

Article

Porcine Vitreous Flow Behavior During High-Speed Vitrectomy up to 7500 Cuts per Minute

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Purpose: To evaluate the impact of high-speed cut rates (up to 7500 cuts per minute [cpm]) on vitreous flow through various gauge probes.

Methods: An open-sky vitrectomy technique was performed on porcine eyes using the CONSTELLATION Vision System with three different gauges of dual-pneumatic probes (27⁺, 25⁺, and 23-gauge UltraVit probes; $n = 5$ for each gauge). Flow rate was calculated by LabVIEW software that converted real-time mass measurements from an electronic scale into flow rate.

Results: Average vitreous flow rate increased slightly with increased cut rate in all probes with 50/50 duty cycle; more dramatic flow rate increases were observed for all probes with biased closed duty cycle. Under both conditions, maximum flow rate was observed at 7500 cpm for all gauges. Under the biased open duty cycle, average flow rate was inversely associated with cut rate.

Conclusion: High-speed cut rate improved efficiency of vitreous aspiration.

Translational Relevance: Increased vitreous aspiration of dual-pneumatic, high-speed vitrectomy probes may improve the efficiency of current vitrectomy techniques, allowing surgeons to take advantage of the benefits of high cut rates without sacrificing flow rate.

Introduction

A multitude of factors including vitreous viscosity, cut rate, and duty cycle converge to impact the performance and customizability of vitrectomy systems.¹ Thus, vitrectomy systems that allow greater control of these aspects may aid surgeons in providing the safest and most efficient surgical procedure possible.²

Vitreous flow is affected by the viscosity of the aspirated material, with increased viscosity resulting in reduced flow rate.³ Increasing cut rate increases fragmentation of the vitreous and lowers vitreous viscosity, resulting in enhanced flow rates.^{3,4}

Manual control of the duty cycle (i.e., the percentage of time in a cutting cycle that the port is open) allows surgeons to modulate vitreous flow rate by maximizing port open time (biased open), minimizing port open time (biased closed), or maintaining a 50% port open time (50/50 mode); traditional electric and spring-return pneumatic cutters provided little to no control over duty cycle.¹ Previous studies with electric and spring-return cutters have confirmed an effect of duty cycle on

vitreous flow, particularly at high cut rates.^{3,5} In previous studies of dual-pneumatic 23-G probes, pure fluid flow rates at a 50/50 duty cycle remained relatively constant as cut rate increased up to 5000 cycles per minute (cpm), whereas pure fluid flow rates increased with cut rate under a biased closed duty cycle and decreased with cut rate under a biased open duty cycle. In contrast to water, vitreous flow rates increased with increasing cut rate under the 50/50 duty cycle and remained relatively constant under the biased open duty cycle. As with water, vitreous flow increased with increasing cut rate under a biased closed duty cycle.^{6,7}

This study extends the previous work by investigating the impact of cut rate and duty cycle on the flow rate of porcine vitreous through high-speed 7500-cpm dual-pneumatic 27⁺, 25⁺, and 23-G UltraVit probes (Alcon Laboratories, Inc., Fort Worth, TX).

Methods

Vitreous flow rates were analyzed in porcine eyes using an open-sky vitrectomy technique and the

CONSTELLATION Vision System (Alcon) with three different gauge pneumatic probes (27⁺-, 25⁺-, and 23-G UltraVit probes; $n = 5$ for each gauge; Fig. 1).

Porcine eyes (Sierra for Medical Science, Whittier, CA) were maintained at 4°C and tested within 12 hours of harvesting. Each eye was pinned to a Styrofoam cube with a hollowed-out half sphere 2.5 cm in diameter. The anterior chamber of the eye and vitreous attachments were removed using a scalpel to make an annular incision 3 to 5 mm posterior to the limbus in the region of pars plana. The Styrofoam block and eye were then set on an electronic balance (model EK-600i, A&D Engineering, Inc., San Jose, CA) to evaluate initial weight. The vitrectomy probe was positioned above the balance with a clamp and a lab stand and was then introduced into the vitreous bolus. The balance was wired to a data acquisition board (National Instruments Corp., Austin, TX) in a personal computer loaded with LabVIEW software (National Instruments) that measured mass in real time and calculated flow rate as the change in weight of the porcine eyes over time during vitrectomy divided by the average porcine vitreous density. Porcine vitreous density was assessed experimentally before testing. To do so, vitreous material (3–4 mL) from the ocular cavity of 10 eyes was removed immediately after the eyes were retrieved from the refrigerator; mass and volume were measured in a tared graduated cylinder.

To assess clinically relevant flow rates, two vacuum levels were tested: 650 mm Hg for enhanced 25- and 27-G probes and 450 mm Hg for 23-G probes. Because of their larger diameter and higher flow rate compared with the smaller gauge probes, 450 mm Hg was used for 23-G probes. Flow rate was measured under each of the three duty cycles available on the Constellation Vision System (biased open, 50/50, and biased closed); flow rate measurements were performed immediately after retrieving eyes from the refrigerator. Cut rates ranged from 2500 to 7500 cpm. Flow rates were calculated as the average of data points starting after flow-rate stabilization following activation of the cutter (approximately 3 seconds) and until just before removal of the final vitreous from the ocular cavity. Flow rates were compared using Welch's two-sample *t*-tests at a significance level of *P* less than 0.05 (R software version 2.15.2; R Foundation for Statistical Computing, Vienna, Austria). Data are presented as the mean and 95% CI with an alpha level of 0.05. Linear regression trends were calculated and coplotted with flow rate data.

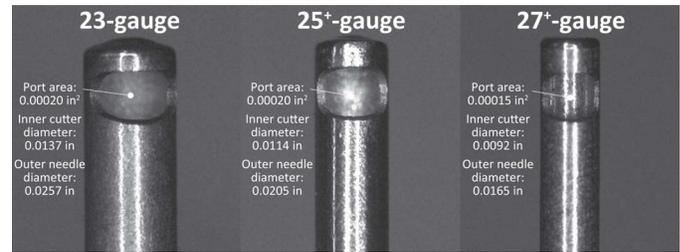


FIGURE 1. Probes that were 23, 25, and 27 G. Port areas are indicated.

Results

Enhanced 27-G Results

In the biased closed duty cycle mode, vitreous flow was strongly dependent on cut rate ($P < 0.001$); mean \pm CI flow rate increased from 0.42 ± 0.14 mL/min at 2500 cpm to 0.88 ± 0.12 mL/min at 7500 cpm (Fig. 2A). The slope of the trend line was $0.09 \mu\text{L}/\text{cut}$ ($R^2 = 0.295$). Vitreous flow was significantly higher at 7500 cpm versus 5000 cpm ($P = 0.006$) and 2500 cpm ($P < 0.001$). In the 50/50 duty cycle mode, vitreous flow was generally unchanged with increasing cut rate ($P = 0.631$). Vitreous flow was 0.62 ± 0.14 mL/min at 2500 cpm, 0.57 ± 0.19 mL/min at 5000 cpm, and 0.68 ± 0.18 mL/min at 7500 cpm (Fig. 2B). The trend line slope was $0.01 \mu\text{L}/\text{cut}$ ($R^2 = 0.005$). In the biased open duty cycle mode, vitreous flow decreased with increasing cut rate ($P = 0.049$) and ranged from 0.89 ± 0.24 mL/min at 2500 cpm to 0.58 ± 0.19 mL/min at 7500 cpm (Fig. 2C). The slope of the trend line was $-0.06 \mu\text{L}/\text{cut}$ ($R^2 = 0.073$).

Enhanced 25-G Results

At the maximal cut rate, vitreous flow rates were approximately 1.9, 2.3, and 2.5 times higher with enhanced 25-G probes than with enhanced 27-G probes using biased closed, 50/50, and biased open duty cycles, respectively. With the biased closed duty cycle, vitreous flow was strongly dependent on cut rate ($P < 0.001$) and increased from 0.52 ± 0.28 mL/min at 2500 cpm to 1.63 ± 0.23 mL/min at 7500 cpm (Fig. 2A). The slope of the trend line was $0.22 \mu\text{L}/\text{cut}$ ($R^2 = 0.525$). Vitreous flow was significantly higher at 7500 versus 2500 cpm ($P < 0.001$). With the 50/50 duty cycle, vitreous flow generally increased with but was not strongly dependent on cut rate ($P = 0.333$). Vitreous flow was 1.36 ± 0.37 mL/min at 2500 cpm, 1.54 ± 0.34 mL/min at 5000 cpm, and 1.60 ± 0.28 mL/min at 7500 cpm (Fig. 2B). The slope of the trend

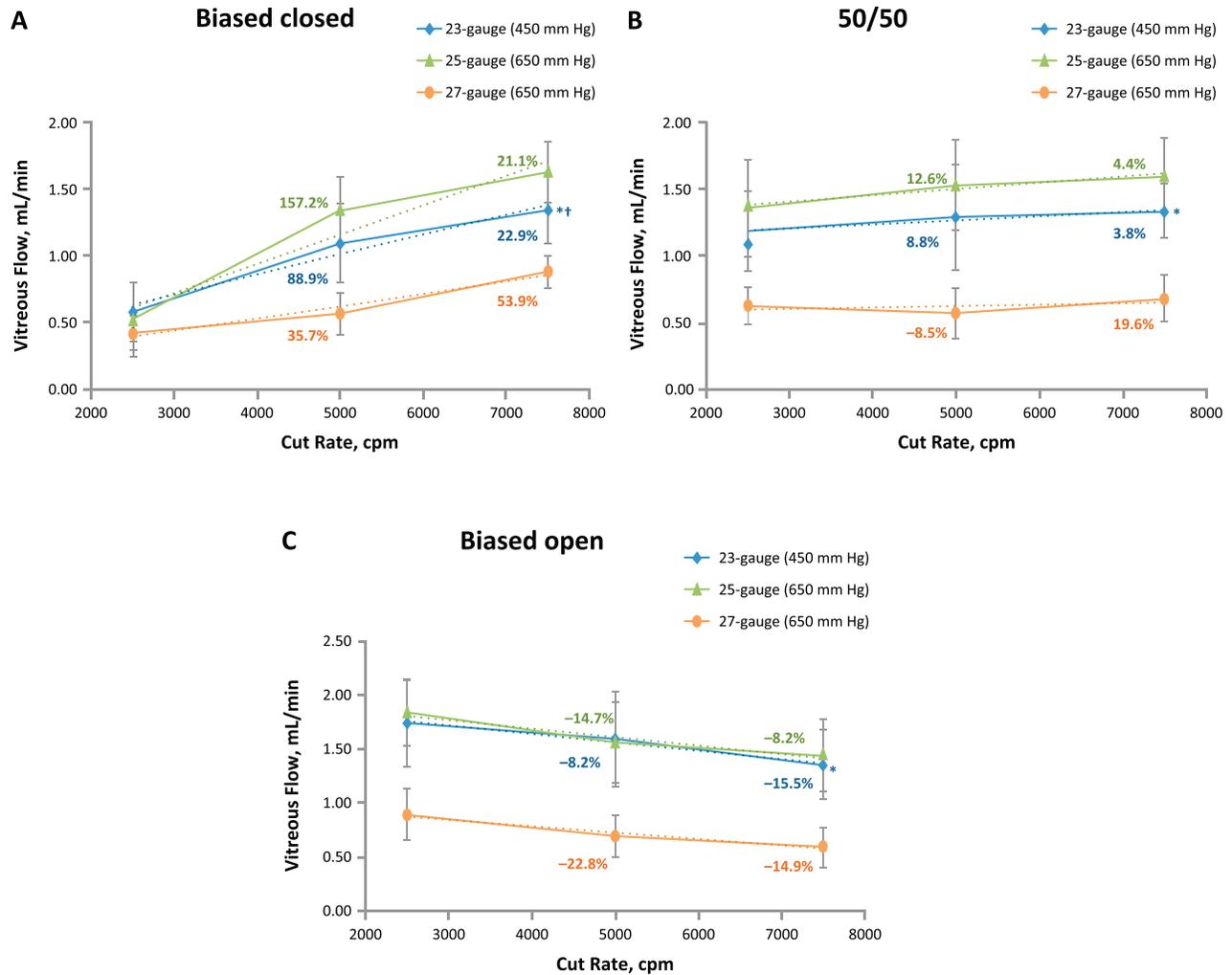


FIGURE 2. Vitreous flow rates (mL/min) through 23-, 25-, or 27-G probes. Each data point represents the mean flow rate calculated from five probes; error bars represent 95% confidence intervals. (A) Biased closed duty cycle, (B) 50/50 duty cycle, (C) biased open duty cycle. Dashed lines indicate linear regression trends. Percent changes in vitreous flow rates from 2500 to 5000 cpm and from 5000 to 7500 cpm are indicated. * $P < 0.001$, 7500 vs. 2500 cpm; † $P = 0.006$, 7500 vs. 5000 cpm.

line was $0.05 \mu\text{L}/\text{cut}$ ($R^2 = 0.032$). With the biased open duty cycle mode, vitreous flow decreased with increasing cut rate ($P = 0.112$); flow rate ranged from $1.83 \pm 0.30 \text{ mL}/\text{min}$ at 2500 cpm to $1.43 \pm 0.34 \text{ mL}/\text{min}$ at 7500 cpm (Fig. 2C). The trend line slope was $-0.08 \mu\text{L}/\text{cut}$ ($R^2 = 0.079$). Vitreous flow at 2500 cpm was significantly higher when using the 50/50 duty cycle compared with the same cut rate using the biased closed duty cycle ($P = 0.002$).

23-G Results

At the maximal cut rate, vitreous flow rates were approximately 10% to 20% higher with enhanced 25-G probes compared with 23-G probes at 450 mm Hg

vacuum with the biased closed, 50/50, and biased open duty cycles, respectively. Using the biased closed duty cycle, vitreous flow was strongly dependent on cut rate ($P < 0.001$); flow rate increased from $0.58 \pm 0.23 \text{ mL}/\text{min}$ at 2500 cpm to $1.35 \pm 0.26 \text{ mL}/\text{min}$ at 7500 cpm (Fig. 2A). The trend line slope was $0.15 \mu\text{L}/\text{cut}$ ($R^2 = 0.278$). Vitreous flow was significantly higher at 7500 cpm compared with 2500 cpm ($P < 0.001$). Using the 50/50 duty cycle, vitreous flow was generally unchanged with increasing cut rate ($P = 0.460$). Vitreous flow was $1.19 \pm 0.30 \text{ mL}/\text{min}$ at 2500 cpm, $1.29 \pm 0.40 \text{ mL}/\text{min}$ at 5000 cpm, and 1.34 ± 0.20 at 7500 cpm (Fig. 2B). The slope of the trend line was $0.03 \mu\text{L}/\text{cut}$ ($R^2 = 0.015$). Vitreous flow was

significantly higher with the 50/50 cycle compared with the biased closed duty cycle at a cut rate of 2500 cpm ($P = 0.005$). Using the biased open duty cycle mode, vitreous flow was dependent on cut rate ($P = 0.173$) and decreased from 1.74 ± 0.40 mL/min at 2500 cpm to 1.35 ± 0.32 mL/min at 7500 cpm (Fig. 2C). The slope of the trend line was -0.08 μ L/cut ($R^2 = 0.059$).

Discussion

New high-speed vitrectomy systems provide surgeons with control over a variety of surgical parameters such as duty cycle and offer enhanced capabilities such as high cut rate.¹ These innovations may aid surgeons in reducing surgical procedure time and increasing patient recovery.² The present study demonstrated that high-speed cut rates of 7500 cpm allowed greater vitreous fragmentation and reduced resistance among three different gauge probes operated using either a biased closed or 50/50 duty cycle, increasing vitreous flow rates. Overall, the largest flow rate increases were observed with the enhanced 25-G probe followed by the 23-G probe, and the highest flow rates were generally observed with enhanced 25-G probes across flow rates and duty cycles.

In a biased closed duty cycle mode, vitreous flow rate was strongly dependent on cut rate, adding further evidence that higher cut rates reduce vitreous viscosity.⁶ In the biased closed mode, the percentage of port open time increases with increasing cut rate. Diniz et al.⁶ showed that in biased closed mode, port open time ranged from 17% at 1000 cpm to 50% at 5000 cpm. Therefore, the increasing ratio of port open time to cut cycle time and increased frequency of opening with greater cut rates allows for a higher rate of vitreous flow.

With the 50/50 duty cycle mode, vitreous flow rates with 7500-cpm probes tended to increase slightly with increasing cut rates, similar to results from previous studies evaluating flow rates with 5000-cpm probes.^{6,7} In contrast to the behavior of vitreous, water and balanced salt solution (BSS) exhibit constant flow rates across all cut rates up to 5000 cpm.^{6,7} Increased flow rates for high-viscosity vitreous with greater cut rates, as observed in the present study, provide further evidence that higher cut rates improve fragmentation of the vitreous, thereby reducing its viscosity and resistance to flow.

Maximum flow rates in biased open duty cycle were achieved for all three probes at the lowest cut

rate tested (2500 cpm) and decreased with increasing cut rates. Vitreous flow behavior with 7500-cpm probes in this study was consistent with previously reported decreases in water and BSS flow rates with increasing cut rate.^{6,7} Because resistance to flow is associated with increased vitreous viscosity, increased cut rate (which increases vitreous fragmentation and lowers vitreous resistance to flow⁸) causes the fluid dynamics of vitreous to become similar to those of BSS (i.e., flow decreases with increased cut rate). In addition, the decrease in port open time imparted by the biased open duty cycle mode at high cut rates⁶ may also contribute to decreased flow. The 7500-cpm cutters appear to maintain efficient aspiration flow similar to 5000-cpm cutters, while at the same time achieving efficient vitreous fragmentation.

In the current study, flow rate through all gauge probes increased slightly (by approximately 10%–20%) with increasing cut rate in 50/50 duty cycle mode and increased more dramatically (by approximately 100%–200%) with increasing cut rate in biased closed duty cycle mode, suggesting that high cut rates reduce vitreous viscosity with all probe gauges. In contrast, flow rate through all probes behaved similarly to aqueous solutions in biased open duty cycle mode.⁶ These data suggest that duty cycle and cut rate further increase vitreous fragmentation without sacrificing the flow efficiency of vitreous aspiration.

This study had some limitations. First, open-sky vitrectomy performed on refrigerated animal vitreous may not completely reflect surgery performed on intact human eyes. Second, the BSS-to-vitreous ratio changes during vitrectomy such that the ratio is smallest (i.e., more vitreous than BSS is present in the ocular chamber) at the beginning of the surgery but increases as the surgery progresses. Thus, the present results are more applicable to flow rates at the beginning of vitrectomy than those at the end of the surgery. Comparisons of 23-G probes with enhanced 25-G and enhanced 27-G probes were influenced by vacuum differences; the tested levels were selected to reflect clinically relevant parameters used by surgeons.

In summary, high-speed cut rates of 7500 cpm allow for greater vitreous fragmentation and reduced resistance to flow in biased open and 50/50 duty cycles. High-speed cutters may improve safety outcomes during vitrectomy by improving vitreous fragmentation without diminishing vitreous flow efficiency. This study expands the previous vitreous flow studies to include 7500-cpm cut rates and helps

surgeons optimize system parameters to maximize vitrectomy efficiency.

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Disclosure: **D.J.K. Abulon**, employee of Alcon Research, Ltd.; **D.C. Buboltz**, employee of Alcon Research Ltd., at the time of his passing

References

1. Trikha R, Beharry N, Telander DG. Small gauge pars plana vitrectomy. In: Song Z, ed. *Vitrectomy*. Rijeka, Croatia: InTech; 2012:55–78.
2. Rizzo S, Genovesi-Ebert F, Belting C. Comparative study between a standard 25-gauge vitrectomy system and a new ultrahigh-speed 25-gauge system with duty cycle control in the treatment of various vitreoretinal diseases. *Retina*. 2011;31:2007–2013.
3. Hubschman JP, Gupta A, Bourla DH, et al. 20-, 23-, and 25-gauge vitreous cutters: performance and characteristics evaluation. *Retina*. 2008;28:249–257.
4. Diniz B, Ribeiro RM, Fernandes RB, et al. Fluidics in a dual pneumatic ultra high-speed vitreous cutter system. *Ophthalmologica*. 2013;229:15–20.
5. Hubschman JP, Bourges JL, Tsui I, et al. Effect of cutting phases on flow rate in 20-, 23-, and 25-gauge vitreous cutters. *Retina*. 2009;29:1289–1293.
6. Diniz B, Fernandes RB, Ribeiro RM, et al. Analysis of a 23-gauge ultra high-speed cutter with duty cycle control. *Retina*. 2013;33:933–938.
7. Abulon DJ, Buboltz DC. Performance comparison of high-speed dual-pneumatic vitrectomy cutters during simulated vitrectomy with balanced salt solution. *Transl Vis Sci Technol*. 2015;4(1):6.
8. Magalhaes O Jr, Chong L, DeBoer C, et al. Vitreous dynamics: vitreous flow analysis in 20-, 23-, and 25-gauge cutters. *Retina*. 2008;28:236–241.