

Micro-incision Vitrectomy Surgery – Past, Present and Future

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Abstract

The advent of micro-incision vitrectomy surgery (MIVS) changed the approach, indications and complications of vitreoretinal surgeries forever. Since its introduction in 2002, MIVS has been gaining popularity amongst retinal surgeons for managing a wide variety of vitreoretinal disorders. MIVS allows for more efficient surgery, faster recovery time and better visual outcomes than 20G vitrectomy. The use of instrumentation having small diameters reduced trauma from conjunctival and scleral manipulation as well as post-operative inflammation and corneal astigmatism. Further refinement of techniques with the introduction of 27G for routine procedures increases the comfort for the patient and minimises the recovery time. In this review, we briefly summarise the journey of MIVS to its present status and discuss the various advances that have taken place to achieve better efficiency and results.

Keywords

MIVS, 27G vitrectomy, history-MIVS, wound construction in MIVS, sutureless vitrectomy

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Small is big in the world of ocular surgeries. As anterior surgeons moved from regular phacoemulsification to phacotom, the advent of micro-incision vitrectomy surgery (MIVS) changed the approach, indications and complications of vitreoretinal surgeries forever. Since its introduction in 2002,¹ MIVS has been gaining popularity amongst retinal surgeons for managing a wide variety of vitreoretinal disorders. MIVS allows for more efficient surgery, faster recovery time, reduced post-operative inflammation and better visual outcomes than 20G vitrectomy.^{2–5}

As with any technology, it has its own pros and cons. But the pros outweigh the cons enough to have made this cutting-edge innovation the first choice of retinal surgeons worldwide. It is a constantly growing field, seeing ever newer micro-instrumentation and ever fewer side effects. Its safety, advantages and disadvantages have been proved in multiple studies.⁶ Thus a constant update of knowledge and skill is now needed to provide the best possible care to patients.

Historical Aspect

The surgical techniques of pars plana vitrectomy (PPV) have significantly refined since the first description of the procedure by Machemer et al. in the early 1970s.^{7,8} Machemer developed the vitreous infusion suction cutter (VISC), 17G (1.42 mm in diameter), which needed a 2.30 mm sclerotomy port.

In 1974, O'Malley et al. refined the technique by introducing the three-port 20G (0.91 mm) approach through the sclera, after a partial dissection of the conjunctiva.⁹ At the end of the procedure, the sclerotomies and the conjunctiva were sutured with absorbable sutures, which, with time, became the cornerstone of vitrectomy procedures.

In 1990, De Juan developed a 25G instrument set for paediatric use, since the conventional 20G cutters proved too large, lacking precision and unsuitable for paediatric use.¹⁰ However, De Juan and others stated that because of reduced aspiration rate, 25G vitrectomy was to be used only in selected delicate cases requiring particularly precise and careful intervention.

Novel attempts to shorten surgical time and trauma led to considerable improvement in surgical techniques and equipment and eventually led to the development of the first 20G transconjunctival sutureless approach by Chen et al.¹¹ in 1996. The 20G sutureless technique, however, did not gain much popularity due to high rates of wound leak, choroidal detachment and need for suture placement in many cases.¹²

Eventually, in 2002, a complete 25G (0.51 mm) transconjunctival vitrectomy system was introduced by Fujii et al. consisting of microtrocar cannulas affording ease as well as safety of instrument introduction and withdrawal, along with an array of integrated 25G instruments.^{1,13,14}

Three years later, Eckardt et al. introduced a 23G (0.61 mm) system.¹⁵ Oshima et al. introduced further miniaturisation of the technique by means of a 27G sutureless vitrectomy system.¹⁶

Wound Construction

The standard system, which required conjunctival incisions and sclerotomies of 0.89 mm diameter (20G), has been made smaller and less traumatic. The use of a trocar and cannula system causes less disruption of the conjunctiva and sclera, and the incisions themselves

are quite a bit smaller (0.51 mm for 25G and 0.64 mm for 23G). The advent of 27G and 30G has further reduced the injury to the ocular tissue. The MIVS scleral incisions are also bevelled and self-sealing, ideally not requiring any suturing.^{17,18}

Wound construction can be broadly divided as the (a) construction of a self-sealing wound and (b) the requirement for suturing. The primary step is the formation of a self-sealing wound. This is achieved by (a) creating an oblique wound to ensure a valve-like effect similar to clear corneal wounds for phacoemulsification and (b) misaligning the conjunctival and scleral entry sites by displacing the conjunctiva over the scleral surface before creating the wound.¹⁹

Two types of wound constructions have been described – one-and two-step incisions. One-step incision involves entry with the sharp trocar with overlying cannula on it. The incision can be made obliquely perpendicular to the scleral fibres, which are arranged in concentric circles near the limbus. Alternatively, Shimada et al. describe a tunnelled scleral incision that is again oblique, but parallel to the limbus.²⁰ This gives the added theoretical advantage of displacing, rather than cutting, the scleral fibres with a reduction in healing time on ultrasound biomicroscopy (UBM) analysis. There is also a biplanar 5°/30° insertion technique for one-step entry devised by John S Pollack.²¹

In the two-step procedure, initial entry is first made with the sharp blade, and then a cannula is inserted with the help of blunt-ended trocar. Two-step incisions offer the advantage of using a sharp instrument for the initial cut, improving the construction of the wound. Oliveira et al. reported the use of a 0.7 mm sapphire knife for stiletto blade. This creates difficulty in locating the initial entry point for trocar insertion.²² The two-step incision is also associated with a greater learning curve than is the one-step incision. Warren used an angled, flat microvitrectoretal (MVR) stiletto blade. The angled blade created a reproducible 15° wound, in part because of the angle and sharpness of the blade. In the same study, he concluded that the eyes in the single-step group required suture closure more frequently than those in the two-step group and that this difference was statistically significant ($p=0.002$). The overall complication rate (5.98 %) was low for all patients, and there was no statistical difference in the complication rates between the groups.²³

Although the recent refinement of trocar–cannula systems has ergonomically improved their self-sealing architectures, special techniques are required. By using the 27G system, opening and closing procedures are simplified, and surgeons can begin vitrectomy immediately after creating sclerotomies with one-step insertion. Simplified opening and closing procedures also translate into shorter total operating time, because sutures are not required after cannula removal, even in cases with thin sclera or multiple surgeries.

The EdgePlus Entry System (Alcon, Fort Worth, TX, US) has a proprietary blade edge and cylinder ridge to create a flat, linear incision. Valved cannulas are designed for quick and easy insertion and are easily removed from the trocars after insertion without a second instrument. The 27G instrumentation can be used to carry out a simple one-step incision at 30°, a technique that has allowed us to achieve a perfect wound closure both with balanced salt solution and air.²⁴

To minimise the risk of post-operative endophthalmitis, a reliably watertight seal is vital in sutureless vitrectomy procedures. Suturing

may be required for cases involving thin sclera, multiple surgeries and paediatric patients. The use of 27G has helped to avoid suturing even in such cases.

In a study performed at the Retina Foundation, a two-step approach with the blade initially at 30° and then entered perpendicular to the sclera was used in 23G and 25G vitrectomies. None of the cases showed wound leak. At the end of 1 month, both the wounds sealed with just a slit. It was also found that with longer surgical duration, sclera fatigue increases. This leads to less efficient self-sealing of the wound.^{25,26}

Dynamics

The biggest difficulty that surgeons initially experienced with MIVS was slow flow rate through the small-gauge vitreous cutters. Today, new machines offer optimised flow rates comparable to 20G.²⁷

Pressure Control Evolution

Initially, gravity was used to move fluid from bottle through infusion tubing into the eye, which had significant disadvantages. Gas-forced infusion (GFI) is better than gravity-based systems, producing a sensor-based direct digital readout of infusion pressure (not intraocular pressure [IOP]). The development of vented gas-forced infusion (VGFI) to pressurise the balanced salt solution (BSS) bottle, and subsequently the eye, was an important advancement, providing instantaneous pressure control.²⁸ It allowed a rapid decrease, as well as increase, of infusion pressure via surgeon foot pedal command thanks to the console-controlled venting.

The new concept with the Constellation Vision system is the integrated pressurised infusion with IOP compensation, accurate to within ± 2 mmHg.²⁹ The machine pressurises the fluid in the cassette, measures the flow into the eye and integrates it through the microprocessor of the computer. The system calculates Ohm's law and adjusts infusion pressure according to the sensed flow rate to produce the selected IOP during surgery.

Flow Rates and Cut Rates

The factors influencing the rate of vitreous removal are the infusion pressures, the aspiration pressures and the duty cycle of the vitrector.^{30,31} With higher cut rates on modern machines, the resulting 'bites' of vitreous are smaller, creating fewer shear forces and better flow rates.

Compared with the 20G probe, where the infusion pressures vary between 30 mmHg and 40 mmHg, vitrectomy with small gauge systems works at higher infusion pressures in the range of 50 mmHg. Because of the smaller internal diameter of a tube, the flow rate is less with small-gauge probes compared with the 20G probes. Increasing the infusion pressure improves the vitreous removal rates in small-gauge systems.

Higher aspiration pressures are used in small-gauge systems to achieve a reasonable rate of vitreous removal. The maximum aspiration varies between 400 mmHg and 650 mmHg compared with 150 mmHg in 20G systems.

Most of the recently developed vitrectomy machines feature high-speed cutters with cutting rates greater than 5,000 cpm. The dual pneumatic valve-driven vitreous cutter (Ultravit, Alcon Laboratories, Fort Worth, TX, US) is a new concept for vitrectomy, in addition to the improvement of the conventional spring pneumatic-driven vitreous cutter.

This cutter is currently capable of ultra-high-speed cutting at up to 7,500 cpm, with duty cycle maintained at 50 %, in a variety of situations. The elegant mechanism that increases or decreases flow without changing the cut rate or vacuum parameters may facilitate more efficient core vitrectomy and safer peripheral vitreous shaving, with less traction force to the retina.^{32,33} The technique is especially suitable for cases with retinal detachment (RD), even with the currently smallest 27G system.

The duty cycle is the length of time the vitrector port is open compared with the time it is closed. Duty cycles with a longer port opening time results in higher flow rates, compensating for the decreased flow in the smaller diameter instruments. The high cutting speed maintains the duty cycle at >50 %, dramatically improving the vitreous cutting efficiency of small-gauge cutters, even with 25G or much smaller 27G system.²⁸

Instrumentation

Poor illumination and fragility of small-gauge instruments, as well as low flow rates through the small-gauge lumen, were the major hindrances in early days of MIVS.

There is a trend in Japan toward increasing use of the new vitrectomy machines with 25G instruments rather than 23G ones, because the smaller cannulas minimise fluid loss, and smaller wound size lowers the chance of suture placement.¹⁶ As the ports of 25G and 23G vitreous cutters are small and the distances from the ports to the tips shorter than those of a conventional 20G vitreous cutter, the cutters can serve as multifunctional tools during diabetic vitrectomy, being used as vitreoretinal scissors, forceps and backflush needle.³⁴

In their recent study, Oshima et al.³⁵ developed several instruments for 27G PPV. Using these instruments, they were able to perform several surgeries safely and effectively.

In 27G, the stiffness experience is similar to that of 25G. The 27G vitrectomy probe, featuring dual pneumatic-driven technology, has the ability to achieve 7,500 cpm and has been produced to minimise flexibility. The 27G accessories currently include internal limiting membrane forceps, end-grasping forceps, Maxgrip forceps, straight scissors, diathermy probe, flexible-tip laser probe, high-flow backflush and soft tip, all of which instruments use a stiffening sleeve on the shaft for improved control and rigidity.

The latest research indicates that smaller-gauge instrumentation and high cutting rates together should theoretically be safer by increasing fluidics stability and potentially minimising vitreous turbulence by allowing only small bits of vitreous to enter the port.

Rigidity

Rigidity of instrumentation is dependent on its material, thickness, diameter (gauge) and length.

One of the potential drawbacks of 27G instrumentation is its increased flexibility. To minimise the flexibility, Oshima et al. shortened the shaft of their vitrector from 32 mm to 25 mm.¹⁶ In doing so, they produced a 27G vitrector with similar stiffness to the standard 25G vitrector. The authors contend that even with a shorter shaft length, they were able to perform core and peripheral PPV in eyes with axial lengths ranging from 22 mm to 28 mm.

Alternatively, a 27G vitrector has been designed with the same length as the current 25G and with a tapered stiffening sleeve that enters the cannula to provide maximum working length and stiffness.

Illumination Devices

In the early 1970s, the first light source originated from an external slit illuminator. However, the transformation to three-port vitrectomy brought the illumination device inside the eye, allowing better visualisation.

The current style of endoillumination, using an fibre optic inserted into the vitreous cavity, was first introduced in 1976 by Peyman for 20G three-port vitrectomy.³⁶

Further refinement and miniaturisation of instrumentation for 23 and 25G fibre optic light pipes had decreased illumination from the conventional vitrectomy light sources. To obviate this, high-intensity discharge (HID) lamps are used,¹¹ being xenon-based sources. The arcs generate high temperature at great efficiency and have a long life (20,000+ hours) in an efficient package.

In 2003, Eckardt³⁷ developed a 'twin light' xenon-based illumination probe, designed to directly penetrate the conjunctiva and sclera.

In 2007, Oshima et al. presented a fiberoptic with a 27G diameter based on the same technology.¹⁶ The fiberoptic remains fixed to the sclera after insertion, enabling execution of bi-manual surgery and providing wide illumination of the vitreal cavity (a 'chandelier'-type illumination). There is also a Torpedo light for a chandelier effect.³⁸ The superior illumination of the new 25G Torpedo light has proved particularly advantageous in surgery for tractional RD.³⁹

Wide-angle Viewing Systems

The viewing systems form the backbone of vitrectomies. The fundus, which cannot otherwise be seen, is made visible. There are several kinds of wide-angle viewing systems, typically broadly classified as contact lens and non-contact systems.⁴⁰ The non-contact systems widely used are BIOM (Oculus, Port St. Lucie, FL, US), Merlin (Volk Optical, Inc., Mentor, OH, US), OFFISS (Topcon Medical Systems, Oakland, NJ, USA), Resight (Carl Zeiss Meditec AG, Jena, Germany) and Peyman–Wessels–Landers semi-wide angle viewing system (Ocular Instruments, Bellevue, WA, US). Two contact lens systems, Clarivit and HRX (Volk Optical, Inc.), are available.⁴¹ The contact lens system was developed by Yasuo Tano. It is a sutureless ring system to hold a contact lens on the cornea by yoking it to the ocular speculum; this device is especially useful for MIVS.⁴² Shunji Kusaka recently developed a new sutureless ring system for MIVS.⁴³ It is the surgeon's choice and expertise that decide the system to be used.

Silicone Oil Injection and Extraction

Silicone oil (SO), introduced by Cibis, was initially used without vitrectomy more as an instrument than as a tamponading agent.⁴⁴ It was Zjovonovic who popularised its use as a tamponading agent.⁴⁵ In addition to the availability of different viscosities of SO (1,000 and 5,000 centistokes), heavy SO (densiron) is also available that sinks in water and that thus can be used to tamponade inferior retina better.⁴⁶

For many years, SO extraction was performed via a 20G sclerotomy after conjunctival dissection. SO can now be injected and extracted using an automated system with both 23G and 25G ports. Oil injection is performed in the same fashion as in 20G vitrectomy, using very low infusion pressures. Studies have shown the ease with which SO can be removed using 23G

owing to the larger diameter of the 23G, providing higher flow rate.⁴⁷ Various authors have also mentioned a hybrid technique of removal of SO.⁴⁸

Time to remove SO depends of viscosity of the oil and using of passive or active aspiration. There have been reports showing SO removal using active aspiration taking 4 to 5 minutes.⁴⁹ Yildirim et al. reported that the mean surgical time was approximately 9 minutes for the passive washout of 1,300 centistokes SO group and 7.6 minutes for the active aspiration of 5,700 centistokes.⁵⁰ Using a 25G system with passive aspiration, removal of 1,000 centistokes SO was achieved in a mean period of 7.3 minutes, which is considerably short. Other researchers also tried to remove passively 5,000 centistokes SO through 25G, but it took a long time, and they did not recommend this technique for 5,000 centistokes SO.⁵¹ Kapran using also 25G system with active aspiration reported mean time of 3.31 for 1,000 centistokes and 10.27 for 5,000 centistokes.⁵²

Siqueira et al. reported subconjunctival leakage of SO in 9.7 % of cases treated with 23G vitrectomy and oil injection, which necessitated second surgery to remove SO from the subconjunctival space.⁵³ Whenever SO is used, the surgeon may consider taking a suture to avoid seepage of oil in the subconjunctival space during the post-operative period.

Prevention and Management of Complications

Intraoperative Complications

Rise of Intraocular Pressure

A theoretical risk of increased IOP to more than 60 mmHg during port construction has been proposed in patients with compromised intraocular blood flow.⁵⁴ Wu et al. have proposed a simple modification of the twisting manoeuvre for sutureless vitrectomy trocar insertion to reduce IOP.⁵⁵

Cannula Retraction

Intraoperative retraction of the infusion cannula is known to occur leading to serous or haemorrhagic choroidal detachment in about 3.5 % of the cases.⁵⁶ It is more common in repeated surgeries and during scleral depression.

Retinal Break Formation

The rate of retinal tears discovered during sutureless vitreous surgery has been reported to be between 0 % and 24 %, with most series reporting an incidence of less than 5 %.^{57,58} In a retrospective series of 177 consecutive 25G PPV cases, the incidence of intraoperative retinal breaks was 15.8 %.⁵⁹ In one comparative series of 25G and 20G vitrectomies, no statistically significant difference in the incidence of intraoperative retinal breaks was found.⁶⁰

Other Complications

In situations in which 20G instrumentation is used for aspiration and 23G or 25G ports are used for infusion, hypotony can occur.¹¹ Jamming and breakage of the vitrectomy cutter may occur with 25G probes.^{61,62}

Post-operative Complications

Hypotony

Prevalence of up to 20 % of post-surgical hypotony using 25G sutureless techniques was reported that normalised within a few days.^{63–66}

Byeon et al. reported young age of the patient as a significant risk factor for hypotony.⁶⁷

In the 23G technique, hypotony was demonstrated in a range of 3.3–11.3 %, scleral sutures were placed in 11.2–38 % in the various studies.^{68–72}

In a comparative study, Haas et al. showed that post-operative hypotony occurred significantly more often after 23G vitrectomy than after 20G vitrectomy.⁷³ Inoue et al. reported use of a 23G MVR blade trocar to reduce post-operative hypotony.⁷⁴

Endophthalmitis

Endophthalmitis is another complication initially suspected to occur more frequently after sutureless vitrectomies.

In 2005, Taylor et al. reported the first case of endophthalmitis after a 25G sutureless vitrectomy.⁷⁵ A similar case report was published by Taban et al. in 2006.⁷⁶ Those authors assumed that open sclerotomies, combined with use of low-flow rate cutters, facilitated the invasion of bacteria to the vitreous cavity. Other factors that may play a role include post-surgery subconjunctival antibiotics, intraoperative use of corticosteroids and whether a partial or complete air–fluid exchange was performed at the end of surgery. Incomplete removal of the peripheral vitreous skirt has also been hypothesised to result in bacterial ingrowth,⁷⁷ possibly predisposing the patient to endophthalmitis.

Various comparative studies between 20G and 25G reported a 12-to 28-fold increase in the occurrence of endophthalmitis.^{78,79} However, later studies did not support this finding.

Parolini et al. and Gupta et al. found no case of endophthalmitis after vitrectomy with the 23G sutureless system.^{80,81} In another study, Patel et al. estimated the rate of post-operative endophthalmitis to be 0.040 % subsequent to 23G vitrectomy.⁸²

Overall, the recently published large retrospective studies do not indicate that sutureless small-gauge vitrectomy is associated with higher rates of endophthalmitis than in 20G vitrectomy.

Retinal Detachment

Iatrogenic retinal breaks leading to post-operative RD is a serious complication of vitrectomy. Breaks are more common anterior to the equator, and majority of these occur in relation to the sclerotomy site. Subsequent to scleral penetration in PPV, vitreous incarceration is seen in all cases histopathologically. Often this is related to high flow rate of infusion fluid and associated increase in IOP.

Though post-operative RD subsequent to microincision sutureless PPV has been reported in several studies,⁸³ the investigators concluded that development of RD did not directly result from the microincision 23G or 25G technique.⁶⁹

In a study, Ibarra et al. reported a RD incidence of 2.2 % after macular hole repair.⁸⁴ However, Chieh et al. reported no case of RD in a retrospective analysis of 118 vitrectomised eyes using 23G technique.⁸⁵ Higher rates of post-25G vitrectomies RD were found in a study by Byeon et al. (6 %) and Kellner et al. (6.67 %).^{86,87}

Future of Micro-incision Vitrectomy Surgery

Oshima et al. recently developed a 29G fibre optic based on mercury vapour that produces light twice as strong as the light produced from a xenon-based probe (at similar diameter) and with a better safety profile.⁹ The concept of the double port cutter, featuring a second port in the internal guillotine blade of the cutter, incorporates into the spring-pneumatic driven cutter to improve the flow efficiency by maintaining the duty cycle without attenuation while increasing the cutting rate.^{7,8}

This approach may be another step forward in flow efficiency during small-gauge vitrectomy. However, further studies are needed to evaluate the potential risk of increasing the traction force on the vitreous with this type of cutter, because the cutting port is almost fully open. Recently, Synergetics, Inc. (O'Fallon, MO, US), introduced a specially designed directional viscod cannula for 25G or 27G surgery. The curvature of the inner cannula is adjustable and extendible, for use in viscodelamination.

Light emitting diode (LED) lights are being studied to replace the Xenon system of illumination. Researchers are also working to develop 29G and 30G systems for vitrectomy in the future.

The journey for an ideal, patient-friendly, minimally invasive and minimally traumatic surgical procedure is well advanced, but the desired destination is still far off. ■

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