Minimally Invasive Vitrectomy Surgery – The New Era

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Pars plana vitrectomy (PPV) is a relatively new addition to ophthalmic surgeries by ‘the father of pars plana vitrectomy’ Robert Machemer. He performed the first PPV on human in 20th April, 1970 for non-clearing diabetic vitreous hemorrhage. After this revolutionary invention the PPV has evolved drastically in last 40 years. Minimally invasive vitrectomy surgery (MIVS) is the newest in this evolution. Small self-sealing sclerotomy (sutureless) wounds are now increasingly being made with 23G (0.6mm), 25G (0.5mm), and 27G (0.4mm) trocars and cannulae. Commercially available sutureless vitrectomy systems include Constellation/Accurus (Alcon, Fort Worth, Texas, USA), Stellaris/Millenium (Bausch and Lomb, Rochester, NY, USA), and Associate (DORC, Zuidland, Netherlands).

History

Traditionally vitreous had been thought to be ‘untouchable’ and ‘sacrosanct’. Von Graefe is noted to be the first to invade the vitreous in 1863. David Kasner in 1968 removed diseased vitreous using sponge and scissors in 2 cases of amyloidosis of vitreous through anterior route by removing the cornea and lens (‘Open Sky’ Vitrectomy). The disadvantages of the technique were need of corneal transplant and aphakia, poor intraocular pressure maintenance (globe collapse), and significant vitreous traction.

Robert Machemer in 1971 described ‘Vitreous infusion suction cutter (VISC)’. VISC was a closed globe, single port 17G pars plana vitrectomy system comprising of a vitreous cutter (diameter 1.5 mm) inserted through a 2.3 mm scleral incision. VISC had a rotating inner tube with sharp edges, a stationary outer tube, an infusion system, and manual suction was applied by a syringe. Suction drew vitreous into the openings and the rotating sharp edge cut the vitreous. The rotation speed could be changed by a rheostat. However, a similar vitreous cutter with infusion and aspiration had been used clinically in Japan and published in Japanese literature before 1971. Parel and Machemer et al described a fibreoptic system to provide endoillumination in 1972 as a 2 port procedure.

Conor O’Malley and Ralph Heinz introduced 3 port pars plana vitrectomy using 20G vitrectomy cutter and 1.4mm sclerotomy. Self-sealing, pars plana sclerotomy was described by Chen JC in 1996. A technique of modified sutureless sclerotomy was devised by Kwok AK and colleagues in 1999. De Juan E and Hickingbotham D have been credited to be the first to design and use 25G instruments through conventional sclerotomies. First 25G transconjunctival sutureless vitrectomy (TSV) system was invented by Fujii GY and colleagues in 2002. 23G TSV was devised in 2005 by Claus Eckardt. Yusuke Oshima and colleagues described 27G TSV in 2009.

Creating self-sealing wound

Self-sealing wounds are created by smaller wound diameter, non-overlapping conjunctival and scleral wound, and multi-planar incision. After conjunctival displacement the transconjunctival wound has been performed both perpendicular or oblique to sclera. Oblique scleral incision has the advantages of better wound closure, reduced risk of hypotony, reduced leakage and better wound apposition under dynamic intraocular pressure when compared to perpendicular incision. However, chances of subretinal or suprachoroidal cannula may increase with very oblique incisions.

Shelved sclerotomy can be constructed in a one step or two step technique. One step oblique incision is made with sharp trocar and cannula...
(ESA system) either perpendicular or parallel to limbus\textsuperscript{21}. Oblique incisions parallel to limbus is preferred as it displaces scleral fibers oriented circumferentially, rather than cutting the fibres and less chances of damage to lens or retina. One step incision can be made bi-planar. After displacing the conjunctiva laterally, initially the trocar-cannula is inserted obliquely parallel to limbus at 30\(^\circ\), and then the direction is perpendicular once trocar has partially entered the sclera. A more acute (5\(^\circ\)) initial angle followed by perpendicular entry has also been used. The valved cannula length may be 4mm or 6mm with 23G, 25G or 23G (Alcon, Fort Worth, Texas, USA). The trocars have mark of 3mm and 4mm at the end opposite to sharp blade to aid pars plana entry without the use of calipers.

Two step method as described by Eckardt involves stabilizing displaced conjunctiva with a pressure plate instrument, while a shelved incision is created using a sharp angled stiletto blade. Then the cannula is inserted in the same wound with a blunt trocar. However it may be difficult to locate the initial point of the blade entry.

**The infusion**

The infusion cannula has a threaded portion to lock it with the cannula to avoid loosening or accidental slippage of infusion cannula during surgery. Alcon 23G infusion cannula is 4 mm long, and 25G cannula is 5 mm long.

**The vitrectomy cutter**

The vitrectomy cutter in MIVS has been improved in terms of smaller outer diameters, fluidics, increased cut rates, less traction on vitreous, control of duty cycle, improved driving mechanism for cutters and decreased distance from cutter mouth to tip.

The outer diameters of vitrectomy probes have been made smaller and smaller (Table 1) with MIVS.

The flow of a non-compressible fluid through a tube is governed by Poiseuille-Hagen formula, which states that

\[
Q = \Delta P \pi r^4/8 \mu L
\]

where:

- \(Q\) – volumetric flow rate
- \(\Delta P\) – pressure gradient along the tube
- \(L\) – length of pipe
- \(\mu\) – dynamic viscosity
- \(r\) – radius
- \(\pi\) – mathematical constant Pi

However, as vitreous does not behave like liquid, vacuum pressure, cut rate and duty cycle of the vitrector also determine the flow through the cutter.

| Table 1: Outer diameter of various vitrectomy systems |
|-----------------|-------------|
| 17G             | 1.47mm      |
| 20G             | 0.9mm       |
| 23G             | 0.6mm       |
| 25G             | 0.5mm       |
| 27G             | 0.4mm       |

According to Poiseuille-Hagen formula flow rates through 23G is more than 25G as the radius is more in 23G.

Higher vacuums (pressure gradient along the cutter) increases flow. Higher cut rates (5000cpm) with decreased aspiration or flow (in shave mode) produces lower turbulence, decreases movement of mobile retina, less traction during vitreous base shaving and the decreasing rates of iatrogenic retinal breaks safely and efficiently.

The duty cycle (the percentage of time the cutter port is open relative to each cutting cycle) can be controlled in modern vitrectomy probes which are pneumatically driven and not electrically driven. The vitrectomy modes in Constellation\textsuperscript{\textregistered} (Alcon, Fort Worth, Texas, USA) can be Core (cutter is open for maximum time ensuring greater flow and efficiency), 50-50, and shave (port open time is reduced, flow is reduced for working at vitreous base to create less pull).

The traditional Accurus\textsuperscript{\textregistered} probe (Alcon) had traditional pneumatic probe design where spring controls the cutter open timing with maximum 2500cpm. Proprietary Ultravit\textsuperscript{\textregistered} (Alcon) design is devoid of spring mechanism and has maximum 5000cpm cut rate, in which the air controls both cutter open and cutter close time enabling duty cycle control.

With MIVS probes the cutter mouth is closer to the cutter tip enabling dissection very near to retina (Figure 1). Increased vitrectomy cut rates and improved fluidics have made it safer to operate closer to the retina.

**Illumination**

Though issues had been raised about reduced brightness of 25G endo-illuminators due to their smaller diameters when compared to 20G or 23G, brightness has been improved by xenon and metal halide light sources. Chandelier illumination is an innovative strategy for illumination during surgery of posterior segment. It is now available in 25G, 27G and 29G (0.33mm) (Photon\textsuperscript{\textregistered}, Synergetics, O’Fallon, MO, USA). The trans-conjunctival entry is self-sealing and both hands of the surgeon are free for bimanual surgery. It reduces retinal photo-toxicity as distance of illuminating fibre from retina is increased. Chandelier is commercially available in both single fibre and double fibre models.

**25 G TSV**

The TSV in 25G is made using polyamide microcannulae
with insertion trocars. The microcannulae have an external collar for holding. Prototype microcannulae (Millennium™ TSV 25™ System, Bausch and Lomb, Rochester, NY, USA) had 3.6 mm length with inner/outer diameters of 0.57 mm/0.62 mm. A metallic infusion cannula of 5 mm length with inner/outer diameters of 0.37 mm/0.56 mm is usually used through inferotemporal cannula. The trocar is then removed. Plugs are used to close the cannula. Cannulae with valves are also available which do not need plug to create a closed globe system. Modern 25G instruments include, but are not limited to vitrectomy cutters, endoilluminator, scissors, diathermy probe, laser probe, end gripping forceps, Internal Limiting Membrane (ILM) forceps, Micro Pic forceps, Asymmetrical Peeling Forceps, Micro Forceps, Backflush Cannula, Membrane Pick, Microvitreoretinal (MVR) blade, viscous fluid injection/extraction kits and soft silicone tip for aspirating fluid.

23G

To address decreased light and rigidity with 25G, 23G TSV was developed. With 23G, the eye can be easily rotated without bending of the instrument for working in vitreous base and peripheral retina. Ad-ditionally, with wide-angle viewing systems, peripheral shaving of the vitreous base can be performed. Also, an-teriorly located pathology can be accessed without bending of the instrumen-tems. The microcannula and the inserter are made of steel (DORC, Zuidland, Netherlands). The length of the prototype cannula is 4 mm, with inner/outer diameter of 0.65 mm/0.75 mm. The external openings of two of the three cannulas were funnel shaped for easy insertion of light pipe and the cutter. 23G instruments include but are not limited to vitrectomy cutters, endoilluminator, scissors, diathermy probe, laser probe, end gripping forceps, Internal Limiting Membrane (ILM) forceps, Micro Pic forceps, Asymmetrical Peeling Forceps, Micro Forceps, Backflush Cannula, Membrane Pick, Microvitreoretinal (MVR) blade, viscous fluid injection/extraction kits and soft silicone tip for aspirating fluid. 23G has the advantages of both 20G and 25G.

27G

Yusuke Oshima and colleagues described 27G transconjunctival nonvitrectomizing vitreous surgery for epiretinal membrane removal to decrease post-vitrectomy nuclear sclerosis in 2007. In 2009, Y. Oshima in collaboration with DORC (Dutch Ophthalmic Research Center International BV, Zuidland, Netherlands) developed a prototype pneumatic 27G cutter. Compared with the 25-gauge vitrectomy port, the 27-gauge vitrectomy port is larger and closer to the cutter tip to help dissection very close to retina. The duty cycle of the 27G cutter was equal to or slightly better than that of a 25G cutter at 1000 or 1500 cpms. 28 eyes of 28 patients were operated epiretinal membrane proliferation, idiopathic macular hole, diabetic vitreous hemorrhage with fibrovacular membrane proliferation, and nonclearing vitreous opacity. No serious intra- or postoperative changes were observed during follow-up. Anatomic success was achieved in all study eyes, including visual improvement by three lines or more in 70%. Because of the smaller gauge, diminished endoillumination and flow rates are drawbacks of 27G. Xenon or mercury vapor bulbs may improve illumination. To improve rigidity of 27G, the shaft length of the 27-gauge vitreous cutter was reduced from 32 mm to 25 mm. Oshima and colleagues advocated 1-step, 27G insertion technique in young or myopic eyes with thin sclera and liquefied vitreous gel or in fluid-filled eyes after vitrectomy with extensive removal of peripheral vitreous. After displacing the conjunctiva anteriorly, trocar is inserted at 90° to the sclera, facing directly toward the vitreous cavity, parallel to the limbus. Available 27G instruments include high-speed vitreous cutter, one-step infusion line, one-step short shaft light pipe, microforceps (asymmetric, end-gripping, pick-forceps type), membrane spatula, endophotocoagulation probe (blunt tip, sharp tip), trocar-cannula system, microvertical scissors, and sharp-point diathermy probe.

Indications of MIIVS-

Currently all vitreous surgeries can be done with MIIVS including but not limited to vitreous hemorrhage, endophthalmitis, epiretinal membranes, macular holes, rhegmatogenous retinal detachments including complex one with proliferative vitreoretinopathy (PVR), tractional retinal detachments, recalcitrant diabetic macular edema, vitreomacular traction, uveal/vitreous biopsy, silicone
oil removal/injection and submacular hemorrhage. The intraocular foreign bodies can be removed with hybrid technique using one 20G port to introduce internal magnet or foreign body forceps. Dropped nucleus can be ultrasonically fragmented by similar one 20G or 23G port for ultrasonic fragmenter. In huge choroidal detachments the 20G long 6mm infusion cannula can be used for infusion to avoid the cannula going subretinal or suprachoroidal. In pediatric population the small gauge vitrectomy systems can be used for retinopathy of prematurity (ROP), cataract extraction, persistent fetal vasculature, and familial exudative vitreoretinopathy.

Advantages of sutureless vitrectomy
Wound size- Wound diameter for 23G, 25G, and 27G vitrectomy systems are 0.6 mm, 0.5 mm, and 0.4 mm, respectively. The colour code for Alcon ports are yellow (20G), orange (23G), blue (23G), and purple (27G). The smaller sclerotomy leads to:
- Sutureless procedure - Time is saved from suturing.
- No suture related complications
- Less inflammation
- Less post-operative pain
- Decreased post-operative congestion
- Faster healing
- Decreased conjunctival scar
- Rapid recovery
- Reduced post-operative astigmatism,
- Decreased redness (Figure 2)
- Decreased ocular discomfort
- Decreased ocular trauma (to conjunctiva, sclera and others)
- In some cases earlier visual recovery
- Decreased surgical time.
- Increased patient satisfaction
- Better cosmesis
- Combined anterior segment surgeries (Phacoemulsification or glaucoma surgery) can be undertaken.
- Less damage to filtering bleb
- Ease in pediatric retinal surgeries (especially ROP in very small eyes)

Concerns
Most of the concerns associated with MIVS are immaterial in current scenario. Higher cost may be a limiting factor in some setup. Like all vitrectomy procedures MIVS can cause iatrogenic retinal break formation, retinal detachment, and cataract.

Intraoperative
As the instruments are thinner with MIVS there is chance of bending or breakage especially during vitreous base dissection or removal of thick membranes in PVR. With 25+G system (Alcon) has 50-90% stiffness improvement form 25G, the sleeve on 25G shaft (27mm) has been stiffened for improved control. Infusion cannula can slip and get disinserted leading to globe collapse, choroidal detachment, suprachoroidal hemorrhage, vitreous hemorrhage and accidental trauma to retina with instrument tip. The infusion cannula may even shift to suprachoroidal space intraoperatively resulting in choroidal detachment. Dissection and visualization of anterior pathologies may be difficult due to flexibility of instruments. Silicone oil injection may take longer time with MIVS. Other intra-operative complications include decompression retinopathy. Though issues had been raised about less brightness of 25G endoilluminators when compared to 20G or 23G, brightness has been improved by xenon and metal halide light sources. Concerns were also raised about reduced infusion flow, than 20G, which has been properly taken care of by the modern fluids. Claims that 25G forceps can hold less amount of tissue, vitrectomy itself takes longer duration and scissors can cut less tissue than 20G are myths. Rare theoretical complications include thermal injury to sclera from Chandelier tube and inability to shave vitreous base properly in vitreoretinal surgery resulting in theoretical rise in post-operative retinal detachment.

Postoperative
Hypotony due to wound leak can occur in 3.8%-16% in 25G vitrectomy as wounds are not sutured. It is usually transient, resolving within the first post-op week as wounds heal. In a study by Woo and colleagues risk factors for intraoperative sclerotomy leakage requiring suture placement after 23G vitrectomy were prior vitrectomy, a young age at operation, and vitreous base dissection.
Factors predisposing to hypotony include:

- Lens status- less hypotony in phakics, may be due to limited peripheral vitrectomy to avoid lens touch in such cases
- History of previous vitrectomy- due to changes in the elasticity and regenerative capacity of scleral tissue, leading to wound leakage. In 2nd vitrectomy more thorough vitreous removal is done leading to less vitreous plugging of the scleral wound.
- Vitreous base dissection
- Myopia with gas tamponade
- Eyes left in fluid post-op: increased surface tension of air or gas prevents leakage and hypotony. Most surgeons advocate partial fluid air exchange after small gauge vitrectomy.
- Perpendicular wound
- Suturing a leaking MIVS wound is a good practice to prevent hypotony.

Classically endophthalmitis rate has been quoted as 0.1% for post-operative endophthalmitis and 0.039% post-vitrectomy. With 25G the endophthalmitis rates has been reported as 0.23-0.84%. Kunimoto and colleagues showed 12 fold higher rate of endophthalmitis in the 25-G (0.23%) as compared to 20G (0.018%) in a retrospective study. However, retrospective nature of study is not optimal to study incidence of such a rare complication, all eyes were left in fluid, the incidence of endophthalmitis in 20G was shown as 0.018% which is almost ½ to 1/3rd of current literature (0.05-0.05%) and incisions were largely nonbeveled. Intravitreal triamcinolone was used in 38% of endophthalmitis cases, which may have caused a sterile inflammation mimicking endophthalmitis or may have predisposed to infectious endophthalmitis. Mention about predisposing factors like dacryocystitis, ocular surface disorder, was not made. Wound leak and the reduced flow rates, resulting in decreased washing effect by the infusion have been postulated as the cause of endophthalmitis in MIVS. Risk of endophthalmitis after MIVS can be decreased by an angled or oblique wound to avoid leakage and fluid-air or fluid-gas exchange. Fluid air exchange improves the self-sealing nature of the oblique wounds by pressing the wound lips together.

Other post-operative complications of MIVS are retinal detachment, and retinal toxicity (macular infarct with gentamycin) due to seepage of subconjunctival gentamycin from sutureless scleral port.

### Conclusion

MIVS has opened new avenues for advanced vitreous surgery. Currently MIVS is becoming the standard for vitrectomy surgery worldwide.

### References


