ABSTRACT: We have reviewed currently available OVDs and their classification. Their use in unusual problems of cataract surgery demonstrates that generally a variant of Soft Shell techniques is optimal for unusual problems and complications. This differs in glaucoma surgery, where space creation and maintenance is the usual goal, making highly viscous cohesive OVDs, and sometimes viscoadaptives the usual agents of choice.


Investigationally used in the 1970’s, but first marketed in 1980 (Healon), ophthalmic viscosurgical devices (OVDs - referred to as viscoelastics before 2000), are pharmacologically inactive, clear, highly viscous and elastic fluids that have properties bordering upon gels and solids¹. The prototype rheologic component of an OVD material is sodium hyaluronate (HA), however chondroitin sulfate, and hydroxypropylmethylcellulose have also become commonly used. Their physical properties, which collectively are the determinants of OVD behavior in surgery, include viscosity, elasticity, pseudoplasticity, and cohesion, which in turn depend on the rheologic polymeric mean chain length (molecular weight) and concentration. Consequently saying that two OVDs are both 1% HA solutions is insufficient to claim equivalence, because they may have different polymeric chain lengths, molecular weight distribution, etc. Therefore, unlike with pharmaceuticals, OVDs must be referred to by their trade names to be accurate about their properties and behavior. Generic names are usually misleading and inadequate descriptions of an OVD preparation.

OVDs serve many purposes in ophthalmic surgery: space creation & maintenance, balancing pressure in the anterior chamber and posteriorly, tissue stabilization, anterior chamber space partitioning, and protection of the corneal endothelial cells. OVDs have been classified based upon their behavior in surgery. The first groups, prior to 1990 were higher viscosity cohesives and lower viscosity dispersives. Viscoadaptives, a class based upon the properties of Healon⁶ were added in 1998, and the subsequent advent of DisCoVisc in 2004, a higher viscosity dispersive, required the classification to become two dimensional and more complicated. The current classification is illustrated in Table 1².

Surgeons should select different OVDs for different tasks based on rheologic properties. All materials found to be useful as OVDs to date, are pseudoplastic polymeric aqueous solutions. They are most viscous when stationary, i.e. at zero shear rate, and their viscosity decreases as shear rate increases. Plastics also exhibit decreased viscosity with increasing shear rates, but their viscosity goes to infinity at shear rate zero, making them solid when stationary. Unlike true plastics, OVDs reach a finite or limiting viscosity as shear rates approach zero and always remain in a fluid state. Thus they are referred to as pseudoplastic. The zero-shear viscosity at a given temperature is one of the few ways to reliably compare OVDs, without requiring a more complex graphical description of properties under different conditions (Figure 1). A simplified, surgically useful classification can be created based upon viscosity and cohesive properties of OVDs (Figure 2).
Current OVDs

**Higher viscosity cohesive OVDs**
(e.g. Healon, Healon GV, Provisc, Amvisc)

Higher viscosity cohesive OVDs (HVCs) are all fairly viscous solutions of long chains of sodium hyaluronate, usually approximating 1% concentration. Their long chain lengths allow for more inter-molecular hydrogen bonding and thus the molecules cohere and move as a mass. This allows cohesive OVDs to create and preserve spaces better, and results in easier, quicker removal at the end of the procedure.

<table>
<thead>
<tr>
<th>Zero shear viscosity range (mPa.s)</th>
<th>Cohesive OVDs CDI &gt; 30 (% asp/mmHg)</th>
<th>Dispersive OVDs CDI &lt; 30 (% asp/mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-18 × 10^6 (ten millions)</td>
<td>I. Pseudodispersive viscoadaptatives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Healon5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• iVisc (MicroVisc) Phaco</td>
<td></td>
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<tr>
<td></td>
<td>• BD MultiVisc</td>
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<tr>
<td>CDI Healon5 = 10.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDI iViscPhaco = 9.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5 × 10^6 (millions)</td>
<td>II. Higher viscosity cohesives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A. Superviscous cohesives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Healon GV</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• iVisc (MicroVisc, HyVisc) Plus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BD Visc</td>
<td></td>
</tr>
<tr>
<td>CDI Healon GV = 72</td>
<td>B. Viscous cohesives</td>
<td></td>
</tr>
<tr>
<td>10^5 – 10^6 (hundred thousands)</td>
<td>• Healon</td>
<td>• Biolon Prime</td>
</tr>
<tr>
<td></td>
<td>• iVisc (MicroVisc, HyVisc)</td>
<td>• Bilon</td>
</tr>
<tr>
<td></td>
<td>• Viscorneal Plus</td>
<td>• Amvisc Plus</td>
</tr>
<tr>
<td></td>
<td>• Provisc</td>
<td>• Amvisc</td>
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<tr>
<td></td>
<td>• Opegan Hi</td>
<td>• Coese</td>
</tr>
<tr>
<td></td>
<td>• Viscornea</td>
<td>• Biocorneal</td>
</tr>
<tr>
<td>CDI Healon = 37</td>
<td>III. Lower viscosity cohesives</td>
<td></td>
</tr>
<tr>
<td>10^4 – 10^5 (ten thousands)</td>
<td>A. Medium viscosity cohesives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• none</td>
<td>• Viscoat</td>
</tr>
<tr>
<td></td>
<td>B. Very low viscosity cohesives</td>
<td>• Biovisc</td>
</tr>
<tr>
<td></td>
<td>• none</td>
<td>• Opelead</td>
</tr>
<tr>
<td>10^3 – 10^4 (thousands)</td>
<td></td>
<td>• Vitrax</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Celofal</td>
</tr>
</tbody>
</table>

Note that viscoadaptives occupy both the cohesive and dispersive columns, as their behaviour may change as a function of flow rate (turbulence) in surgery. mPa.s = milliPascal.seconds; CDI = cohesion-dispersion index (% aspirated/mmHg)


**Lower viscosity dispersive OVDs**
(i.e. Viscoat, Healon D, Ocucoat)

Lower viscosity dispersive OVDs are made up of shorter chains of sodium hyaluronate, often with another low molecular weight polymer (chondroitin sulfate (CDS) or hydroxypropylmethylcellulose (HPMC) added or substituted for HA. The shorter chain length induces less molecular interaction and thus the molecules don’t cohere as well, but the material, instead tends to fall apart under the stresses commonly induced by surgical maneuvers. Thus these OVDs resist removal as they fall apart when...
exposed to even moderate aspiration forces, resulting in only small bits being removed at a time. Lower viscosity dispersives (LVDs) are also less pseudoplastic than HVCs. Their initially unintended property of difficult removal has become important with modern high flow phacoemulsification because of the tendency of LVDs to be retained longer, protecting the endothelium, while phacoemulsification using high flow rates proceeds. LVDs have been found to be particularly useful in the management of complications.

The problem of HVCs and LVDs having different properties, which make each class best for a different part of the phacoemulsification procedure, was overcome by the development of the Soft Shell Technique.

Viscoadaptives (Healon5, MicroVisc Phaco, iVisc Phaco)

Viscoadaptive OVDs (VAs) were designed to play the roles of both HVCs and LVDs by spontaneously adapting their rheologic behaviour to the fluid environment created by the surgeon. VAs behave as ultra viscous cohesive when the flow rate is below 25 cc/ min. and as fracturable pseudo-dispersives at high flow rates (a behaviour due to them acting as solids under higher flow rate stress or increased shear rate). Healon5 is excellent to viscodilate small pupils, and during phaco its retention can be increased to rival LVDs by lowering the flow rate. An excellent summary and explanation of the behavior of the above OVD classes is given by Arshinoff and Wong (Figure 3). Some aspects of phacoemulsification were found to be improved with a variant of the soft shell technique for viscoadaptives, referred to as the ultimate soft shell technique.

Higher viscosity dispersive OVDs

The newest class of OVDs is higher viscosity dispersive (HVDs). The first HVD was DisCoVisc, introduced in 2004. HVDs were intended to compete with viscoadaptives, by being both viscous (like Healon) and dispersive (like Viscoat), thus being able to maintain spaces better than HVCs, while being retained in the anterior chamber longer, similar to LVDs, during phacoemulsification. DisCoVisc is rheologically similar to Amvisc Plus. Neither of these OVDs has replaced Soft Shell Technique variations, because the surgeon can never achieve the same variety of desirable effects with a single OVD as with two different ones. But some surgeons prefer the simplicity of single OVD use. DisCoVisc’s properties, as a higher viscosity OVD, required new classifications of OVDs to be two dimensional, because all previous viscous OVDs were cohesive, and with the inclusion of DisCoVisc, the high correlation between an OVD’s zero shear viscosity and cohesion was not necessarily present.
OVDs in complex anterior segment and cataract surgery

OVDs have been developed and used primarily for cataract surgery, simply because so many more cataract operations are done, when compared to anything else. Before discussing the use of OVDs for glaucoma surgery, it is instructive to look at how OVD use has been adapted for other complicated anterior segment procedures, involving cataracts, to establish some general principles.

Capsulorhexis in young children

Capsulorhexis on a pediatric capsule is challenging due to higher capsular elasticity, increased anterior capsular convexity, and less rigid sclera. To counteract these problems, an OVD with very high zero shear viscosity (Healon 5) is preferred to flatten the anterior capsule, along with trypan blue, which decreases capsular elasticity as it increases visibility.

Posterior capsular opacification is a major problem in the pediatric population, because of its almost invariable rapid post-operative development, and the difficulty getting sufficient cooperation in children needing YAG laser capsulotomy. Gimbel was the first to describe posterior continuous curvilinear capsulorhexis (PCCC) under OVD control in children. The high viscosity OVD keeps the capsular bag formed and concave, to prevent the capsulorhexis from running peripherally, and the posterior capsule is pierced with a needle. OVD is then injected into Berger’s space, but not so much that the capsule loses its concavity. Following this, the PCCC is fashioned with a traditional rhexis forceps. An excellent review of this procedure is provided by Vasavada et al.

Mature and intumescent cataracts

Performance of a CCC in mature and intumescent cataracts represent a significant challenge due to the absence of retroillumination from a red reflex, poor visualization of the capsule which is also sometimes fibrosed to underlying cortex, and posterior pressure. All of these factors can lead to the unplanned and unfortunate development of the “Argentinean Flag Syndrome”. As with pediatric cataracts, this can be relatively easily overcome with the use of viscoadaptives to flatten the capsule, with trypan blue underlying it, to enhance visualization.
Intraoperative floppy-iris syndrome (IFIS)

IFIS represents a challenge in cataract surgery, in which the iris is miotic and flaccid due to sympathetic denervation, and consequently has a tendency to prolapse with the pupil constricting progressively during surgery\(^1^6\). Different mechanical devices are available to maintain pupil dilation throughout surgery, and Arshinoff described a technique using only OVDs to maintain pupil dilation throughout surgery, now referred to as the IFIS Bridge\(^1^1\). The method is as follows: At the beginning of the case, a dispersive OVD, preferably Viscoat is injected in the perimeter of the AC, to cover the iris. Then, Healon5 is injected centrally, on the surface of the anterior lens capsule, which pushes the dispersive Viscoat into the angle, covering the iris. It is the layer of Viscoat that prevents the iris from flopping by tamponading it during I/A, while resisting aspiration. However, Viscoat alone, like any dispersive, has low viscosity and will not dilate the pupil well. The Healon5 is therefore used to fill the AC, and dilate the pupil, maintaining the entire OVD bridge structure stable. Balanced Salt Solution (BSS) is the injected below the Healon5, in Ultimate Soft Shell Technique fashion to create a small working space filled only with BSS\(^1^2\). This IFIS Bridge provides a working space to proceed with phaco under low-flow conditions, preventing the Healon5 from being aspirated by the phaco tip and keeping the bridge intact with the Viscoat tamponading the iris, preventing its flopping (Figure 4).

Viscodissection

Cortical cleaving hydrodissection using BSS prior to nuclear phacoemulsification is a well-established technique first described by Fine\(^3\). Viscodissection with lower viscosity dispersive OVDs has described in special cases such as posterior polar cataracts and zonulopathy such as with pseudoxfoliation syndrome, in order to support and stabilize the capsule, decrease zonular stress and assist in peeling cortex off the capsule\(^1^4\). Viscodissection has also been suggested for use in routine cataract surgery, to provide additional safety, and decrease the rate of posterior capsular rupture\(^1^5\). Hydrodilatation is done first and the central nucleus is removed. Subsequently, viscodissection of the peripheral cortex is performed, protecting the capsule, and keeping the vitreous back in case a hole in the posterior capsule is present, while the cortex is dissected free of the capsule and brought forward by the viscodissection to a position from which it is easily removed.

OVDs in glaucoma surgery

Visco-synechialysis for angle closure

In the presence of complicated cataract extraction (ex: uveitic, post-trauma), the OVD can be used as a soft spatula to break both anterior and posterior synechiae. For stronger adhesions, OVDs can serve to create space, to allow the surgeon to dissect synechiae with microforceps or microscissors. Viscogoniosynechialysis, in combination with phacoemulsification, has been demonstrated effective to control IOP in acute angle closure glaucoma refractory even after laser peripheral iridotomy\(^1^6\). Chronic angle closure glaucoma (CACG) can also be the consequence of the development of extensive peripheral anterior synechiae secondary to prolonged apposition of the iris and the trabecular meshwork (e.g. pupillary block, phacomorphic glaucoma, uveitis …). Even if the underlying cause is successfully treated, residual adhesions can persist and cause chronically elevated IOP\(^1^7\). When more than 270 degrees of the angle is closed, medical therapy may be insufficient, and a surgical approach\(^1^6,1^8\), or YAG laser synchialysis\(^1^9,2^0,2^1\), may be required. IFYAG synchialysis proves insufficient, classic filtration surgeries (like trabeculectomy) are also often ineffective, with poor outcomes in this population\(^2^2\).

Goniosynechialysis using sodium hyaluronate and an irrigating cyclodialysis spatula was first described by Cambell & Vela\(^2^3\), but it appears that it can usually be accomplished with less trauma using OVDs alone\(^1^6\). Although cases vary individually, the more viscous the OVD, the easier the opening of the angle will be, although care must be taken not to cause a dialysis with over enthusiastic injection of a very highly viscous OVD\(^3^). The use of OVDs is preferable to BSS to attain better space maintenance and stability of the anterior chamber with better protection of surrounding ocular structures during manipulations. It also permits better visualization and containment of possible hemorrhage. Different techniques have been described to remove synechiae from the angle, but viscogoniosynechialysis appears minimally traumatic and very promising, especially if cataract surgery is also needed. After performing phaco with intracapsular IOL insertion, breaking synechiae in the angle is performed with injection of a high molecular weight OVD at the iris root to expose the trabecular meshwork and restore filtration. This technique is more effective when the anterior synechiae have developed relatively recently\(^1^9\), but has also been shown effective in CACG\(^1^6,2^4\). Prolonged angle closure affects the anatomy of the meshwork, and can decrease its filtration properties. With viscogoniosynechialysis the angle itself is never touched but gently dissected, thus decreasing potential damage to the TM with surgical instruments. The length of time between initial angle closure and successful goniosynechialysis will vary with individual patient circumstances, before causing irreversible damage.

Chronic open angle glaucoma procedures and OVD use

In the recent evolution of glaucoma surgery, OVDs have played an important role, though not as significant as in cataract surgery. Different new procedures, such as viscocanalostomy and deep sclerectomy have
been described; but given their limited indications and effectiveness, trabeculectomy remains the gold standard\textsuperscript{25, 26}. Unlike during phacoemulsification, where BSS infusion is used to maintain space, OVD is usually the only way to preserve spatial stability and ocular pressurization during glaucoma surgery. It is especially important to protect the lens and prevent cataract formation\textsuperscript{27}. IOP stability is very important in glaucoma surgery considering that the optic nerves in advanced disease are more sensitive to IOP fluctuation. High viscosity at zero shear is the most important characteristic of an OVD during glaucoma surgery\textsuperscript{27}. It will maintain space while there is no movement, allowing the choroidal vascular bed to adapt to the intraoperative IOP level, and thus is generally injected into the anterior chamber early in the surgical procedure. Other advantages of an OVD filled anterior chamber are to control bleeding and to decrease excessive early filtration, thus limiting the incidence of hypotony, which may be difficult to manage and have detrimental visual consequences\textsuperscript{28, 29}. In a prospective study, Gulkilik et al have described the beneficial effects of sodium hyaluronate on the incidence of early post-op complications in trabeculectomy\textsuperscript{30}. Early complications, such as hypotony, anterior chamber shallowing and choroidal detachments, were significantly lower in the study group compared to the control group. Other studies have shown supportive results\textsuperscript{31, 32}. Blondeau demonstrated, at 1 year follow-up, that patients in the sodium hyaluronate group had better visual acuity, less hypotony, better visual field and IOP was easier to control\textsuperscript{29}. The availability of a product that can be left in it has the potential to lower pressure surgically, while reducing most of the severe complications associated with trabeculectomy, such as hypotony, blebitis and endophthalmitis. Since the 1950s, many variations of NPGS have included sinusotomy, the use of a guarding scleral flap, dilation of the ostia of Schlemm’s canal, and the use of implants at the surgical site\textsuperscript{33, 34, 35, 36, 37, 38, 39, 40}

A common step to all NPGS is the creation of a trabeculo-Descemet’s window (TDW) done by unroofing Schlemm’s canal, which acts as a natural outflow resistance membrane. A 5.0 mm × 5.0 mm superficial scleral flap is dissected to a depth of approximately one third of scleral thickness after a limbal conjunctival peritomy. Within the borders of this flap, a second, deeper scleral block of 4.0 mm × 4.0 mm is created to a depth at which the choroid is visible through a very thin remaining layer of sclera. This deep block is dissected forward in the same plane until a TDW is formed and the circumferential scleral fibers of the scleral spur are visualized. Careful dissection forward at this point with upward traction of the deep scleral block allows for the unroofing and entry into Schlemm’s canal\textsuperscript{34, 38}. As Descemet’s membrane stays intact, this creates a scleral reservoir where aqueous humor will drain and be resorbed into blood vessels. On the other hand, a trabeculectomy creates a subconjunctival bleb because all of Descemet’s membrane is removed. The viscocanalostomy, as described by Stegmann, consist of viscodissection of Schlemm’s canal over only few clock hours\textsuperscript{39}

A newer technique that dilates the entire canal and thus theoretically improving aqueous outflow and IOP control has been developed. Canaloplasty (also known as Viscocanaloplasty) incorporates a 200 μm flexible microcatheter used to explore Schlemm’s canal\textsuperscript{39}. After unroofing the canal, the ostium of the canal is dissected to facilitate access by the microcatheter. The use of optical fibers for illumination of the tip allows for surgical guidance, as the tip can be seen transsclerally during catheterization to identify where Schlemm’s canal is being explored. The microcatheter also contains a lumen for insertion of a syringe containing OVD (Healon GV). The microcatheter is advanced slowly circumferentially through all 12 clock hours of the canal while the surgeon injects the OVD and monitors the location of the beacon tip through the sclera\textsuperscript{40}. Typically a highly viscous and pseudoplastic OVD (Healon GV) is injected into the cut ends of the canal with the intention of dilating the canal and creating a passageway to the sclera reservoir. After catheterization of the entire canal length with the microcatheter, a 10-0 Prolene suture (Ethicon Endo-Surgery, Inc.) is pulled into the canal\textsuperscript{41}. It is tied using a slipknot to encircle the inner wall of the canal. The suture loop is tightened to distend the trabecular meshwork inward, placing the tissues in tension and further dilating Schlemm’s canal\textsuperscript{40}. Sutures are then placed to achieve watertight

Viscocanaloplasty

The use of non-penetrating glaucoma surgery (NPGS) is a fairly new concept that was first described by Robert Stegmann in the early 1990s as an alternative to the classic trabeculectomy\textsuperscript{33}. The great interest for this type of surgery is explained by the fact that it has the potential to lower pressure surgically, while
closure of the superficial scleral flap. Canaloplasty is promising as a form of NPGS, which may be of higher efficacy than prior techniques, while maintaining lower complication rates than penetrating surgeries.

Many studies comparing efficiency of find that IOP post-canaloplasty seems to be higher than with trabeculectomy. Nevertheless, canaloplasty has practical and theoretical advantages over trabeculectomy. Because it reduces bulk outflow of aqueous, the complications of overfiltration seen with trabeculectomy can be avoided. Since there is no subconjunctival bleb, there is also a theoretically decreased risk of infection. The most common complications are microhyphema, early-elevated IOP, passage of the microcatheter into the anterior chamber/suprachoroidal space and descemet membrane detachment. Grieshaber et al. described that a microhyphema presents during the first few days post-op could represent a patent outflow system and would be a positive predictive indicator with respect to IOP control. Wishart’s study showed that phacocanalostomy was effective in managing glaucoma and cataract, without a major increase in rate of complications.

**Minimally invasive glaucoma surgery (MIGS)**

Minimally invasive glaucoma surgeries (MIGS) are group of glaucoma procedures that allow ab-interno approach, without a bleb formation, that may be performed at time of cataract extraction or as a sole procedure. Examples of such procedures are the Endoscopic cyclophotocoagulation (ECP), Glaukos-iStent (trabecular microbypass stent, iStent, Glaukos Corp. Laguna Hills, CA, USA) and the ab-interno trabeculotomy (Trabecome, Neomedix, Inc. Tustin, CA, USA). ECP allows direct visualization and photocoagulation of the ciliary process in order to reduce the IOP. To facilitate the access and visibility to the ciliary processes, the ciliary sulcus is inflated ideally with higher viscosity cohesive OVD (Provisc, Healon). This step prevent trauma to surrounding tissues, such as iris, capsular bag and lens, and allow good exposure of the tissue to be treated. A dispersive OVD (Viscoat) may be placed on the cornea as a coupling agent for the Swan-Jacobs gonio-prism. The OVD in the AC is aspirated upon completion of the MIGS.

**Post-operative hypotony and anterior chamber re-formation**

A significant early and late post-operative complication of trabeculectomy and other glaucoma surgeries is hypotony, usually due to overfiltration, but occasionally due to hyposcretion of aqueous, and can potentially result in a flat anterior chamber, with lens-to-cornea touch and posterior choroidal detachment. Other complications of hypotony include corneal endothelial damage, peripheral anterior synechia, closure of the filtering fistula, cataract, serous retinal detachment, macular folds, optic nerve swelling and irreversibly decreased visual acuity. In 1999, 196 members of AGS were surveyed by Salvo, who then reported that slit-lamp AC reformation with OVD was commonly used in trabeculectomy post-op. The most frequently used OVDs were Healon, Viscoat and Healon GV. The main reasons to proceed with AC filling were hypotony, irido-corneal touch and lenticulo-corneal touch, which respectively prompted 19%, 47% and 88% of glaucoma specialists to inject OVD. Only one event of endophthalmitis was reported in this series. More recent reports suggest that Healon5 is a better choice than Healon because it is even more viscous at low shear rates. Although any filtering procedure may require surgical revisions, especially if overfiltration occurs, OVDs can be an effective short-term measure to counteract hypotony and its various complications. They can provide extra time until the surgeon must operate. Using them routinely post-operatively may help to maintain the anterior chamber depth and prevent choroidal detachments.

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