130	150
MiniQuad XL	Volk Optical	0.39×	112	134
MiniQuad	Volk Optical	0.48×	106	127

DynaView	Volk Optical	0.39x	95	127
Landers Wide Field	Ocular Instruments	0.38×	130	146
A.V.I lens	Advanced Visual Instruments	0.48×	130	N/A

N/A data not available

Table 3. Selection of commercially available high magnification contact lenses

System	Manufacturer	Magnification/ Power	Field of view (°)	
			Static	Dynamic
Central Retinal	Volk Optical	0.71x	73	88
Super Macula	Volk Optical	1.03x	64	77
GRIESHABER® DSP Aspheric Macular Lens	Alcon	59D	30	N/A
ODVM Ocular Disposable Vitrectomy Magnifying Lens	Ocular Instruments	1.49x	30	N/A

N/A data not available

Endoillumination: Improving the view once inside the eye

Innovations in external surgical viewing systems and vitrectomy instrumentation have driven the evolution of tools used to enhance the surgeon's view once inside the eye. (12-14)~~,~~ resulting in a wide variety of products that are optimal in different circumstances (Table 4). Widefield illumination facilitates visualization of~~into~~ the retinal periphery, ~~for example,~~ providing for more efficient and safer surgery, but it is susceptible to excessive glare during air-fluid exchanges. Shielded endoilluminators protect the surgeon from excess light exposure~~,~~ but diminish the view of the vitreous. (12-14)~~.~~

Table 4. Selection of commercially available endoilluminators

Bausch and Lomb Stellaris PC	Alcon Constellation

Type	**Gauge**	**Type**	**Gauge**
Focal Illumination	20, 23, 25, 27	Straight Endoilluminator	20, 23, 25, 27
Vivid	20, 23, 25	-	
Midfield	20, 23, 25	-	
Widefield	20, 23, 25	Sapphire wide angle	20, 23, 25
Corona Shielded Widefield	20, 23, 25	Shielded The Bullet RFID	20

Smaller gauge surgery has necessitated the development of more intense light sources, including xenon and mercury vapor, and more recently, light emitting diode (LED) and laser light sources, allowing for improved illumination. (12, 19)~~.~~ Such light sources have opened the door to the use of chandelier illumination ~~, permitting true bimanual surgery for complex pathology or improved visualization of breaks during scleral buckling procedures,~~ and illuminated instrumentation, including infusion chandeliers, bipolar cautery, laser endoprobes, membrane picks, and irrigating and aspirating endoilluminators. (12, 13, 19)~~.~~ The newer lighting sources permit true bimanual surgery for complex pathologies and improved visualization of retinal breaks during scleral buckling procedures.

Light Filters

Given the increased intensity of these light sources, safeguards to protect the ~~ing against~~ retinal from excess light exposure ~~damage~~ are essential. Specifically, retinal photodamage may occur by one of three mechanisms ~~(20)~~: mechanical (e.g. pulsed laser causing fragmentation of tissue), thermal (e.g. when tissue temperature elevations result in denaturation of proteins and loss of macromolecular structure), and chemical (e.g. when high photon energy breaks molecular bonds, creating free radicals and increasing oxidative stress). (20)

In this respect, increasing the distance between the light source and the retina, such as ~~for example~~ with chandelier illumination, serves to decrease phototoxicity. (19, 20)~~.~~

Several commercially available endoillumination devices have incorporated built-in filters to decrease retinal exposure to ultraviolet and blue light from the light source. T~~ – including platforms from t~~he Stellaris PC (Bausch and Lomb) ~~with~~ has green, yellow and amber filters~~, to~~; the Brightstar (D.O.R.C. Dutch Ophthalmic Research Center) ~~with~~ has cutoffs at 435, 475, 515 nanometers; and ~~, to~~ the Photon (Synergetics) ~~with~~ has a cutoff at 485 nm. (19-21)~~.~~

Importantly, adjunctive technologies have facilitated visualization, improving efficiency and illumination, even in challenging circumstances. Endoscopy has been used to illuminate anterior structures such as the ciliary body for cyclitic membranes and is particularly useful when corneal opacity obfuscates the view. (22-24)~~.~~ Additionally, the use of 3D heads-up vitrectomy systems has been shown to be effective ~~an effective~~ means to decrease light exposure with similar outcomes to standard surgical techniques. (25-27)~~.~~

Chromo-vitrectomy

In parallel with these advances in equipment and instrumentation, the use of vital dyes and stains has greatly improved visualization during vitreoretinal surgery. (13)~~.~~

Peeling the internal limiting membrane (ILM) for macular hole surgery, for example, demonstrated improved anatomic and visual outcomes when it was first introduced in the 1990s, but ~~did not gain~~ widespread ~~-~~acceptance ~~because of technical difficulty with~~did not occur ~~visualization~~ until ~~the application of~~ indocyanine green (ICG) was used to help visualize the ILM.~~to this problem~~ (10, 28-35).

ICG is an inert, amphiphilic dye, with little systemic toxicity; it ~~that~~ was initially introduced to o~~O~~phthalmology in the 1970s for the study of the choroidal circulation. (11, 36)~~.~~ Its ability to bind basement membranes was first made use of by surgeons staining the anterior capsule in dense cataracts, but it is now used to primarily stain the translucent ILM in vitreoretinal surgery. (28-35)~~.~~ While reports of ~~toxicity that are both~~ time and dose dependent toxicities have been described, surgical outcomes have typically been superior for guided chromo-vitrectomies~~y~~ (36).

Infracyanine green (IfCG) is~~,~~ an iodine-free vital dye diluted in glucose that also avidly stains ILM. I~~,~~ has a superior safety profile to ICG, reducing osmotically ~~-~~induced retinal toxicity; (13, 36)~~.~~ however, i~~I~~t ~~has~~ is not yet ~~in~~ widely used, in part~~-usage, partially~~ because it is more cumbersome to reconstitute. (11, 13, 36)~~.~~

Trypan (or membrane) blue is an anionic, hydrophilic vital stain that, like ICG, was shown to have significant affinity for the lenticular anterior capsule, facilitating capsulorrhexis during cataract surgery. Trypan blue ~~,~~was ~~and~~ soon thereafter ~~was~~ introduced for staining preretinal structures, such as the epiretinal membrane (ERM) and ILMs. (13, 36)~~.~~ Of note, the safety profile of Trypan blue is superior to that of ICG; when combined with Xenon light in an RPE-glial cell culture model, Trypan blue does not demonstrate the combined phototoxic effect to cultured Mueller cells that ICG does.(37) However, Trypan blue binds less avidly than ICG, ~~G – it exhibits less avid binding than ICG,~~ has a higher relative~~ly~~ affinity for the ~~-~~ERM rather than ILM, and is more easily rinsed out.~~, and when combined with Xenon light in an RPE-glial cell cell culture model, does not demonstrate the combined phototoxic effect to cultured Mueller cells that ICG does (37).~~

Brilliant blue is another vital dye used primarily for staining the ILM. Its ~~reported~~ advantages include lower cytotoxicity and faster staining than T~~t~~rypan blue or ICG, as well as higher affinity for ILM and lower affinity for ERM than T~~t~~rypan blue. (38)

However, it is not currently approved by the Federal Drug Administration (FDA) for use in the United States.

Patent blue is another hydrophilic vital dye that is in preclinical studies. It demonstrates excellent staining of the ERM with only minimal toxicity; however, ~~—~~ its advantage over other stains is not yet clear. (13, 36)~~.~~

The corticosteroid triamcinolone acetonide has significant avidity for acellular vitreous and has been applied intraoperatively to facilitate complete excision of the posterior and anterior vitreous and help identify ~~precipitate on the~~the ILM. ~~assisting in its identification~~ (13, 36)~~.~~ However, t~~T~~here are some reports of RPE toxicity, so extra caution should be taken especially in macular hole repairs to remove excess triamcinolone. (13)~~.~~

Vital dyes and stains, most of which have excellent safety profiles, improve visualization during vitreoretinal surgery and will likely remain useful surgical tools for the foreseeable future. The utility, however, of such adjuncts are necessarily limited by inherent biological constraints of surgery through the clear cornea.

Corneal clarity

Clarity of the cornea is an essential component of vitreoretinal surgery that is difficult to preserve, particularly in long cases. Intraoperative corneal edema is an important source of reduced corneal clarity and can be caused by several factors, including fluctuations in intraocular pressure, production of inflammatory mediators, and mechanical trauma. (39)~~.~~ Corneal wetting agents are frequently employed in vitreoretinal surgery because they reduce edema, and preservative-free options are preferred in prolonged surgeries to avoid epithelial toxicity. (40-41)~~.~~

Balanced salt solution (BSS) is the most commonly used corneal ~~wetting~~ hydration agent due to the ease of availability and cost efficiency. (42)~~.~~ While frequently employed in anterior segment surgery, BSS presents several challenges for vitreoretinal surgery. Due to the short duration of action, frequent BSS administration is disruptive to the surgical procedure any may cause discomfort to patients who are not under general anesthesia. (43)~~.~~ There is also the additional risk of corneal epithelial damage from BSS that can lengthen the postoperative course. (42)~~.~~

Viscous lubricants are the preferred corneal wetting agents in vitreoretinal surgery. Compared to non-viscous solutions, such as artificial tears or BSS, viscous lubricants consistently provide better optical clarity. (38, 42, 43-46)~~.~~ Importantly, the use of viscous agents allows for both a reduced frequency of application and longer duration of ~~of~~ action, preventing frequent disruptions during surgery. (46)~~.~~ However, ~~as a result of higher molecular weight,~~ these viscous lubricants are slow to dissipate on the cornea due to the higher molecular weight and can delay the start of surgery. (43)~~.~~

There are several different viscous formulations available for use. The most common solutions ~~used~~ include the elastoviscous hylan surgical shield (HsS) or gel formulations of hyaluronic acid (HA) and hydroxypropyl methylcellulose (HPMC).

Each of these three of these formulations are superior to BSS in achieving optical clarity. (41, 44, 46, 47)~~.~~ If these fail ~~, for example,~~ with excessive corneal edema, careful scraping of the corneal epithelium may be undertaken to preserve or recover viewing clarity intraoperatively. When this is ineffective, endoscopic techniques, (48)~~,~~ temporary keratoprostheses or combined penetrating keratoplasty with vitrectomy, (49-53)~~,~~ and open-sky vitrectomy (54) should remain in the toolkit of the modern viteroretinal surgeon.

Iris

Control of pupillary size is a critical component to ensuring an adequate posterior segment view during vitreoretinal surgery. Pharmacologic and ~~,~~ mechanical ~~, and device~~ strategies exist for assistance in manipulating the iris and facilitating a posterior surgical approach.

Pharmacologic Dilation

Appropriate mydriasis is critical to the success of surgery and has been investigated extensively in regards to phacoemulsification. This is usually obtained by preoperative use of mydriatic drops, which is sufficient in most cases. A number of different anticholinergic or sympathomimetic medications are used alone or in combination to achieve adequate dilation within the time constraint of the preoperative period. If surgery is prolonged, a gradual miosis has been observed due to the release of prostaglandins. (55)~~.~~ Interventions with topical and intracameral non-steroidal anti-inflammatory medications have been examined in regards to preventing miosis. (56, 57)~~.~~ Many cases warrant supplementation with intracameral epinephrine at a concentration of 1:1,000,000. This dose has been shown to be a safe and effective technique to improve mydriasis during surgery. (58)~~.~~ This epinephrine can be added to the irrigation fluid used during surgery to avoid the washout anticipated with the use of bolus dosing. An alternative technique that avoids direct intervention in the anterior chamber includes subconjunctival injection of epinephrine 0.2 cc of epinephrine (1:1000). In limited study, no systemic side effects were identified in association with absorption of epinephrine in to surrounding vasculature. (59, 60)~~.~~ As larger studies have yet to be undertaken, caution is advised in regards to changes that may occur in the patient's blood pressure.

Iris Expansion Devices

In cases where pharmacologic medications are insufficient or likely to be ineffective, mechanical devices may help in achieving adequate mydriasis to complete the vitrectomy. The use of traditional flexible iris retractors has been studied most extensively in assistance with management of ~~IFIS or~~ intraoperative floppy iris syndrome or IFIS.(61, 62)~~.~~ Use of iris hooks allows the surgeon to expand the pupil in either a four or five-sided figure. The~~ir~~ use requires additional corneal manipulation but the~~ir~~ flexibility in the choice of location makes them an excellent tool for improving surgical exposure for the retina surgeon. (63)~~.~~ Additional variability in the amount of tension forces applied makes them excellent for ensuring adequate pupil size. Critical technical components to effective insertion include maintaining the appropriate mid iris trajectory when corneal channels are created, appropriate planning of retractor location, and additional management of remaining posterior synechiae if these are present. (64)~~.~~

Pupillary expansion rings can be used to assist in pupillary dilation, but their size and shape can be prohibitive during vitrectomy surgery targeted at the posterior segment. (65)~~.~~ Direct mechanical pupillary dilation is rarely utilized given the additional risk of iris tears, bleeding, and residual pupillary abnormalities. However, this can be an effective strategy in the appropriate clinical context. (62)~~.~~ If mechanical dilation is to be undertaken, one strategy is to use two Cooglan hooks to mechanically stretch and dilate the pupil 180 degrees apart. Care must be taken to avoid applying excess force and causing tears in the iris.

Pupillary Membranes and Posterior Synechiae
In cases where patients have had episodes of uveitis (66) or prior vitrectomy (67), posterior synechiae may limit pupillary dilation. In cases where a pupillary membrane has caused a near total occlusion of the pupil, a peeling of the membrane at the pupil edge can be undertaken. Micro-forceps can be used to grasp the edge of the offending membrane and strip the fibrotic tissue band ~~apart~~ from the pupillary margin and allow for pupillary dilation. (68)~~.~~

Lens
In cases where the crystalline lens requires removal in order to allow for a clear posterior view, multiple approaches may be undertaken. This may include pars plana lensectomy or removal with phacoemulsification. (69)~~.~~

Conclusion
Successful vitreoretinal surgery is uniquely dependent on intraoperative visualization. Spurred by tremendous technical advances in optical viewing systems, instrumentation for endoillumination, tools for differentiation of preretinal anatomical structures, and preservation of biological transparency, the view has never been so clear. Accordingly, vitreoretinal surgery has become increasingly safe, efficient, and effective, a trend that is likely to continue for years to come.

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