Although there is some uncertainty about who coined the phrase, “We are like dwarves perched on the shoulders of giants,” there is no uncertainty that our current advances in vitrectomy platforms are based on the innovations of giants in our field dating back to more than half a century ago.

Marc Comaratta, MD, and Rahul Reddy, MD, MHS, provide us with a very interesting and beautifully illustrated overview of the evolution of vitreoretinal surgery platforms. They go back to the beginning of our history and summarize each step of innovation leading up to our currently available vitrectomy platforms.

Furthermore, they discuss future directions such as piezoelectric hypersonic vitreous liquification and three-dimensional heads-up displays that can be used during vitrectomy surgery.

Those of us who perform vitreoretinal surgery in an attempt to help patients with vision-disabling disease should take a moment to revere our ancestors, who developed earlier generations of the technologies we routinely take for granted. Drs. Comaratta and Reddy remind us of our proud history, and I am certain their review will be very interesting to those who read it.

MANUAL VITRECTOMY

American vitreoretinal surgery began in a garage in Coral Gables, FL, in the 1960s. It was there that David Kasner, MD, a young faculty member at Bascom Palmer Eye Institute, was performing cadaveric eye dissections to deepen his knowledge of anatomy relevant to intracapsular cataract surgery (Figure 1). During the course of his work, he observed that the acrylic resin used to embalm his cadaveric eyes turned vitreous cloudy and obscured his view of the relevant anatomy. To solve this problem, he began removing the vitreous gel with forceps and scissors and soon discovered that a Weck-Cel sponge (Meroxel, Mystic, CT) was effective for engaging solid vitreous at the pupillary margin. Kasner then applied this experience to the operating room, first using the technique to address vitreous loss during cataract surgery. He soon began performing primary “radical anterior” and “open sky” manual vitrectomies via 300° limbal incisions in what were previously considered inoperable cases of vitreous opacification in penetrating trauma and amyloidosis. Kasner and his associates in Miami were surprised to find that the human eye tolerated meticulous vitreous removal well, and this early success prompted them to delve further into more advanced techniques of vitreous removal.

SINGLE HANDPIECE VITRECTOMY

Kasner’s colleagues in Miami, including Robert Machemer, Helmut Buettner, and Jean Marie Parel, were among the first in the world to develop a mechanized vitrectomy instrument. In the course of experimenting with a way to more efficiently excise vitreous, they found that a drill bit rotating inside a thin cylinder could effectively remove the yolk from an egg. They used this experience as the basis for a device they called the “VISC,” which consisted of a syringe and a 17-gauge needle (Figure 2). Within the needle was a small rotating drill bit powered by an electrical model airplane motor and a battery placed within the syringe. A small opening at the end of the needle allowed vitreous to be engaged, and
suction applied manually by an assistant served as aspiration. A gravity-based infusion line attached to the needle maintained the intraocular pressure (IOP) (Figure 3).

In 1970, the VISC was used on the first human subject with a diabetic nonclearing vitreous hemorrhage via the “open sky” approach after penetrating keratoplasty. The VISC performed an effective core vitrectomy, and the patient gained surprisingly good postoperative vision with less iris irritation and inflammation than Kasner’s manual vitrectomy.3

Machemer was not alone in this approach. His vitreous cutter, or VISC, was developed simultaneously with and was essentially identical in concept to the Roto-Cutter developed by Nicholas Douvas in Port Huron, MI.4 Banton Anko developed a vitreous cutter for use in the anterior segment with phacoemulsification prior to Machemer without patenting the device. An instrument for mechanized vitreous removal with aspiration and infusion had been developed earlier in Japan and published in the Japanese literature, though this work was not known in the United States.5

Machemer soon began using a pars plana sclerotomy to access the vitreous cavity with the VISC, negating the deleterious effects of an anterior segment approach. The VISC continued to evolve as well. The initial version experienced the problem of “vitreous winding,” wherein vitreous strands would become wound around the drill and pulled in lieu of being cut, causing traction on the retina and iatrogenic breaks. Later versions attempted to solve this problem by eliminating the rotating drill bit. They instead featured an outer stationary needle and an inner rotating tube with small openings at the distal end of each. Vitreous was aspirated manually through the opening in the outer tube and cut when the inner tube rotated beneath it. These later versions of the VISC integrated infusion, aspiration, cutting, and eventually fiberoptic endo-illumination developed by Parel all into a single handpiece to serve as a complete vitrectomy unit.3

THREE-PORT VITRECTOMY

The next great leap in American vitreoretinal surgery arrived in 1974 with the idea of three-port vitrectomy developed by O’Malley and Heintz. Driven by their Ocutome 800 console (Berkeley Bioengineering, Berkeley, CA), this system separated the cutting and aspiration device from the illumination and infusion, allowing for a more lightweight and less cumbersome vitreous cutter. The cutter and fiberoptic endo-illumination light pipe were placed superior to the medial and lateral rectus muscle insertions through 20-gauge pars plana sclerotomies, and the vitreous infusion probe was sewn into place inferotemporally. The Ocutome 800 replaced manual aspiration with surgeon foot-controlled, on/off setting aspiration. The infusion remained gravity based. The 20-gauge, reusable cutter handpiece was pneumatically driven and functioned as a “vitreous guillotine,” with an inner tube moving axially along the length of the outer tube, shearing aspirated vitreous as it crossed the open side port at the distal end of the outer tube. All vitrectomy platforms have been based on the basic approach of three-port pars plana access with foot pedal control since its inception, and 20-gauge technology remained the gold standard for another 30 years thereafter.6

There were other clinicians investigating vitreo-retinal surgery techniques at this time as well. In 1971 in the United States, Gholam Peyman developed an electrically driven guillotine cutter system similar in concept to that of O’Malley and Heintz.7 By 1973, Rudolf Klöti in Zurich had devised a three-
port vitrectomy system of his own that also used an electrically driven cutter. Substantial progress in vitreoretinal surgery technology continued throughout the mid-to-late 1970s. In 1973, Mcewen developed the first air pump for fluid-air exchange, replacing manually operated syringes and providing for a controllable IOP. After acquiring Berkeley Engineering, CooperVision replaced the Ocutome 800 with the Ocutome 8000 (CooperVision, Pleasanton, CA). Engineered by Wang and Charles, this platform improved on the foot pedal control of its predecessor with the introduction of linear aspiration control. Compared to the on/off, single-aspiration setting of the 800, the linear control of the 8000 series eliminated the abrupt onset of suction. This advance reduced the risk of iatrogenic breaks during surgery, allowing the minimal necessary suction force to be applied at the surgeon’s discretion.

MidLabs systems and the engineering tandem of Wang and Charles developed the MVS system (MidLabs, San Leandro, CA) and disposable pneumatic cutters, which represented a major advance in cutter quality and efficiency over reusable cutter/aspiration units.

Steve Charles continued as one of the principal pioneers of vitrectomy platforms for the next three decades. In the mid 1980’s he began InnoVision (Memphis, TN) and developed the Ocular Connection Machine (OCM). The dual actuation, limited rotary InnoVit cutter (Alcon, Fort Worth, TX) of the OCM was capable of 1,500 cuts per minute. There was no spring return to slow down the cutter, and the limited rotary movement prevented vitreous winding. More importantly, it integrated multiple systems (vitrectomy, fragmentation, fluid-air exchange, etc.) into one interface with a single housing, foot pedal, and power supply. It had an array of other features that were integrated into and improved upon in its successor, the Accurus system by Charles and Alcon Laboratories (Fort Worth, TX). These were the first platforms with a graphical

Figure 2. Robert Machemer, MD, with the VISC vitrectomy device.
user interface, linear diathermy, an articulated arm, an integrated xenon illuminator, fragmenter, autogas mixing, auto fluid-air exchange, powered scissors, and powered silicone oil injector with foot pedal control, eliminating the need for manual injection. The OCM was the first system with vented forced gas infusion, replacing gravity-dependent infusion and enabling the surgeon to rapidly raise the IOP when necessary for tamponade of intraocular bleeding. The OCM and later the Accurus represented the gold standard of vitrectomy units well into the early 2000s.

**VITRECTOMY TODAY**

The current generation of vitrectomy platforms are all relatively new and feature improvements in the user interface, fluidics, and instrument compatibility. The main platforms include the Constellation (Alcon, Fort Worth, TX), the Stellaris PC (Bausch + Lomb, Rochester, NY), and the EVA (DORC, Zuidland, The Netherlands). Despite their common foundation based on the three-port, foot controlled system of O’Malley and Heintz, they are remarkable for their different engineering approaches to vitreous removal.

**The Constellation Vision System**

The Constellation Vision system is the latest iteration of the Steve Charles legacy of machines, which began with the Ocutome in the 1970s. The Constellation more than tripled the cut rate of the Accurus to 7,500 cuts per minute with the Ultravit...
handpiece (Alcon, Fort Worth, TX). Like its predecessor the Innovit, it is a dual pneumatic cutter, sparing spring return. Unlike the Innovit, it utilizes axial cutting as opposed to a limited rotary cutter motion. The system features variable duty cycle control, operated by either the surgical tech or the surgeon via the foot pedal. The duty cycle control allows for a biased open approach for more efficient aspiration in core vitrectomy mode. Conversely, it allows a biased closed approach when addressing peripheral or mobile retina in shave mode.

The fluidic and IOP control of the Constellation system is a major advance from the vented forced gas infusion of the Accurus. Linear optical sensors monitor the fluid level in the aspiration chamber, signaling a Venturi pump that constantly empties the chamber and maintains a consistent fluid level, allowing for a real-time measurement of the flow rate. When priming prior to surgery, the Constellation uses a noninvasive flow sensor to measure the resistance across the tubing and infusion cannula and adjust for the secondary drop in IOP over the course of surgery. The system can compensate for a fluctuation in IOP and prevent “fluid surge” after momentary occlusion of the cutter tip by routing infusion fluid through the aspiration cassette, enabling continuous proportional reflux. The infusion machinery consists of two small cassettes, one of which is filling while the other empties via pressurized infusion controlled by a proportional valve and dual pressure sensors. Linear optical sensors monitor the fluid level in the aspiration chamber, signaling a peristaltic pump that constantly empties the chamber and maintains a consistent fluid level, allowing for a real-time measurement and control of the flow rate. This approach allows the IOP to be constantly controlled within 1 mm Hg to 2 mm Hg throughout the case.

In addition, the sterile, graphical interface of its predecessor was improved while maintaining the integration of multiple functionalities in one system. With its ability to change cut rate, the IOP, and switch to fluid-air exchange or vitrectomy modes (core versus shave), the wireless foot pedal allows for more surgeon autonomy in the operating room. Additional innovations in the Constellation include: an auto-infusion valve that replaces the manually operated stop cock system for switching between fluid and air for fluid-air exchange, a radio frequency identification system that automatically configures and primes chosen handpiece tools and supplies inventory information, as well as power backup for all electronics in the case of power failure in the operative suite.10,11

The Stellaris PC

The Stellaris PC shares many similarities with its competitor, the Constellation. It features an intuitive graphical interface that integrates the full array of vitrectomy tools and applications into a single system. As with the Constellation, these functions are fully programmable into the wireless foot pedal. The Stellaris uses a Venturi pump system with available shave and core vitrectomy modes. The highest achievable cut rate on the Stellaris is currently 5,000 cuts per minute. The system automatically adjusts the duty cycle as the surgeon increases the cut rate with linear control of the foot pedal, keeping it above 50% at all times to maintain efficient aspiration. In addition to shave and
core vitrectomy modes, the cutter is capable of a single cut mode that is useful in dissecting retinal membranes.\textsuperscript{11}

The Stellaris currently has a number of innovations that distinguish it from its peers. The system provides two light sources via traditional xenon gas and mercury vapor. The mercury vapor source is ideal for longer, complex cases and decreases the risk of phototoxicity from light exposure.\textsuperscript{12} The illumination also has three filters available for facilitating the view during specific parts of a case. There is a green filter for membrane peeling, a yellow filter for vitrectomy, and an amber filter for air-fluid exchange.\textsuperscript{13}

The most unique aspect of the Stellaris system has yet to become available in clinical practice, though it has the potential to become the next great leap in vitrectomy technology. A soon-to-be-released next-generation Stellaris system, the Stellaris Elite (Bausch + Lomb, Rochester, NY), features a new vitrectomy handpiece called the Vi-tesse (Figure 4). It replaces the conventional dual-needle guillotine cutter design with a single needle designed with a small, continuously open port. The needle is mounted on a piezoelectric transducer element that vibrates harmonically, creating a cutting rate of approximately 1.7 million cuts per minute. In a process termed “hypersonic liquefaction,” vitreous fibrils are fragmented prior to being aspirated into the vitrectomy port, theoretically eliminating the potential for vitreous traction and iatrogenic breaks.\textsuperscript{13} If experimental success translates to clinical experience, hypersonic liquefaction technology has the chance to greatly increase the safety and efficiency of vitrectomy, and perhaps create a platform that will revolutionize vitreoretinal surgery.

The EVA

Granted U.S. Food and Drug Administration approval in March of 2015, the DORC EVA brings a number of innovations in cutting and fluidics to the vitrectomy system market. The EVA’s Twin Duty Cycle technology, available in 20-, 23-, 25-, and 27-gauge instrumentation, offers the highest currently available cut rate at 16,000 cuts per minute. The system achieves this high rate via a “back and forth approach,” whereby the inner axial tube of the probe cuts vitreous strands in both the distal and proximal directions. The EVA achieves this high cut rate while maintaining a 92% open duty cycle, maintaining efficiency of both aspiration and cutting. These features allow for both a rapid core vitrectomy, reportedly as fast as 3 to 4 minutes with 27-gauge instrumentation, while also optimizing safety when shaving peripherally and over mobile retina.\textsuperscript{14}

The second major innovation in the EVA system is the VacuFlo VTi (DORC, Zuidland, The Netherlands), a new invention that enables the surgeon to alternate between both peristaltic (flow) and Venturi (vacuum) aspiration control. Using a sophisticated system of pistons that combine to work equivalent to a syringe, the system aspirates and eliminates intraocular contents simultaneously, allowing more minute control of aspiration settings, down to 0.1 cc per minute. Rival platforms currently enable control of settings to within 1.0 cc per minute.\textsuperscript{15}

The proprietary Automatic Infusion Control technology on the EVA constantly monitors the infusion and aspiration rates during surgery, elevating the pressure settings (and thus flow) as the aspiration rate increases in order to maintain a constant IOP. In this way, the aspiration is prevented from outstripping the infusion and prevents collapse of the eye.\textsuperscript{15}

FUTURE DIRECTIONS

Vitrectomy surgery will continue to evolve with a greater emphasis on efficiency, safety, and instrument compatibility. Most vitreoretinal surgeons currently in the middle to later part of their careers employ tools and techniques that were not available when they trained, and that is sure to be the case for those who recently completed or are in training now. There are a number of novel trends and innovations on the horizon that today’s young surgeons will incorporate into their practice after training. The aforementioned Bausch + Lomb hypersonic liquefaction handpiece is due to be released in the near future, and three-dimensional, heads-up display intraoperative viewing systems have been trialed across the United States with positive reviews.\textsuperscript{16} The increasing availability of compact, high-performing, cost-efficient vitrectomy platforms has the potential to make office-based surgery a viable option for healthy patients with minimal anesthesia needs.\textsuperscript{17}

The increasing availability of compact, high-performing, cost-efficient vitrectomy platforms has the potential to make office-based surgery a viable option for healthy patients with minimal anesthesia needs. The VersaVIT 2.0 (Bausch + Lomb, Rochester, NY) represents one such platform, capable of 6,000 cuts per minute as well as 23-, 25-, and 27-gauge valved trocar access. The 25-pound system is easily portable via a rolling carrier case and costs half the price of a traditional vitrectomy
 platform. The accompanying surgical packs are 20% of the expense of its established, operating-room-based competitors. Systems such as these are ideal for low-complexity cases of 60 minutes or less, including nonclearing vitreous hemorrhages in diabetic retinopathy and epiretinal membrane peels. Saving a trip to the operating room with the VersaVIT 2.0 may become more appealing as the future brings increased patient burden, hospital costs, and declining reimbursement.

Finally, robotically controlled vitrectomy technology has been tested in animal models and is already capable of performing core vitrectomy and induction of a posterior vitreous detachment. If the past and present are any indication, the only certainty for the future of vitreo-retinal surgery is the certainty of change.

**REFERENCES**