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Review article

Advances in small-gauge vitrectomy

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A B S T R A C T

With the advent of small-gauge vitrectomy, there has been a paradigm shift in the surgical management of posterior segment disorders. However, when this concept was first introduced, there were numerous technical hurdles and limitations. Over the years, various technological advances, especially the introduction of new generation vitrectomy machines capable of powering small-gauge instrumentation and improvised fluidics, have overcome these limitations. This review presents the evolution of sutureless vitrectomy to its present status and discusses the various advances that have taken place in various concepts, such as instrumentation, to achieve better efficiency and results. Shorter operating times, improvements in patient comfort, and faster visual recovery are the main benefits of this approach.

1. Introduction

One of the principles that guides the development of a surgical procedure is the desire for less invasive approaches that achieve similar if not better clinical outcomes. The quest to find ways to reduce the duration of surgery and minimize trauma has led to developments in surgical techniques and instrumentation. Reduction in the incision size has lead to the minimization of tissue trauma and reduction in the postoperative convalescence period. The transition from conventional extracapsular surgery to phacoemulsification has shown a resulting decrease in surgical time, less postoperative inflammation, and faster recovery. A similar analogy lies in the development of small-gauge vitrectomy systems, which shorten the operating time, obviate the need of sutures (and hence suture-related inflammation), and remarkably reduce tissue damage.

The development of a 17-gauge vitreous-infusion-suction-cutter (VISC) system by Machemer et al in 1971,[1] which required a single 2.3-mm pars plana incision, was a huge step forward from the concept of "open-sky" vitrectomies conceived by Shafer in 1950 and propagated by Kasner in the 1960s.[2] This expanded the use of vitrectomies and made it an essential procedure for treating a wide variety of vitreoretinal disorders. In 1975, O'Malley and Heintz[3] divided the system to give rise to the "conventional" 0.9-mm, 20-gauge "bimanual" vitrectomy. This has remained the standard of care for over three decades.

Although Chen[4] advocated self-sealing sutureless sclerotomy for the 20-gauge system, it still needed a conjunctival opening and suturing. Eugene de Juan Jr. is credited with inventing the 25-gauge (0.5-mm) system in 1990 with Hickingbotham and describing its use for transconjunctival sutureless vitrectomy (TSV) along with Fujii in 2002.[5,6] Just 3 years later, in a modification of the procedure, Eckardt devised a 23-gauge system with a diameter of 0.75 mm.[7] Further minimization of vitrectomy instrumentation was introduced by Oshima et al who presented the 27-gauge vitrectomy system.[8]

Transconjunctival sutureless vitrectomy (TSV) has opened up a new realm of minimally traumatizing surgeries that results in a reduced mean surgical time, less postoperative inflammation, less corneal astigmatism, greater postoperative comfort, faster recovery time, and fewer postoperative medications.[5,9–12]

The transition from the standard 20-gauge vitrectomy towards small-gauge vitrectomy is directly linked to advances in the overall approach to vitrectomy in terms of incision making, fluidics, cutting technology, and illumination. Because the gauge has got smaller, the overall instrumentation has had to adapt to overcome size and lumen handicaps. Advances in each of these aspects are discussed in detail in the following sections.

2. Incision making

How to make the incision has been one of the most important aspects of the shift toward smaller gauge-based procedures. The

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standard 20-gauge approach was based on opening the conjunctiva and making scleral ports using microvitreoretinal blades. With small-gauge procedures there is no need to open the conjunctiva and instead trocar cannula-based systems are used to make a direct entry through the conjunctiva and sclera in order to pass various instruments through the cannulae.[6] At the end of surgery, these cannulae are removed without having to suture the sclera or the conjunctiva, thus bringing about a paradigm shift in the concept of vitrectomy.

One of the major concerns of any sutureless procedure is the higher risk of endophthalmitis. Traditionally, the rate of endophthalmitis after 20-gauge vitrectomy is approximately 0.03–0.05%[13–15] and after a 25-gauge vitrectomy the rate ranges from 0.23–1.6%.[16–18] These numbers point to the fact that the rate of endophthalmitis after sutureless surgeries is higher compared with the rate after surgery using 20-gauge sutures. Of course, these initial reports were from the early phase following the advent of small-gauge surgery. This may be related to the method of sclerotomy construction and its learning curve. So, the important and fundamental aspect of sutureless vitrectomies is the method or design of wound construction.

3. Instrumentation: trocar cannula system

The currently used noncoring trocar (Edgeplus; Alcon Laboratories, Inc., Fort Worth, TX, USA) (Fig. 1) is based on a modified MVR blade and requires less insertion force than the hypodermic needle-based, coring-type design.[19] The cannula fits over the trocar, which allows 23- or 25-gauge sclerotomy and simultaneous insertion of a cannula. The cannula maintains alignment between the conjunctival and scleral openings and facilitates insertion of the instrument, thus preventing breaks at the vitreous base due to repeated insertion of the instrument. The earlier generation of cannulae were metallic and the incisions were made using the older blades that were chevron-shaped and patulous, thus increasing the chances of wound leakage. The newer blades have a hump that is perpendicular to the horizontal plane of the blade, which stretches the tissue in the direction perpendicular to the horizontal plane of the blade, thus ensuring a slit-like incision. A slit-like incision is always better because it is stable and not patulous.[20]

4. Different types of incisions

The various types of incisions are the stab incision, oblique incision, and biplanar incision, and among these the biplanar incision helps to prevent hypotony and makes the wounds the most secure.

4.1. Stab incision

For a 25-gauge vitrectomy, direct entry is made using small-gauge trocars after conjunctival displacement at the pars plana at the required distance from the limbus, depending on the phakic status of the patient. The disadvantage of this incision is that leakage of intraocular fluid can occur, increasing the risk of endophthalmitis.[21]

Fig. 1. 25 gauge Edgeplus trocar blade (Courtesy Alcon Laboratories, Fort Worth, USA).

4.2. Oblique incision

Entry is made in an oblique fashion using a trocar 30° to the sclera. The length of the incision should be adequate. The disadvantage of the oblique incision is that the inner tissues are often disrupted, resulting in an insecure postoperative wound.[22]

4.3. Biplanar incision

The incision requires two steps. Initially, the blade is inserted at a 30° angle, and then entry is made perpendicular to the sclera.[23] The advantage of this incision is that it achieves better wound apposition, thus reducing the chances of hypotony.

5. Advice for performing self-sealing incisions

In order to achieve a stable self-sealing incision, it is important to displace the conjunctiva, maintain good fixation of the globe, and use the biplanar incision technique. Port placement is also important, particularly in the 25-gauge microincision vitrectomy system (MIVS). If the ports are too close to one another, excess stress on the instruments can occur, raising the chance of flexibility problems to occur when maneuvering the shafts of the small-gauge cutter and light pipe. The trocar cannula system overcomes this problem by allowing the surgeon to place the infusion in any of the three cannulae rather than being required to use the inferotemporal cannula. This gives vitrectomy cutter the access to any of the three ports which eventually allows flexibility and a better approach to the engage tissue planes in the superior quadrant particularly between 10 o′ clock and 2 o′ clock. We insert the infusion cannula midway between the vertical and horizontal axes temporally. The superonasal and superotemporal ports are made above and as close to the horizontal axis as possible in order to achieve maximum maneuverability.

6. Fixation forceps

We use the trocar-Fixation plate (pressure plate forceps) from ASICO (Westmont, IL, USA) (Fig. 2) in a multifunctional manner in order to make the incision.[20] The pressure plate forceps have

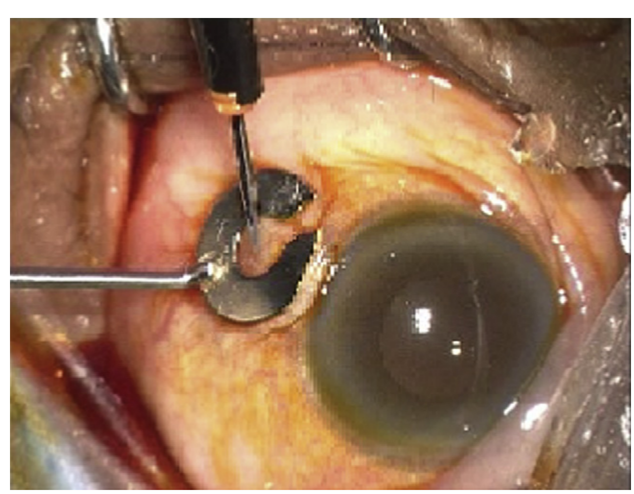

Fig. 2. Insertion of cannula with Trocar Fixation Plate.

incorporated calipers that can be used to measure the distance from the limbus and have serrations on the undersurfaces that provide good grip on the conjunctiva for alignment over the proposed scleral entry. The pressure plate forceps allow a stable, fixed globe while making the biplanar incision. The pressure plate forceps' inner margins slide into the groove of the cannula, allowing easy withdrawal of the trocar without disturbing the integrity of the cannula. Immediately prior to making the incisions, the eye is washed with a jet of saline, and a few drops of povidone-iodine drops are instilled to address conjunctival flora. Initially, the blade is obliquely inserted into the sclera at an angle of about 30–45° up to the cannula mark. Then, the direction of the blade is adjusted perpendicular to the sclera as it is inserted into the vitreous cavity. The biplanar incision not only holds the cannula in place but also prevents the postoperative egress of fluid. We use biplanar incisions during both the 23- and 25-gauge procedures. The biplanar incision has the added advantage of reducing the chance of inadvertent slipping of the cannula during instrument withdrawal.

7. Cannulae removal

At the end of the vitrectomy, the cannulae are plugged to prevent egress of fluid. At this stage, the infusion pressure is reduced to 15 mmHg and, one by one, each of the cannulae are removed by holding them with plain forceps. The lower infusion pressure prevents the egress of intraocular fluid during removal. Immediately after removal of each cannulae, the port site is massaged with the blunt tip of the applicator for 10–15 seconds in order to allow the stretched scleral fibers to regain their elastic memory (Fig. 3). This technique allows better sealing of the scleral fibers and prevents any inadvertent vitreous incarceration. A drop of povidone-iodine is then instilled.[20]

At the end of the procedure, subconjunctival antibiotics are injected into the inferonasal quadrant. The quadrants of the port entry are avoided to prevent accidental entry of antibiotics into the vitreous cavity, which may lead to retinal toxicity. On Postoperative Day 1, the port sites are carefully examined under a slit lamp to look for any wound leakage. We have been examining postoperative wound healing of these ports using the anterior segment component of Spectralis (Heidelberg Engineering Inc., Heidelberg, Germany) (Fig. 4). These scans reveal sequential healing stages of the sclerotomy sections from Postoperative Day 1 through Days 15 and 30. The wounds created using the Edgeplus design trocars have excellent healing characteristics. We have also noted that the average outer and inner opening diameters of the sclerotomy sites tend to increase with longer surgical times.[24] This may be due to the latency of the scleral fibers to retract back in relation to the actual time they had been stretched by the cannulae.

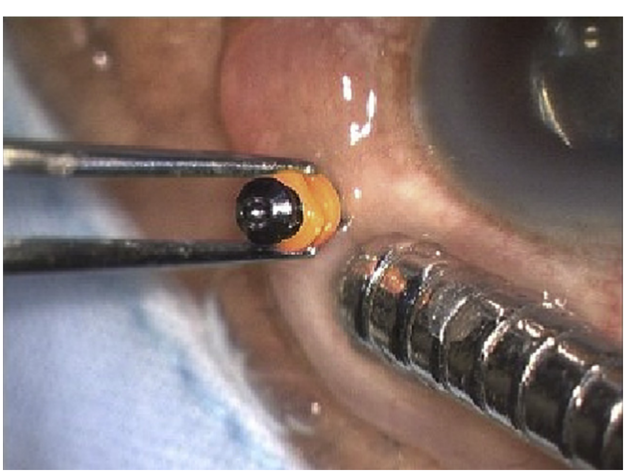

Fig. 3. Removal of cannula.

8. Addressing hypotony

The prevention of hypotony during the early postoperative period is also crucial to ensuring a safe MIVS procedure. Early postoperative hypotony can create a siphoning effect, drawing surface bacteria into the vitreous cavity. As stated earlier, measures to prevent hypotony include partial or total fluid-air exchange or intermittent closure of the infusion while the cannulae are removed. Usually, we decrease the infusion pressure during the removal of cannulae; however, if hypotony is persistent, we inject air in order to maintain proper postoperative tone in the eye. Ports are carefully observed for leakage, which can manifest as increased conjunctival bleb. Good closure will not reveal any signs of a conjunctival bleb after the removal of all cannulae.

If there is any suspicion of leakage from these incisions, adding a suture is the best course of action. This is also the case if the wound is suspected of leaking silicone oil. There has been much debate regarding the role of vitreous incarceration around the cannula and in the wound. Various methods have been proposed to prevent vitreous incarceration into the cannula. One method recommended by Dugel is to remove the cannula with the light pipe inside the cannula, thus preventing vitreous entry into the cannula and incarceration.[20] In one of our studies,[25] we endoscopically observed that the residual vitreous surrounding the cannula is inaccessible to any cutter. This vitreous remnant usually plugs the ports to some extent during cannula removal. In the same study, we also noted, however, that there was no increased rate of complications, such as peripheral breaks or retinal detachments. In these cases. This vitreous does not lead to increased complications because all of the instruments enter the vitreous cavity though a protected cannula sleeve at the vitreous base.

9. Valved cannulae

The most recent development is the introduction of valved cannulae for 23- and 25-gauge vitrectomies (Fig. 5).[26] The insertion of these cannulae is as simple as the nonvalved Edge-plus trocar-cannula system. Additionally, the new valved cannulae are easily removed from the trocar without the need of additional forceps. The valved cannulae also remove the need for plugs during their removal. An additional feature of the valved cannulae is a vented extension that can be inserted to allow air to go through the cannulae for air/silicone oil exchange. With a closed procedure, there is less risk of wound leakage, no turbulence while working with a perfluorocarbon liquid, and less possibility of vitreous or retina incarceration during the sclerotomy. Furthermore, the valved cannulae provide true intraocular pressure (IOP) control under air, a scenario that was previously impossible when exchanging instruments.

10. Advantages of the new generation vitrectomy machines: the Constellation platform

In the past, the vitrectomy systems that were designed for use with 20-gauge fluidics had obvious limitations with 23- and 25-gauge instruments, primarily the inability to maintain good flow at high cut rates. The new generation Constellation vision system (Alcon), however, incorporates fluidics that are designed to work

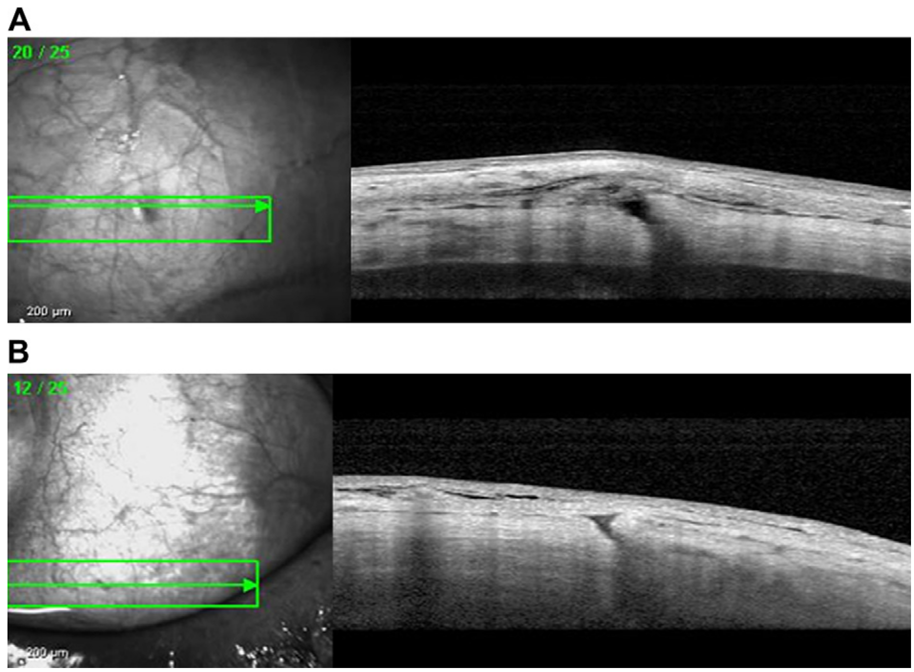

Fig. 4. Anterior Segment OCT of Scleral Ports on 1st post-operative day. A. 23 gauge B. 25 gauge.

during small-gauge surgery, overcoming the limitations of the previous machines. Relative to 25-gauge cannulae, the new 25+-gauge infusion cannulae feature a larger cross-sectional area and create a slightly more turbulent flow that actually has a gentler impact on the retinal surface than the flow generated using smaller cannulae (Fig. 6).

ULTRAVIT High-Speed Vitrectomy Probes (Constellation, Alcon) deliver 5000 cuts per minute (cpm) with dual pneumatic drives that operate on a variable duty cycle with all gauges. This represents a new concept in pneumatic probes that use pulsed air, in order to both open and close the port, thus controlling the duty cycle independent of the cut rate and eliminating the spring-return release mechanism. This probe allows surgeons to regulate the bias of the duty cycle alternatively between core mode, shave mode, and 50/50 mode.[27] Using this probe, surgeons can efficiently control flow in both open and closed duty cycles and choose a cut rate that maximizes their specific needs during the procedure. For most situations, and when on the retinal surface in particular, an open-bias duty cycle yields excellent efficiency while still allowing a 5000 cpm cut speed, which results in very little tissue movement. Using a port-biased, closed duty cycle with a lower cut rate results in a lower flow rate, whereas as the cut rate increases, the duty cycle and flow also increase. Thus, the rate of vitreous removal using 23- and 25-gauge systems is markedly improved on the Constellation platform (Fig. 6).

When performing a core vitrectomy, one can use an open-bias cutter operating at 5000 cpm with a vacuum of 500–600 mmHg. The detached retina can then be addressed in shave mode with the closed duty cycle. So, for the first time, we are able to maintain 5000 cpm with the ability to have the flow characteristics of the core vitrectomy be consistent with detached retina manipulation.

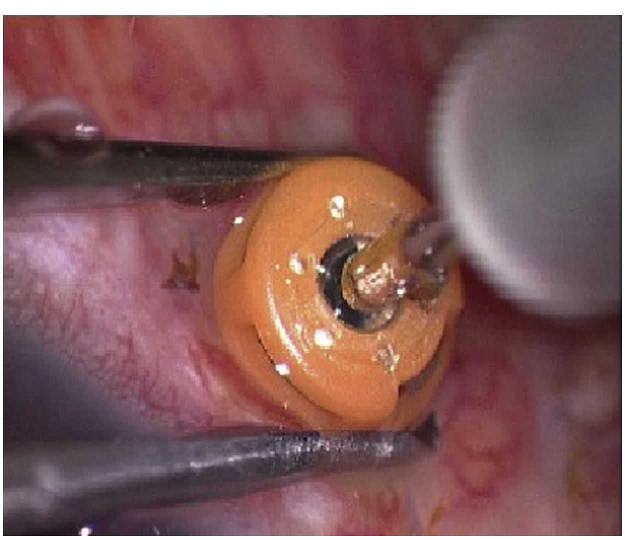

Fig. 5. Valved Cannula.

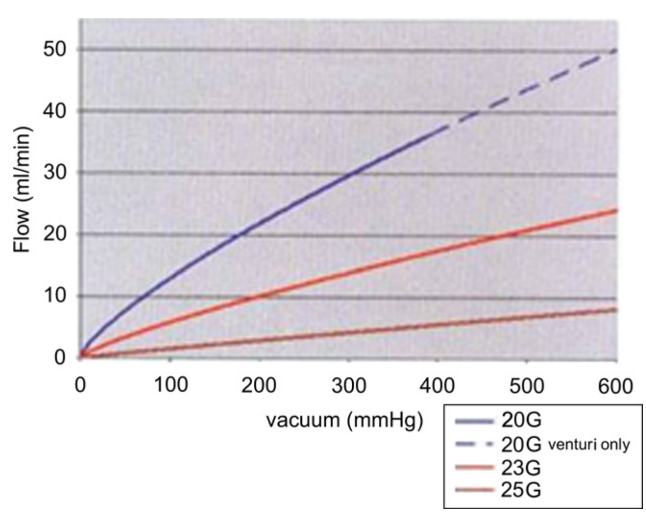

Fig. 6. Flow dependence of 20-, 23-,25- gauge cutters (in open state) with peristaltic and venture using balanced salt solution.

11. Fluid dynamics of vitrectomy

A good understanding of the fluid dynamics of vitrectomy is needed to address the actual implications on the fluidics of small-gauge vitrectomy systems. The use of smaller cutters is associated with a number of drawbacks, the foremost being the decrease in the flow rate during vitrectomy, which can lead to longer surgeries. The flow rate through the cutter is influenced by several factors, such as the diameter of the cutter's opening, the duty cycle, the vacuum strength, the viscosity of the aspirated vitreous, the mechanism upon which the cutter is based (pneumatic or electrical), the movement of the blade, and the internal diameter of the cutter's lumen.[28] The fundamental goal of a vitrectomy is to relieve traction with minimum disturbance to the underlying retina.[29] A greater understanding of fluidics is of utmost importance to achieving greater globe stability and reducing related complications during vitrectomies. Substances can enter the suction port of a vitrectomy instrument when there is a pressure difference (gradient) across the port, which is called the transorifice pressure (TOP).[30] When TOP is too low, the process of vitreous removal is prolonged; if the gradient is too high, traction between the vitreoretinal interfaces can become an issue.

12. Interactions between cutting speed, vacuum, and flow rate

The pressure differential across the cutter and tubing is proportional to the flow; high vacuums cause greater flows, while higher cutting speeds cause lower flow rates while still maintaining a reasonable vacuum for tissue retention. A decreased flow rate reduces intraocular turbulence because there is a smaller pressure difference between the open and closed cycles of the probe port. Less intraocular turbulence is desirable because it minimize movement of the mobile retina. The flow rate and cutting frequency determine the average vitreous fiber travel between cuts (i.e., average effluent fiber length) and, therefore, the amount of vitreoretinal traction. The valve dynamics, drive electronics, cutter friction, and moving mass determine the frequency of cutting. The fastest possible cutting rate is best for all tasks in all cases. The fast cutting technique maximizes the safety of all gauges of vitreous cutters.

13. Fluidics of MIVs

Early in the development of vitrectomy, cutters had slow cut rates and there was a significant lag between reducing the depression on the foot pedal and the resulting reduction in suction at the opening of the cutter. This made shaving the vitreous or removal of proliferation from the surface of the retina very difficult. In order to secure tissues of varying consistency, an aspiration system should be able to generate small changes in the suction force over a wide range. This means that the infusion should simultaneously replace the evacuated fluid and tissue through the aspiration system, even when a strong vacuum is required.[29] Also, the TOP gradient between the vitrectomy probe, fragmenter, and an extrusion device should be zero when the surgeon's foot is off the pedal. These effects should occur in real time, without delay. With the advent of high-speed cutters and improvements in machine technology, these steps are now much easier with both 23- and 25-gauge vitrectomy approaches.

14. Fast cutting

Small-gauge technology helps to move the cutter towards the retina as opposed to pulling the collagen fiber in from a distance away from the retina. As Steve Charles said, "You move your vacuum cleaner around the room to clean the carpet; you don't put the vacuum cleaner in the middle of the room and try to clean the whole area."[31] Thus, the best method is to use the highest cut rate, move the port towards the vitreous, and always move the cutter forward while cutting and increasing the proportional vacuum until vitreous removal is sufficient, then decreasing the vacuum when working close to the retina.

Lower flow rates are always safer and are an issue only if they significantly increase the operating time. The actual advantage of MIVS is limiting the port-based flow rate.[32] Pulse flow is defined as the volume of fluid that goes through the port with each open-close cycle. Port-based flow is inherently limited by a smaller lumen. Limiting the port-based flow reduces the pulse flow. Intra-operatively, the surgeon runs very little fluid through the eye, 50–75 ccs on average in MIVS versus 200–400 cubic centimetres (ccs) with the 20-gauge system. This reduction in the fluid volume traversing the port with each open-close cycle reduces cutter-induced motion of the detached retina, thereby enabling the safer removal of peripheral vitreoretinal traction. In addition, limiting the port-based flow prevents surges after the sudden elastic deformation of dense epiretinal membranes through the port, facilitating safer conformal cutter delamination for diabetic traction during retinal detachments. The crucial point is that 25-gauge cutter lumens are smaller than the 23- or 20-gauge lumens and are, therefore, able to produce better fluidics because of increased port-based flow.

However, the increasing use of smaller gauge systems has led to the finding that there is decreased flow performance during vitreous removal in 25-gauge vitrectomies relative to the standard 20-gauge vitrectomy. The aspiration rate is lower in the 25-gauge system even if the aspiration pressure is set to 500–600 mmHg compared with that of the 20-gauge system. Besides lower flow rates, a 25-gauge port also increases the overall resistance to vitreous removal. Induction of a posterior vitreous detachment would not only take longer but would be much more difficult due to less suction, smaller ports, and lower flow rates. These issues can lead to increased surgical times.

The 25-gauge sutureless system also had disadvantages related to dimmer illumination, but these issues were resolved with the advent of a xenon-powered light source. Constellation Illuminator incorporates ENGAUGE radio frequency identification device technology (RFID) to recognize the light probe's gauge size and automatically adjust the light intensity. It also controls the amount of light and warns the surgeon if he is using brighter than average settings for any given fiberoptic probe so as to avoid toxicity concerns.

When using 25-gauge instruments, it might be difficult to rotate the eyeball or reduce small saccadic eye movements (during fine maneuvers, including the removal of epiretinal membranes or internal limiting membranes) because the instruments are so soft. The newer 25-gauge instruments are stiffer and will most likely become even more so in the future, and they will probably be used just like the 20-gauge instruments. Some limits are also set by the surgical instrument manufacturing due to the smaller size cannulae. The 25-gauge curved intraocular scissors, for instance, cannot have a pronounced curve that renders them much less effective, forcing surgeons to compromise with other methods.

The 23-gauge systems are emerging as a very viable approach for balancing the pros and cons of the 20- and 25-gauge systems, thereby leading to the expansion of the use of transconjunctival sutureless vitrectomy (TSV). The 23-gauge system pioneered by Eckardt[7] allows angled incisions, thereby allowing the surgeon to perform sutureless TSV while retaining the feel, movement, and stability of the stiff 20-gauge instruments that surgeons prefer.

Another principal benefit of choosing a 23-gauge system over a 25-gauge system is the significant improvement in fluidics. For diabetic traction detachments, we need to have low flow rates with a precise ability to cut. Using the vitrector to reliably create a posterior vitreous detachment requires a high-net flow rate. Both the 23- and 25-gauge vitrectomy approaches are quite good at achieving low-flow fluidics. For instance, each can be used to shave the vitreous base and remove proliferations associated with diabetes. The separation between the 23- and 25-gauge vitrectomy approaches becomes most evident in the high-flow domain. Peak flow rates through a 25-gauge vitrectomy system are limited by the small internal diameter of the cutter and the infusion cannula. In a 23-gauge surgery, both the cutter and the infusion cannula have improved designs that afford higher flow rates. In this sense, we use flow as a tool. Our ability to grasp and remove a posterior-vitreous face depends on the amount of suction, the diameter of the cutter opening, and, because thin vitreous sheets do not readily occlude openings, the flow rate.

Moreover the port of the 23/25-g cutter is closer to the end of the tip, adding to its efficiency because it is possible to come extremely close to the retina in order to dissect the membranes. Normally, one would most likely need bimanual instrumentation or specialized scissors, but with these cutters one can go almost flush over the retina and cut the membranes safely, sparing most of the underlying retinal tissue. Having the port so close to the tip also allows the suction to peel neovascular proliferation by increasing the force of the vacuum.[33]

In fact, the efficiency of the 23-gauge cutter has been shown to be similar to that of the 20-gauge cutter, and by using vacuums of 200–250 mmHg it is possible to duplicate the same efficiency as the 20-gauge cutter when cutting dense vitreous. The increased rigidity of the instrumentation helps to overcome any control problems due to the overflexibility of the 25-gauge instrumentation. However, when operating on eyes with large filtering blebs, such as patients with macular pucker, the 25-gauge system is preferable because it is smaller and less invasive, allowing for preservation of the bleb.

15. Illumination system

The miniaturization of instruments created the need for the development of smaller illumination probes that would give a brighter illumination and wider panoramic view.[34,35] Miniaturization of illumination devices became possible because of the strong light produced by the xenon-based source. Eckardt[36] developed a “twin light” xenon-based illumination probe, which was designed to directly penetrate the conjunctiva and sclera. In 2007, Oshima et al[8] presented a fiberoptic with a 27-gauge diameter based on the same technology. This fiberoptic remains fixed to the sclera after insertion, which enables the execution of bimanual surgery and provides wider illumination of the vitreous cavity (i.e., “chandelier” illumination). Presently, chandelier fiberoptic tips can be inserted into a fourth port using the same 25-gauge cannulae that are used for the regular ports and are eventually removed at the end of the surgery without suturing.

16. Hybrid approach (20/25- or 20/23-gauge)

There are certain situations where standard small-gauge vitrectomy cannot be used at present.

16.1. Nucleus drop removal or intraocular foreign body (IOFB) removal

In the case of nucleus drop or intraocular foreign bodies, one of the ports has to be enlarged to accommodate the fragmatome and remove intraocular foreign bodies. In such situations, the other two ports can be made of 23- or 25-gauges whereas one port can be of a 20-gauge.[37] Moreover, there are 20/25-gauge and 20/23-gauge adaptors available that can be inserted into a 20-gauge wound after the nucleus or IOFB removal so that the rest of the procedure could continue using small-gauge dynamics.

17. Three-dimensional technology

The new generation MIVS systems offers a dual dynamic drive, which allows for simultaneous linear control of cut and vacuum to produce the resulting flow rate. These abilities enhance efficiency and maximize control. The three-dimensional (3D) interface stands for “dual, dynamic, drive,” where the three D’s represent these concepts:

- Dual: combines dual control of the vacuum and cut rate.
- Dynamic: provides dynamic changes to the flow rate as the pedal is depressed.
- Drive: allows the flow parameters to be visualized via the foot pedal.

This interface works on the concept of dual linear control, which means that any point in time the surgeon can have two different preprogrammed settings for the vacuum and cut rate. As the surgeon travels through the range of the foot pedal, he can change the settings on the machine from a preset starting point for cutting and the vacuum to a preset endpoint. However, 5000-cpm cutter speeds and making the fluidics unable to limit the overall flow dynamics are preferred. This allows the surgeon to always remain at the highest possible cut rate, thus improving overall safety.

The 3D system has been in practice with 20-gauge surgeries for some time, but the advantages are even more apparent with small-gauge sutureless surgery. The new cutters are designed in such a way that the port opening is extremely close to the tip of the cutter shaft. This allows the surgeon to use the cutter extremely close to the retina without disrupting it. The port-based flow resistance makes it extremely safe in a wide range of cases, and with 3D surgery it makes small-gauge incisions not only safer but also more efficient.

Moreover, the cutters are pneumatically driven and have variable duty cycles, thus adding greater safety at the port opening without compromising speed. This means that even at 2500 cpm, the variable duty cycle is able to keep the port opening time at a sufficient duration so that the actual speed of the surgery does not reduce proportionately, which is the usual case when using high-speed electrical cutters. This allows the cutters to be used at a high speed, giving better control for cutting near the retina. Thus, the combination of small-gauge cutters and their safety advantage in relation to the port-based flow resistance and 3D technology is now an ideal choice for the vitreoretinal surgeon.

18. Future research

Further refinements in instrumentation are ongoing and will continue to improve the results of small-gauge vitrectomy and reduce the limiting factors. Cutting rates of 7500 cpm are already in the pipeline, and a 27-gauge platform will gain further acceptance in the future as the machines continue to improve their overall fluidics.

Oshima et al developed a 27-gauge instrument system that includes an infusion line, a high-speed vitreous cutter, an illumination system, and a variety of vitreoretinal instruments, such as membrane forceps and sharp-tipped endophotocoagulation probes.[8] They measured the duty cycle of 27- and 25-gauge cutters at several cut rates using a high-speed imaging camera. Infusion and aspiration rates were measured using a balanced saline solution and porcine vitreous with different aspiration levels. The surgical outcomes, including anatomic success rate, visual outcomes, operating times, and intra- and postoperative complications, were also evaluated. Their results show that although the infusion and aspiration rates of the 27-gauge system measured in BSS were reduced to an average of 62% and 80%, respectively, compared with those of the 25-gauge system, the duty cycle of the 27-gauge cutter (61% at 1000 cpm and 38% at 1500 cpm) was equal to or better than those of the 25-gauge cutter (62% and 28%, respectively). Analysis of the fluid dynamics showed that vented gas-forced infusion can be set to range from 20–30 mmHg in order to control intraocular pressure (IOP) during 27-gauge vitrectomy. Anatomic success was achieved in all study eyes (100%); 20 eyes (65%) showed visual improvement of three lines or more. No eyes required conversion to a larger gauge instrument. All sclerotomies were able to self-seal without hypotony (IOP $\leq$ 7 mmHg) from Postoperative Day 1. So, although the fluid dynamics and cutting efficiency of 27-gauge instruments are lower compared with 25-gauge MIVS, the 27-gauge system is feasible and may reduce concerns about wound sealing-related complications in selected cases.

When small-gauge vitrectomy using a 25-gauge system was first introduced, the machines on which this gauge were used were originally configured to drive 20-gauge fluidics. Hence, there were limiting factors because surgeons were used to the dynamics of the 20-gauge surgery. However, the new generation machines have been designed to cater its fluidics in a customized manner for 23- and 25-gauge systems and will eventually cater to 27-gauge systems.

References

1. Machemer R, Parel JM, Norton EW. Vitrectomy: a pars plana approach. Technical improvements and further results. *Trans Am Acad Ophthalmol Otolaryngol* 1972;**76**:462–6.
2. Kasner D, Miller GR, Taylor WH, Sever RJ, Norton W. Surgical treatment of amyloidosis of the vitreous. *Trans Am Acad Ophthalmol Otolaryngol* 1968;**72**:410–8.
3. O'Malley C, Heintz RM. Vitrectomy with an alternative instrument system. *Ann Ophthalmol* 1975;**7**(585e8):591–4.
4. Chen JC. Sutureless pars plana vitrectomy through self-sealing sclerotomies. *Arch Ophthalmol* 1996;**114**:1273–5.
5. Fujii GY, de Juan E, Humayun MS, Chang TS, Pieramici DJ, Barnes A, et al. Initial experience using the transconjunctival sutureless vitrectomy system for vitreoretinal surgery. *Ophthalmology* 2002;**109**:1814–20.
6. Fujii GY, de Juan E, Humayun MS, Pieramici DJ, Chang TS, Awh C, et al. A new 25-gauge instrument system for transconjunctival sutureless vitrectomy surgery. *Ophthalmology* 2002;**109**:1807–13.
7. Eckardt CM. Transconjunctival sutureless 23-gauge vitrectomy. *Retina* 2005;**25**:208–11.
8. Oshima Y, Wakabayashi T, Sato T, Ohji M, Tano Y. A 27-gauge instrument system for transconjunctival sutureless microincision vitrectomy surgery. *Ophthalmology* 2010;**117**:93–102.
9. Chen E. 25-gauge transconjunctival sutureless vitrectomy. *Curr Opin Ophthalmol* 2007;**18**:188–93.
10. Ibarra MS, Hermel M, Prenner JL, Hassan TS. Longer-term outcomes of transconjunctival sutureless 25-gauge vitrectomy. *Am J Ophthalmol* 2005;**139**:831–6.
11. Rizzo S, Genovesi-Ebert F, Murri S, Belting C, Vento A, Qresti F, et al. 25-gauge, sutureless vitrectomy and standard 20-gauge pars plana vitrectomy in idiopathic epiretinal membrane surgery: a comparative pilot study. *Graefes Arch Clin Exp Ophthalmol* 2006;**244**:472–9.
12. Fine HF, Iranmanesh R, Iturralde D, Spaide RF. Outcomes of 77 consecutive cases of 23-gauge transconjunctival vitrectomy surgery for posterior segment disease. *Ophthalmology* 2007;**114**:1197–200.
13. Eifrig CW, Flynn Jr HW, Scott IU, Newton J. Acute-onset postoperative endophthalmitis: review of incidence and visual outcomes. *Ophthalmic Surg Lasers* 2002;**33**:373–8.
14. Eifrig CW, Scott IU, Flynn Jr HW, Smiddy WE, Newton J. Endophthalmitis after pars plana vitrectomy: incidence, causative organisms, and visual acuity outcomes. *Am J Ophthalmol* 2004;**138**:799–802.
15. Aaberg Jr TM, Flynn Jr HW, Schiffman J, Newton J. Nosocomial acute-onset postoperative endophthalmitis survey: a 10-year review of incidence and outcomes. *Ophthalmology* 1998;**105**:1004–10.
16. Kunimoto DY, Kaiser RS. Wills eye retina service. incidence of endophthalmitis after 20- and 25-gauge vitrectomy. *Ophthalmology* 2007;**114**:2133–7.
17. Scott IU, Flynn Jr HW, Dev S, Shaikh S, Mittra RA, Arevalo JF, et al. Endophthalmitis after 25-gauge and 20-gauge pars plana vitrectomy: incidence and outcomes. *Retina* 2008;**28**:138–42.
18. Shaikh S, Ho S, Richmond PP, Olson JC, Barnes CD. Untoward outcomes in 25-gauge versus 20-gauge vitreoretinal surgery. *Retina* 2007;**27**:1048–53.
19. Charles S. Tips and tricks for 25-ga. sutureless vitrectomy technique change and attention to detail can help maximize the advantages of 25-ga. retinal surgery. Review of Ophthalmology. Available from: http://www.revophth.com/content/d/retinal_insider/i/1319/c/25382/. [accessed 25.11.11].
20. Nagpal M, Videkar R. Wound construction in MIVS surgical pearls for the ideal small-gauge incision for vitrectomy. *Retina Today* 2010;Jan/Feb:58–60.
21. Shimada H, Nakashizuka H, Hattori T, Mori R, Mizutani Y, Yuzawa M. Incidence of endophthalmitis after 20- and 25-gauge vitrectomy causes and prevention. *Ophthalmology* 2008;**115**:2215–20.
22. Singh A, Stewart JM. 25-gauge sutureless vitrectomy: variations in incision architecture. *Retina* 2009;**29**(4):451–5.
23. Singh R, Bando HD, Brasil OFM, Williams DR, Kaiser P. Evaluation of wound closure using different incision techniques with 23 ga and 25 ga microincision vitrectomy systems. *Retina* 2008;**28**(2):242–8.
24. Nagpal M, Paranjpe G. *Evaluation of wound closure morphology of sclerotomy sites of sutureless vitrectomy using spectralis anterior segment optical coherence tomography. Clinical Poster (PO1–023).* Hyderabad, India: 6th APVRS Congress; December 1–3, 2011.
25. Nagpal M, Wartikar S, Nagpal K. Comparison of clinical outcomes and wound dynamics of sclerotomy ports of 20, 25 and 23 gauge vitrectomy. *Retina* 2009;**29**(2):225–31.
26. Charles M. Closed system and expanded instrumentation improves MIVS outcomes. *Retina Today* 2011;Jul/Aug:84–9.
27. Guttman C. Intraoperative control comprehension of vitrectomy fluidics underlies safe and effective surgery. *Ophthalmology Times* 2010;Feb:18.
28. Magalhaes OJ, Chong LM, DeBoer CB, Bhadri P, Kerns R, Barnes A, et al. Vitreous dynamics: vitreous flow analysis in 20-, 23-, and 25-gauge cutters. *Retina* 2008;**28**:236–41.
29. Michels RG. Instrumentation. In: Micheals RG, editor. *Vitreous surgery*. St. Louis: CV Mosby; 1981. p. 59–97.
30. Charles S. An engineering approach to vitreoretinal surgery. *Retina* 2004;**24**(3):435–44.
31. Charles S. Fundamentals of fluidics and fast cutting: Ophthalmology World Report: October 2007 supplement; 6–7.
32. Charles S. The physics of vitrectomy and advanced fluidics: how cutting rates affect flow and outcomes. *Retina Today* 2008;Sep/Oct:2–4.
33. Nagpal M. The advantages of 3D technology and lighting systems with MIVS: advanced vitreoretinal techniques and technology symposium in Hong Kong. *Retina Today* 2008;Sep/Oct:13–5.
34. Nakata K, Ohji M, Ikuno Y, Kusaka S, Gomi F, Kamei M, et al. Wide-angle viewing lens for vitrectomy. *Am J Ophthalmol* 2004;**137**:760–2.
35. Peyman GA, Canakis C, Livir-Rallatos C, Easley J. A new wide-angle endoillumination probe for use during vitrectomy. *Retina* 2002;**22**:242.
36. Eckardt C. Twin lights: a new chandelier illumination for bimanual surgery. *Retina* 2003;**23**:893–4.
37. Parkes C, Nagpal M, Little B, Prasad S. Drop and stop: the dropping and the dropped nucleus. *Retina Today* 2011;Jan/Feb:76–80.