Review

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Vitrectomy Fluidics

David H.W. Steel[a] Steve Charles[b, c]

[a]Sunderland Eye Infirmary, Sunderland, UK; [b]Charles Retina Institute and [c]Department of Ophthalmology, University of Tennessee College of Medicine, Memphis, Tenn., USA

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Vitrectomy · Fluidics · Aspiration · Infusion · Cut rate · Duty cycle

Abstract

The goal of all vitreous surgery is to perform the desired intraoperative intervention with minimum collateral damage in the most efficient way possible. An understanding of the principles of fluidics is of importance to all vitreoretinal surgeons to achieve these aims. Advances in technology mean that surgeons are being given increasing choice in the settings they are able to select for surgery. Manufacturers are marketing systems with aspiration driven by peristaltic, Venturi and hybrid pumps. Increasingly fast cut rates are offered with optimised, and in some cases surgeon-controlled, duty cycles. Function-specific cutters are becoming available and narrow-gauge instrumentation is evolving to meet surgeon demands with higher achievable flow rates. In parallel with the developments in outflow technology, infusion systems are advancing with lowering flow resistance and intraocular pressure control to improve fluidic stability during surgery. This review discusses the important aspects of fluidic technology so that surgeons can select the optimum machine parameters to carry out safe and effective surgery.

Introduction

Although historically there has been less discussion of the fluidics occurring during vitrectomy surgery than of those during phacoemulsification, the varying demands encountered during vitrectomy actually require a greater understanding of fluidics than is required in other types of intraocular surgery. The consequences of uncontrolled vitreoretinal traction and inflow/outflow mismatch can be very severe. Furthermore vitrectomy can occur in surgical environments which range from vitreous to aqueous and air to oil, and can include dense membranes and pieces of dislocated nuclei. Indeed the medium of vitrectomy is constantly changing from moment to moment, placing great demands on systems and surgeons to react appropriately. Perhaps the most important concept of vitrectomy fluidics within a closed system is the concept of fluidic stability [1]. Inflow must equal outflow to maintain stability, and these two processes will be discussed separately.

Inflow

Infusion Systems

During vitrectomy surgery an irrigating solution is infused into the eye to maintain globe shape and a physiological intraocular pressure (IOP). Low pressure can

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D. Steel
Sunderland Eye Infirmary
Queen Alexandra Road
Sunderland SR2 9HP (UK)
E-Mail david.steel@chsft.nhs.uk

Table 1. Pressure conversion table

mm Hg	cm H_2O	Inches of H_2O
10	13.6	5.5
20	27.2	11.1
30	40.8	16.6
40	54.4	22.2
50	68	27.2
60	81.6	33.3
70	95.2	38.3
80	108.8	44.4

Governs flow of a Newtonian fluid through a pipe

Volume flow rate (*'Q'* in ml/min) = $\Delta V/\Delta T$, i.e. change in volume/time
= $\Delta P \pi r^4/8\eta l$

Where:
ΔP = change in pressure along the pipe
r = radius of pipe
l = length of pipe
η = viscosity of fluid ←

Viscosity
Air = 0.018
Water at 37°C = ~1
Vitreous = ~2–4
Oil = 1,000–5,700

Fig. 1. Poiseuille's law.

cause choroidal haemorrhage and globe collapse with the risk of inadvertent retinal damage. Overly high pressure, although less of a worry during the short times associated with modern vitrectomy, could potentially exacerbate glaucomatous optic atrophy, retinal ischaemia or corneal oedema in predisposed eyes.

Infusion fluid can be infused either by a gravity-fed system or a pressurised system achieved either by mechanical compression of an infusion bag or air pressurisation of a rigid infusion bottle. In gravity-fed systems, infusion pressure at the end of the infusion line where it enters the eye is equivalent to the bottle height above the eye. This is measured in centimetres of water and can be approximated to millimetres of mercury by the conversion factor of 3:2 (i.e. 60 cm H_2O is approximately equal to 40 mm Hg) (table 1).

In a pressurised system the infusion pressure would equal the pressurisation of the infusion at the point where this occurs plus/minus the height above or below the infusion cannula. For example in the Alcon Accurus vented gas-forced infusion system the infusion bottle itself is pressurised, and therefore ideally the bottle is placed at about eye level to avoid having to correct for any height difference above or below the eye. In the Alcon Constellation System the infusion solution is pressurised within the cassette, and therefore this should be at approximate eye level. Both systems allow for software compensation for height offsets. Proposed advantages of pressurised systems relate to the speed of response – rapid increases and decreases in IOP can be achieved as required.

Pressure Drop and Setting Infusion Height or Pressure

In any infusion system when fluid flows into the eye from the infusion tubing, there is a pressure drop across the cannula, and to a lesser extent the tubing, passing into the eye related to the diameter change. In 20-gauge infusions this is typically in the range of 1–2 mm Hg per 1 ml/min flow. With achievable outflow rates from the eye during 20-gauge surgery ranging from 0 to 20 ml/min then an infusion height of approximately 30 mm Hg is adequate for most cases to allow for the approximately 20-mm Hg drop (20 × 1). However with the first narrow-gauge systems that became available the pressure drop across the infusion cannula was higher, meaning that the infusion pressure had to be higher to allow for this pressure drop. Some of the earlier 25-gauge designs for example had a 5 mm Hg per 1 ml/min pressure drop, meaning that infusion pressures of 40–50 mm Hg were needed to compensate for this (less than expected as achievable outflow rates are less with narrower gauges). New designs are minimising the infusion pressure drop by maximising the internal diameters of the infusion cannula and minimising the length of the narrowed segment as it enters the eye (as per Poiseuille's law, which demonstrates that flow is proportional to the fourth power of radius of the transmitting tube and inversely proportional to the length) (fig. 1).

At low flows there is not a significant problem with infusion pressure drop. However, it can be a problem at high flows. The approximate values can be worked out, e.g. to compensate for an outflow of 8 ml/min and a system with an infusion cannula with a 2 mm Hg per 1 ml/min pressure drop, the infusion pressure needs to be raised by 16 mm Hg, so in a typical situation this would be 20 mm Hg + 16 mm Hg = 36 mm Hg, which is approximately equal to 50 cm H_2O. Some surgeons actually titrate their infusion pressure in individual cases by aspirating at high flow in the mid vitreous and adjusting the IOP so that the eye does not collapse. However, most surgeons simply increase the bottle height by a small amount according to the gauge of surgery and vitrectomy system they are using, e.g. 25–30 mm Hg for 20 gauge, 30–35 mm Hg for 23 gauge and approximately 40–50 mm Hg for 25 gauge.

IOP Control/Compensation

Some systems, e.g. the Alcon Constellation, use IOP compensation where the infusion pressure is automatically increased according to the amount of fluid flowing into – and by assumption out of – the eye. In an infusion cannula with a known pressure drop, if the infusion flow is measured, then the infusion pressure can be automatically adjusted to maintain a set IOP. The infusion flow needs to be measured in as near to real time as possible to allow rapid infusion pressure changes to be instituted.

There is an obvious problem with this when the instruments or plugs are removed (assuming a non-valved port system is used) in that outflow will increase as fluid flows freely from the ports (again dictated by the pressure drop across the ports themselves). The IOP control system will automatically increase the inflow, resulting in a rapidly evolving 'fountain' effect from the ports. To avoid this, algorithms are built into the system to limit inflow to a set level when no active aspiration is occurring ('inflow flow limitation'). Valved ports avoid this problem.

Inflow/Outflow Mismatch

No matter how well designed an infusion cannula is, infusion flow will still be limited by the gauge of the system used. Twenty-five-gauge maximum inflow will be less than 20-gauge maximum inflow [2]. This can be partially compensated for by increasing infusion pressures, but infusion inflow/outflow mismatch is far more likely to happen in a case where the infusion gauge is different from the outflow gauge, e.g. if a 25-gauge vitrectomy for a dropped nucleus is started and one of the sclerotomies is enlarged for a 20-gauge fragmenter, the risk of infusion/outflow mismatch is high and the infusion pressure needs to be set to high levels (60 mm Hg or more) to compensate for the large outflow during high-vacuum high-flow 20-gauge fragmentation [1].

Air Infusion

Air Infusion Set-Up

Air is infused into the eye via the infusion line using a separate air line attached to the line just outside the eye by means of a three-way tap or one-way valve. Being significantly less dense and having a much lower viscosity (viscosity of 0.018 mPa•s compared with 1 mPa•s for water at 20°C and 2–4 mPa•s for vitreous), air pressure is practically not altered by height above or below the eye of the source. Air infusion pressure is set to the desired level on the machine console typically at pressures of 20–30 mm Hg. This pressure is achieved either by a pump in the machine or a pressure reduction valve attached to the air source.

Infusion/Outflow Mismatch

In a completely air-filled eye, infusion/outflow mismatch is usually not a major clinical problem with standard aspirating vacuums, although eye collapse can occur if both sclerostomies are left unplugged. Infusion/outflow mismatch, however, can be a problem when moving from air to fluid, i.e. an air/fluid exchange as opposed to a fluid/air exchange. Air outflow via the vitrectomy probe can be exceptionally high using standard vacuum aspirating pressures regardless of gauge, whilst fluid inflow is low by comparison; care must be taken to limit outflow in these situations to match maximum fluid inflow rates. The effect can be particularly marked with the high preset aspirating vacuums during narrow-gauge vitrectomy.

Air Blocks

Air blocks can also be a problem in infusion lines. Air is compressible and has a high surface tension, meaning that a small amount of air can significantly 'block' and impede liquid flow in an infusion line; care thus needs to be taken to avoid inadvertently allowing air access into the infusion line, e.g. by careful priming at the start and avoiding incorrect three-way tap turns. If air block occurs with reduced inflow, then raising the infusion pressure temporarily will usually overcome the block.

Outflow

Flow out of the eye can occur by a variety of mechanisms and needs to be performed in several different media. Removal of vitreous gel by active aspiration, i.e. vitrectomy, is the main design feature to be considered. Although flow to achieve this is created by pumps, several other factors related to vitrectomy probes affect flow and also the extent of retinal traction created by vitreous removal. At times dense membranes need to be removed during surgery. Non-cutting aspiration of fluid and air is also required, and passive outflow either intentionally through 'flute' needles or inadvertently through sclerotomies need to be considered. These will now be discussed separately.

Active Aspiration and Pumps

The primary purpose of a vitreous cutter is to remove vitreous gel from the eye with minimal retinal traction.

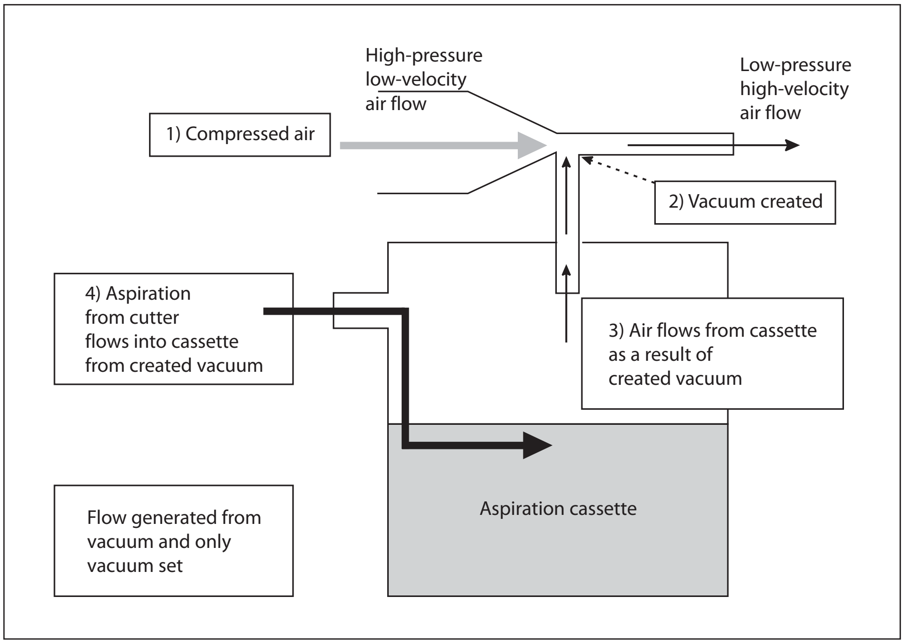

Fig. 2. Venturi pump mechanism.

However, there are many stages to even a routine vitrectomy procedure, and safe and efficient surgery demands variable but carefully controlled levels of aspiration to control outflow through the vitrectomy probe. At times during surgery, a moderately high flow is desirable, and at other times a low flow is vital. To add to the complexity, vitreous itself is a heterogeneous substance which exhibits viscoelastic properties: it is elastic and deformable and this affects the resultant tractional forces applied to the retina during vitrectomy. As such it is also hard to model, but clinical experience confirmed by careful experimental studies shows that retinal traction increases with proximity of the cutter to the retina during vitrectomy as well as with aspiration flow rate and reduces with increasing cut rate [3]. During core vitrectomy, in the centre of the vitreous cavity with an attached retina, higher aspiration flows are useful, but during vitreous shaving with a mobile detached retina, lower flows are needed. High cut rates are vital in both situations to reduce pulsatile and continuous retinal traction.

Vitrectomy systems have conventionally used Venturi pumps to achieve aspiration. In these systems flow is induced by vacuum changes within the cassette. Flow hence occurs as a result of vacuum, and in homogeneous low-viscosity Newtonian substances, flow is directly proportional to the vacuum applied (fig. 2).

There are a number of other important factors, however, which affect flow through a vitrectomy probe:

(1) Aspiration gauge size – narrow-gauge vitrectomy probes have higher resistance to flow than wider-gauge probes, with resultant lower flow rates for a set vacuum; specifically it is the internal diameter of any set gauge that is important as opposed to the external diameter, which is set by the gauge size selected, and manufacturers have aimed to maximise inner lumen diameters. There is a limit to this, obviously, as the thinner the walls, the lower the stiffness of the instrument [4, 5].

(2) Port size – large ports allow higher flow; e.g. vitreous shavers have been designed with small port size to limit flow and reduce the risk of inadvertent retinal hole creation, whilst newer 25-gauge systems have increased port size to allow higher flows for core vitrectomy. Ultimately, certainly in vitreous, the effect of port size on flow reaches a plateau as it approaches the inner lumen area, and increasing single port size beyond this does not increase flow [6].

(3) Cut rate – traditionally it has been observed that with spring return pneumatic cutters, the higher the cut rate, the lower the flow. This, however, is mainly related to changes in duty cycle with increasing cut rate and the finite speed of cutter opening and closing. It should also be noted that vitreous cannot be aspirated without cutting through vitrectomy probes and standard aspiration vacuums [5].

(4) Cutter duty cycle, i.e. the amount of time the port stays open for each cut cycle – this has a huge bearing on the flow rates that are experienced at varying cut speeds and will be discussed further below.

These four factors all contribute to what has been termed 'port-based flow limiting' [1].

Duty Cycle Control

In electric cutters, the duty cycle is set at 50%, i.e. the cutter is 50% closed and 50% open for each cut cycle. The duty cycle is fixed and flow remains near constant up to the maximum set cut speed of the cutter. This is not, however, the case with pneumatically driven cutters. Pneumatic cutter design has gradually evolved. Pneumatic cutters with spring return systems (i.e. air drives the cutter guillotine down and a spring drives the cutter guillotine back) are limited in their ability to control duty cycle. As cut speed increases, the duty cycle reduces to some degree, i.e. at higher cut speeds the cutter is mainly closed, meaning that flow rates become disproportionally lower as cut speed increases [5] (fig. 3).

Dual pneumatic cutters have partially overcome this problem (e.g. the Alcon InnoVit cutter with a horizontal guillotine and the Alcon Ultravit with a vertical guillotine). They use separate air lines to both close and open the cutter, and in the case of the Alcon Ultravit to allow duty cycle to be controlled independently of cut rate. A low or biased closed duty cycle will mean lower flow and a high or biased open duty cycle will mean higher flow. At high cut rates, with a persistently high duty cycle, flow can be maintained [4, 8–10]. Similarly with low cut rates, a low duty cycle can be used to limit flow. Duty cycle has an interesting effect on flow at low cut rates: low duty cycles mean that the port is only open for very limited periods, resulting in low flows. High duty cycles at low cut rates result in high flow rates as the port stays open most of the time. Duty cycle control allows flow and vacuum to be separated to some extent even in Venturi pump systems. At low cut rates with a low duty cycle, it is possible to have a low flow, but with a high vacuum setting.

Effect of Cut Rate and Duty Cycle on Flow Rates

If guillotine speed was infinite and duty cycle control could be maintained at any set cycle up to any speed, then flow rate would be constant as cut speed increased. However guillotine speed is finite, and hence as cut speed increases, there is a slight change in duty cycle even with dual pneumatic cutters – on an open duty cycle this gradually reduces as cut rate increases, and on a closed duty cycle, duty cycle increases slightly as cut rate increases. As cut rates rise, the curves slope towards each other so that at high speeds, duty cycle control has less effect (fig. 4).

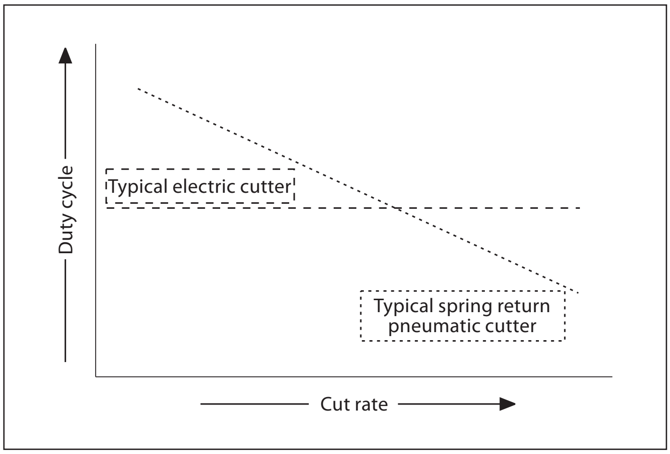

Fig. 3. Graph of duty cycle against cut rate for effect on flow, illustrating changes with increasing cut speed for electric and spring return pneumatic cutters. Flow rate is closely related to duty cycle in saline.

This convergence of slopes also means that flow rates in saline solutions reduce as cut rate increases on an open duty cycle (and increase on a closed duty cycle). However an important observation is that high cut rate effectively reduces viscosity in heterogeneous non-Newtonian fluids such a vitreous [5]. Hence the effect of reduced duty cycle (with a biased open duty cycle) with high cut rate is less than might be hypothesised, and the flow rate can be largely maintained in vitreous with increasing cut rate as viscosity reduces. Similarly flow rate in vitreous increases as cut rate increases with a 50:50 duty cycle, and it increases more than might otherwise have been achieved with a biased closed duty cycle [7] (fig. 5).

'Bite' Size and Cut Rate

'Followability' is a term often used during phacoemulsification surgery. The surgeon aims to attract tissue to the phaco instrument. However, during vitrectomy, 'followability' is not desirable and ideally no force would be generated in the vitreous itself, i.e. the surgeon would aim to constantly advance and cut into the vitreous rather than attempting to generate flow of vitreous into the port. At a fixed flow rate, the higher the cut rate, the smaller the bite size, i.e. the amount of vitreous aspirated into the cutter for any one cut. Indeed at very high cut rates, vitrectomy is near to or 'quasi' continuous and the pulsatile flow generated by cutting is very low. Flow is smoothed and surge (i.e. variable flow) in heterogeneous vitreous is reduced.

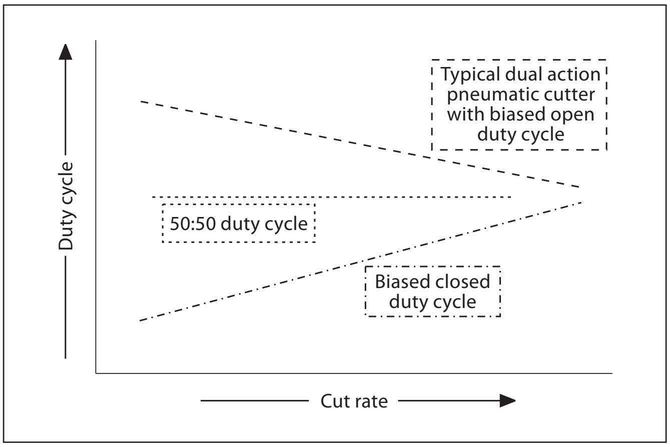

Fig. 4. Graph of duty cycle against cut rate for effect on flow, illustrating changes with increasing cut speed for dual pneumatic cutters. Flow rate is closely related to duty cycle in saline.

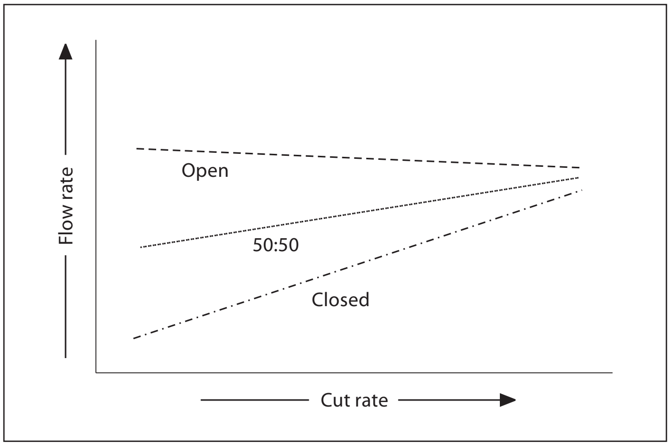

Fig. 5. Graph of flow rate in vitreous against cut rate, illustrating changes with increasing cut speed for dual pneumatic cutters.

The smaller the bite size, the lower the traction on the vitreous. Traction on vitreous is theoretically transmitted directly to the retina, and so smaller bite size reduces vitreous traction and may lead to less tractional complications. Decreasing bite size still further by reducing duty cycle can enhance this effect. Small bite size with fast cut rate reduces the speed of movement of vitreous gel into the cutter and results in less elastic recoil [7]. An interesting analogy can be drawn with sound waves. Low-frequency (and high-amplitude) sound waves can travel large distances with significant effects – conversely, high-frequency low-amplitude waves dissipate quickly over short distances and exert only limited 'far-field' effects [1].

Opening and Closing Phases of Guillotine

The transition phases between the open and closed phases of the duty cycle are also important, affecting not only duty cycle efficiency, but also the fluidics around the time of port opening and closing. High-speed imaging of cutter action has shown that during each cycle of the cutter there is a vortex created at the orifice which increases as flow rate increases. The pressure wave created by guillotine opening and closure creates fluidic disturbance which increases as cut speed increases, but paradoxically a slower opening speed reduces this effect and leads to greater flow for a set vacuum and cut speed. The closing phase appears to have less effect on flow, but faster closing speeds increase the size of the transorificial pressure variation, and hence pulsatile flow and the potential for retinal tractional damage. Hence if cut rates can be maintained, both slower opening and closing phases are possibly desirable [8, 11].

Peristaltic Pumps and Aspiration Flow Control

Because vitreous is heterogeneous, with a Venturi pump and a fixed vacuum, flow will theoretically vary as viscosity varies. Traditionally vitrectomy machines have used Venturi pumps. Venturi pumps were chosen because in the early stages of peristaltic pump design these peristaltic pumps were characterised by slower rise times than Venturi pumps because of pump inertia, and inherently pulsatile flow. However, the newer peristaltic pumps have reduced these deficiencies and peristaltic pumps are now becoming increasingly common on vitrectomy machines (fig. 6). Several of the newer machines offer both pump systems and the surgeon is given a choice, e.g. the Oertli OS3, Alcon Constellation, Dorc Associate and Geuder Megatron S4, whilst other machines are produced with only a peristaltic pump, e.g. the Oertli Faros.

Peristaltic pumps allow the surgeon to set upper limit flow rates with proportional control. Flow rates can be set high for core vitrectomy with an attached retina and conversely set low for vitreous shaving with mobile detached retinae. Clearly the same effect can be aimed for with Venturi pumps by setting high maximum vacuum for core vitrectomy and low maximum vacuum for vitreous shaving; however, it is vacuum and not flow that is set, and flow will vary according to viscosity – with a peristaltic pump, flow is controlled and vacuum varies to maintain flow with variable-viscosity substances.

It is interesting to consider what theoretically might happen to flow rate when vitreous cutters attached to the two pumps meet substances with higher viscosity, such as when a cutter moves from an aqueous medium into a

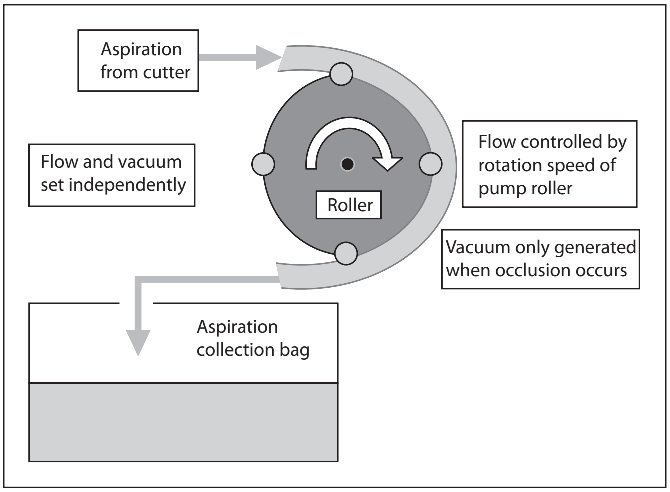

Fig. 6. Peristaltic pump mechanism.

vitreous frill during peripheral vitreous trimming. With a peristaltic pump, flow will decrease as the cutter moves into higher-viscosity vitreous but vacuum will then increase (after a feedback delay time) to maintain flow. With a Venturi pump, flow will decrease for a set vacuum as the cutter encounters higher-viscosity material. Potentially this may actually paradoxically increase the safety of Venturi pumps whilst cutting near the vitreous base in mobile retinae. However, this imagined scenario is ignoring the effects of port-based flow-limiting mechanisms. With a high cut rate, viscosity is effectively reduced and flow smoothed, and different pump mechanisms may have little effect on flow fluctuation with high-speed cutting.

There is a debate as to whether a peristaltic pump with low flow settings gives more control when cutting near the vitreous base with a mobile detached retina. The maximum vacuum settings in this situation have to be very carefully assessed. If the vacuum setting is set to a low level, this will enhance the safety of peristaltic pumps when working in the vitreous base area, especially when low cut rates are selected. Indeed some surgeons use very low cut rates with low flow and vacuum when working in the vitreous base area with a mobile detached retina. They are essentially aspirating then cutting vitreous with visual feedback in an operator-controlled manner.

The discussion essentially boils down to: 'Where is the best place to limit flow during vitrectomy'? At the cutter tip (with 'port-based flow limiting') or at the cassette with either a peristaltic pump or a Venturi pump and flow control. Port-based flow limiting is obviously nearer the point of action – feedback is instantaneous. Conversely with any pump-based flow limitation there will be feedback delays and residual vacuum related to the flow controller being 7 ft away and connected by elastomeric tubing with capacitance and inductive components between the machine cassette and the cutter port, i.e. fluidic response time. Peristaltic pump feedback times are longer than those of Venturi systems by their very nature. Furthermore this delay is further enhanced if using surgeon visual feedback with low cut rate and low flow, i.e. a 400-ms delay between visualising an impending problem and stopping flow by removing the foot from a pedal. Port-based flow control can perhaps be viewed as being in real time as opposed to reactive. Of course a mixture of the two systems can be used, i.e. high cut and flow control; however, the additional surgical benefit of flow control over vacuum-controlled flow is difficult to measure.

It is also possible to cap flow at set levels using Venturi pumps. The Alcon Constellation device can monitor aspiration flow in the cassette generated using a Venturi pump. Flow can be capped and set not to exceed a certain level by using real-time operating systems with rapid response times.

Membrane Dissection

Cutter design is evolving with an incremental movement of the cutter port towards the tip of the vitrectomy probe to allow improved near-retinal surface peeling/cutting with short tip-to-port distances. The cutter can be used to delaminate diabetic membrane using either 'foldback' delamination where the cutter is placed on the anterior surface of the membrane (if flexible) just behind the leading edge, allowing the membrane to fold back into the cutter port sequentially. Alternatively for more rigid membranes a technique of conformal delamination can be used where the membrane is 'fed' into the port in a controlled way by adjusting the angle of approach to the membrane [1]. During this procedure it is potentially useful to be able to control flow and vacuum separately. Again this has to be done in a predictive way and is perhaps more optimally done by using port-based flow limitation rather than by a console-based procedure with a peristaltic pump. High cut rates with consequential low flow can be used, but machines with duty cycle control allow an alternative approach: lower cut rates can be used with a closed duty cycle, achieving a low flow but high vacuum setting to allow conformational removal of membranes in a controlled way. The closed duty cycle and limited flow also has the effect of limiting surge when occlusion break occurs.

Occasionally very dense membranes are encountered, and here the situation is similar to that which occurs during cutter removal of lens remnants after a dropped nucleus. In these situations high vacuum settings with even an open duty cycle can fail to achieve aspiration of tissue with a high cut rate. Lowering the cut rate in these situations can help, but postocclusion surge will be greater and infusion pressure will need to be increased, or aspiration flow limiting used, to guard against globe collapse.

Aspiration with No Cutting

In many instances during vitrectomy surgery, it is necessary to aspirate without cutting. For example during posterior vitreous detachment induction, aspiration alone is used to move vitreous into the cutter port. Once occlusion of the port is achieved, vacuum is built up and the vitrectomy probe is moved away anteriorly from the retina to achieve posterior hyaloid face separation. Using a Venturi pump without flow limitation means that if an occlusion break occurs with high vacuum, then flow in the surrounding low-viscosity infusion solution is very high, possibly resulting in globe collapse at a time when the cutter is near the retina. One possible advantage of peristaltic pumps in this situation is that flow can be limited so that if occlusion break occurs, the flow level can be capped to a level where globe collapse does not occur [12]. Again flow limitation can be used with a Venturi pump in the same way.

The same situation can occur with soft lens matter or epinucleus aspiration during dropped nucleus surgery with a fragmenter. Postocclusion surge technology, as used in phacoemulsification surgery, is increasingly being used in probe and vitrectomy machine design for this scenario.

Aspiration in Air versus Fluid

Aspiration with a Venturi pump in an air-filled eye can result in very high flow rates with standard vacuum settings. Aspiration flow cannot be controlled or monitored with Venturi pumps using air, and the only way flow can be limited in this situation is with a peristaltic pump. Using a Venturi pump, low vacuum levels should be set for these procedures. This is particularly important to be aware of when using narrow-gauge systems with high preset vacuum levels.

'Flute Needles'

Flute needles with passive egress of fluid or air are commonly used during vitrectomy. Essentially the flute needle consists of a single-lumen cannula. The distal cannula opening is placed on the side of the instrument so that it can be closed by a finger. With the distal opening free, fluid will flow from the eye through the cannula driven by the difference in pressure between eye and atmosphere. With the distal opening closed, no flow occurs.

A collapsible closed lumen tube over the distal opening allows reflux to be generated, i.e. a 'backflush'. The drawback of the technique is that the flow rate is not proportional and is relatively uncontrolled. For this reason active proportional extrusion is often used in its place. A backflush system can also be used with this in the same way. Alternatively active proportional reflux can be generated with some systems by creating a positive pressure in the aspiration cassette. Flow rates with passive egress are significantly limited in narrow-gauge systems, especially 25-gauge systems. Flow rate can be partly increased by temporarily increasing IOP.

Sclerotomy Port Leak

The two superior sclerotomies in any form will leak fluid or air when instruments are removed. The degree of leak will depend on the design and size of the sclerostomies. Sclerotomies should be plugged when not in use. Alternatively valved sclerostomies are increasingly being used; this can either be achieved using scleral tunnels or valved cannulated sclerotomies, adding greatly to fluidic stability during instrument exchange.

Conclusion

The fluidic demands of vitrectomy surgery are high. Vitreous must be removed efficiently but with as little retinal traction as possible to minimise collateral retinal damage. Fluidic stability is paramount to avoid intraocular complications, and inflow must be adjusted to meet a constantly changing outflow. Instruments must be as lowly invasive as possible, but capable of meeting the demands of surgery. Surgical systems are incrementally developing to meet these demands.

Disclosure Statement

D.H.W.S. has received travel expenses for attending educational events and a conference from Alcon UK. S.C. is a consultant for Alcon Laboratories and has royalty interests in the Alcon Constellation system.

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