Innovations in 27-Gauge Vitrectomy for Sutureless Microincision Vitrectomy Surgery

Duty cycle control and dual-port cutters may allow wider use of ultrasmall-gauge vitrectomy.

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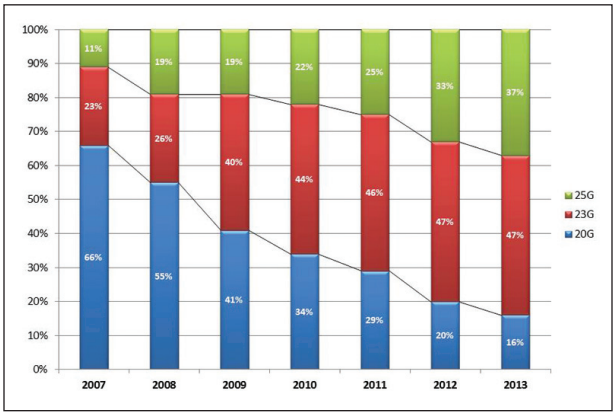
The common thinking regarding surgical wounds is that "much smaller is much better." Based on this concept, microincision vitrectomy surgery (MIVS) with 25- or 23-gauge instruments has taken over from conventional 20-gauge vitrectomy in many cases, and the technology has evolved radically during the past several years. Along with the development of ergonomic instrumentation and new-generation vitrectomy machines, there has been a rapid adoption of smaller gauge instrumentation on a global scale over the past several years (Figure 1).

The above-mentioned trends and future perspectives in modern MIVS led us to initiate a 27-gauge vitrectomy project in 2007. Development of a 27-gauge chandelier illumination fiber was the first step.[1] After years of strenuous efforts, DORC was the first company to offer a complete 27-gauge vitrectomy system. The preliminary surgical results using the first-generation 27-gauge vitrectomy system to treat vitreoretinal diseases were reported in 2010.[2] At that time, the system was used only in select cases—mainly macular disease and simple vitreous hemorrhage—similar to the situation in the early days of 25-gauge vitrectomy. Nevertheless, both the anatomical and visual results were very promising. The most remarkable findings were that there was no need to transition to a larger gauge, no suturing was required, and no hypotony was observed in any of the study cases.

To explore the potential for more widespread use of this ultrasmall-gauge system, its functionalities must be upgraded to treat more challenging conditions, such as cases of advanced proliferative diabetic retinopathy and primary rhegmatogenous retinal detachment. The most critical aspect of 27-gauge vitrectomy that must be improved is the cutting efficiency of vitreous cutter. According to the Hagen-Poiseuille law (Figure 2), the flow volume of fluid through a pipe can be increased by increasing the pressure differences between the ends of the pipe and/or by decreasing the coefficient of viscosity. This suggests that the cutting efficiency (vitreous flow) of the 27-gauge vitreous cutter can be improved by (1) reducing the bite size at higher cut rates to decrease the flow viscosity (resistance) and/or (2) maintaining a longer opening time of the cutting port with a maximum aspiration pressure.

In this article, we describe 2 recently introduced technologies that may help surgeons realize ultrahigh performance with 27-gauge vitrectomy probes.



(courtesy of Alcon)

Figure 1. Global trend in surgeons' preferences for vitrectomy gauge, 2007-2013.

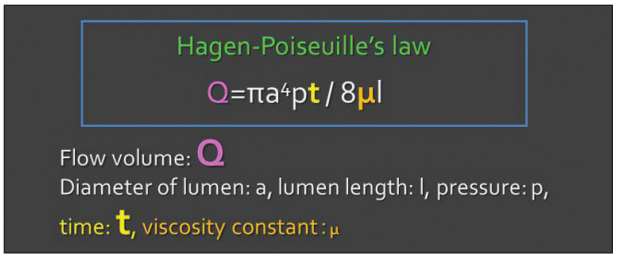


Figure 2. Hagen-Poiseuille law defines the flow through a tube in terms of flow rate, pressure drop, and resistance to flow. The flow rate in vitreous is proportional to the fourth power of the inner radius of the tube, aspirating time, and inversely proportional to viscosity and lumen length.

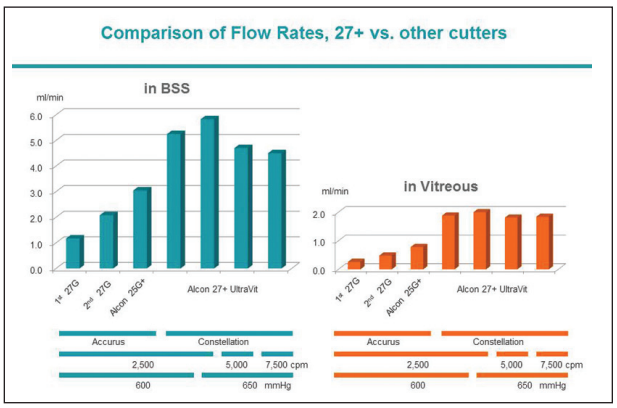


Figure 4. Comparison of flow rates flow rate in balanced saline solution and in vitreous among 27+ UltraVit probe and other standard vitrectomy cutters.

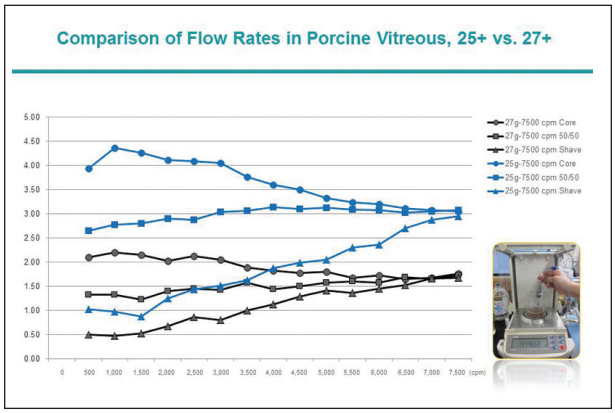


Figure 3. Comparison of flow rates between 27+ and 25+ probes in porcine vitreous.

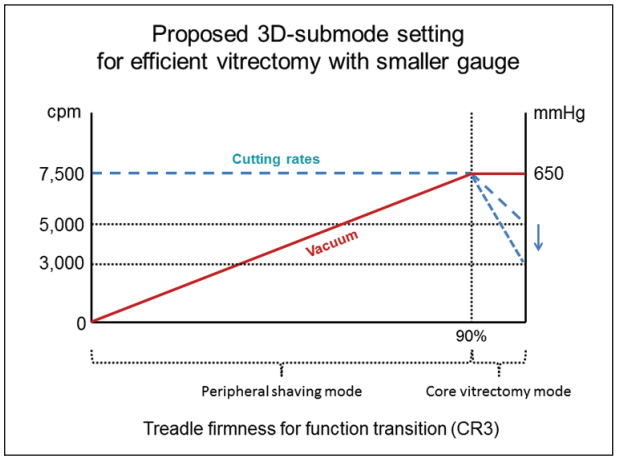


Figure 5. A proposed 3-D submode setting for efficient vitrectomy. Core vitrectomy is possible with full depression of the footpedal to maintain maximum aspiration of 650 mm Hg with higher duty-cycle cutting rate of 5000 cpm, and safer peripheral vitreous shaving is possible sequentially by releasing the footpedal to obtain proportional control of aspiration with the highest cutting rate of 7500 cpm.

DUAL AIR-DRIVEN, DUTY-CYCLE CONTROL 27-GAUGE CUTTER

The Constellation Vision System (Alcon) features a dual pneumatic-driven technology enabling ultrahigh-speed cutting with duty cycle control. This provides a promising platform for the development of an efficient 27-gauge vitrectomy system. The company's 27+ product line features a 27-gauge vitrectomy probe capable of cutting at up to 7500 cpm with a function of duty cycle control based on cutting rate.

An experimental study compared the practical performance of the UltraVit 27+ cutter in porcine eyes with that of a 25-gauge cutter (25+; Alcon) with the Constellation Vision System. In this setting, the 27+ cutter showed approximately 60% of the flow efficiency of the 25+ (Figure 3). When compared with the 25-gauge system at 2500 cpm, the vitreous cutting flow of 27+ at 7500 cpm with the Constellation Vision System had better efficiency by approximately 2 times or more (Figure 4).

The latest addition to the Constellation is a customizable three-dimensional (3-D) submode that allows the operator to easily switch different cutting and aspiration settings during vitrectomy using the foot pedal. For example, it is possible to customize 2 different settings with different cutting rates based on duty cycle (Figure 5); core vitrectomy is possible with full depression of the foot pedal, with maximum aspiration of 650 mm Hg and maximum duty cycle cutting rate of 5000 cpm, and safer peripheral vitreous shaving is achievable sequentially by releasing the foot pedal to obtain proportional control of the aspiration with a maximum cutting rate of 7500 cpm.

This dual setting enables an efficient core vitrectomy with full pedal depression and safer peripheral shaving

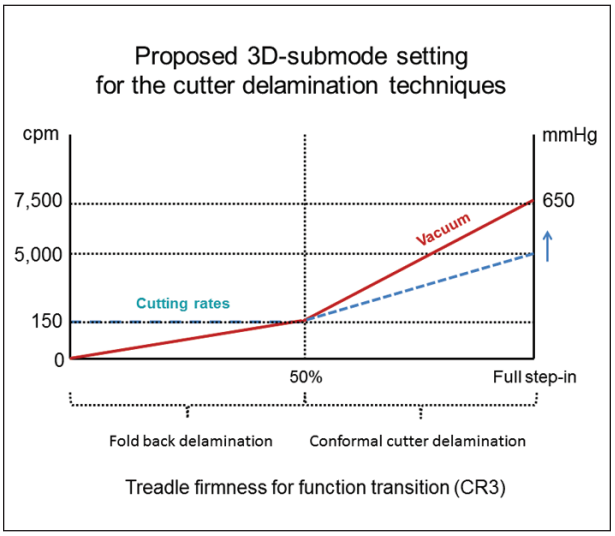


Figure 6. Another proposed 3-D submode setting for membrane delamination. The 2 cutter settings for membrane dissection can be switched and adjusted quickly and sequentially by footpedal control.

by releasing the foot pedal to allow proportional control of the aspiration for retinal detachment surgery with the 27+ system.

A smaller gauge cutter would be useful for membrane dissection in diabetic eyes. The 27+ is currently the best for this indication because it can be easily inserted into the tiny spaces between membranes without the need for complex instruments and special techniques. To maximize the potential of 27+ for membrane dissection, the treadle control 3-D submode could be used to customize 2 cutter delamination settings for sequential use based on 2 membrane dissection techniques first proposed by Steve Charles, MD.[3] The so-called foldback delamination is a useful and safe technique for removing flexible, weakly fixed membranes by putting the cutter port just behind the membrane's leading edge and folding back the membrane into the port with high-speed cutting in shave mode with gentle aspiration. The membranes between the cutter port and the retina may reduce the potential risk of creating iatrogenic breaks. By contrast, thickened fibrovascular membranes, large blood clots, and retained lens fragments can be engaged and cut off with the small-gauge cutter using reduced cut rates. In the case of thickened membranes, it is preferable to use the conformal cutter delamination technique. Thickened membranes can be dissected directly by moving the cutter port forward into the leading edge

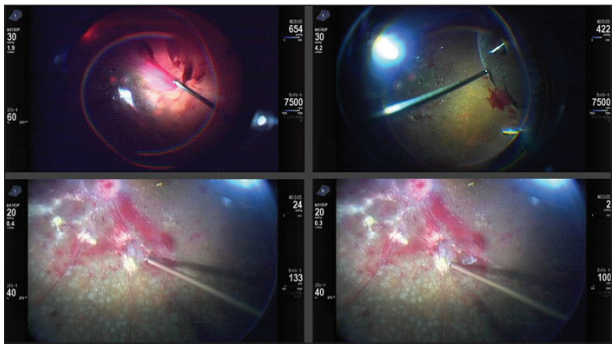


Figure 7. Ultra highspeed cutting with a 27+ cutter in an eye with a massive vitreous hemorrhage (A). Use of this instrumentation allows the surgeon to safely and completely shave the peripheral retina (B). The small probe can act like a pick and allow the surgeon to lift up abnormal tissue and get into the space between the proliferative membrane and the retina (C). The 27+ cutter can also act like vertical scissors by cutting the proliferative membrane safely with efficient segmentation (D).

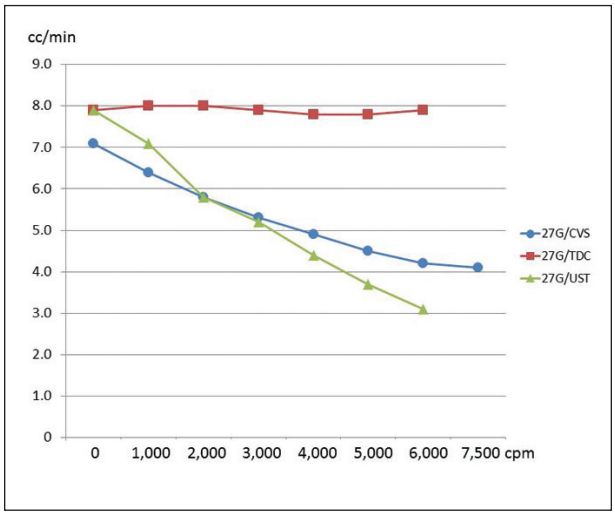


Figure 8. Flow rates in vitreous compared among the 27-gauge twin duty cycle (TDC) cutter and other cutters. The TDC cutter has constant vitreous flow regardless of cutting rate.

of membranes while adjusting the port away from the retina to reduce the risk of retinal tissue entering the port.

In conjunction with the programming capabilities of the Constellation Vision System, these 2 cutter delamination settings can be customized sequentially (Figure 6). The surgeon can switch between the 2 techniques quickly

by rotating or repositioning the cutter port while changing the pedal depression to select the preferred cutting setting depending on the thickness and fragility of the fibrovascular membranes (Figure 7).

DOUBLE-PORT 27-GAUGE CUTTER

The concept of a double-port cutter, with a second port in the internal guillotine blade of the cutter, has been proposed. The second port, incorporated into the pneumatic spring-driven cutter, improves flow efficiency by allowing the maintenance of duty cycle without attenuation while cutting rate is increased. The original idea for this type of cutter received a US patent more than 20 years ago (Hayafuji et al; 1992).

Because the cutting port was almost fully open in this design, it was not suitable in the 20-gauge era, because the potential risk of increasing the tractional force on the vitreous was a major concern in a cutter with a large inner lumen and low cutting rate. However, because of the increased cutting efficiency with a small-lumen cutter, as in 25- or 27-gauge instruments,[4,5] the potential risk of tractional forces will be lower, and the potential to increase cutting efficiency is promising. DORC, in collaboration with Claus Eckardt, MD, has developed a double-port 27-gauge twin-duty cycle (TDC) cutter with cutting rates of up to 6000 to 8000 cpm.

We carried out a laboratory experiment comparing the aspiration flow rate in balanced salt solution and porcine vitreous with the 27-gauge TDC cutter with that of a conventional 27-gauge cutter. As expected, the flow rate in saline solution remained constant regardless of the cut rates (Figure 8). The aspiration flow of the 27-gauge TDC cutter in porcine vitreous was better than that of the standard 27-gauge cutter by 50% or more and, surprisingly, almost equal to or a little bit better than that of a standard 25-gauge cutter. The 27-gauge TDC cutter is very efficient for vitreous hemorrhage removal and membrane dissection during diabetic vitrectomy.

EXPANDED SURGICAL INDICATIONS

Similar to 25-gauge instrumentation, when a 27-gauge systems first became available, it was suitable only for simpler cases, such as macular surgery or simple vitreous hemorrhages.[2] The latest generation 27-gauge instrumentation can be used for more complex cases such as rhegmatogenous retinal detachment,[6,7] proliferative diabetic retinopathy,[8] retained lens fragments, and subretinal hemorrhage.

The latest surgical technologies and techniques discussed above have greatly improved the efficiency and safety of 27-gauge vitrectomy systems. Ultrahigh-speed cutting, duty-cycle control, and double-port design are the most critical new factors influencing the performance of 27-gauge cutters. New generation 27-gauge systems will likely enable widespread use of this modality for the full spectrum of vitreoretinal pathologies in the very near future. ■

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