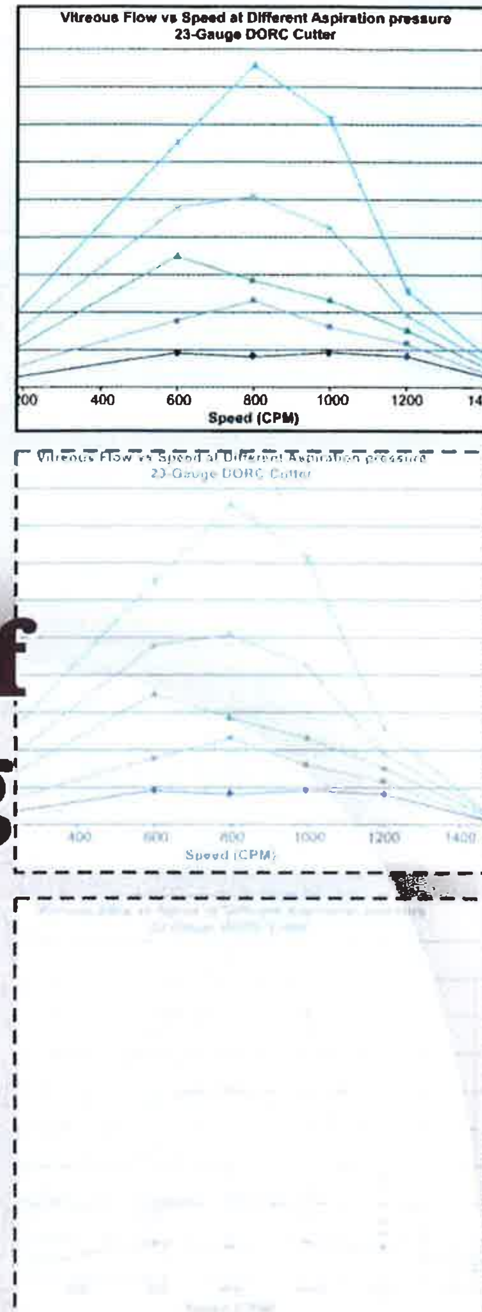

An Improved Understanding of Vitreous Cutting

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Introduction

Thirty-seven years have passed since Robert Machemer developed a device and the technique for the mechanized removal of vitreous from a closed eye. In the past 37 years vitrectomy has improved and is safer and more efficient. We routinely operate not only on eyes with severe disease like complicated retinal detachment, penetrating ocular injury and diabetic retinopathy, but also on eyes with less severe disease such as an idiopathic epiretinal membrane. Instead of waiting until the vision declines to a low level, we are now operating on eyes before significant visual loss. Yet, our understanding of the fundamental mechanisms of automated vitreous removal is incomplete. If we are to achieve important breakthroughs in the design of vitreous cutters, this understanding needs to be improved. In this chapter we hope to summarize some of the work performed in our Eye Concepts laboratory at the Doheny Eye Institute on the mechanics of automated vitrectomy.

Measuring Vitreous Flow Rates: Water versus Vitreous

The efficiency of vitreous cutters has historically been evaluated by measuring water flow rates. Concerned that this method of measurement was misleading, we developed techniques to study vitreous flow rates. Vitreous cutters were suspended in vials of porcine vitreous and the weight of the vials was constantly measured as the cutter was operated. For one particular cutter, data from water flow rates suggested a linear decrease of volume flow versus cut rate **(Figure 14.1)**. However, the same cutter performing in vitreous demonstrated a different curve **(Figure 14.2)**. Examples, such as these convinced us that the efficiency of cutters is best assessed by measuring vitreous flow rates rather than saline flow rates.

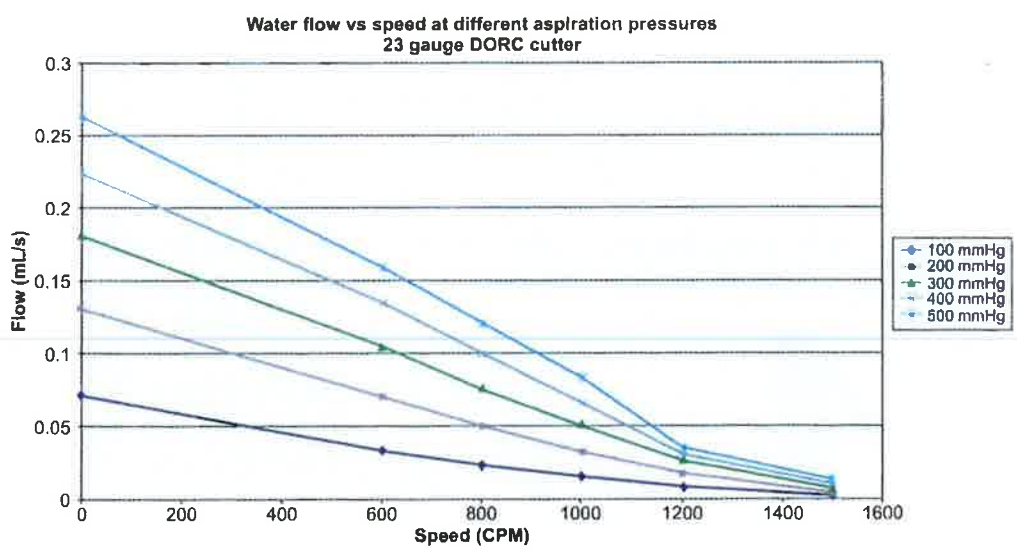

FIGURE 14-1: Water flow decreases as the cut rate increases for this 23 gauge cutter

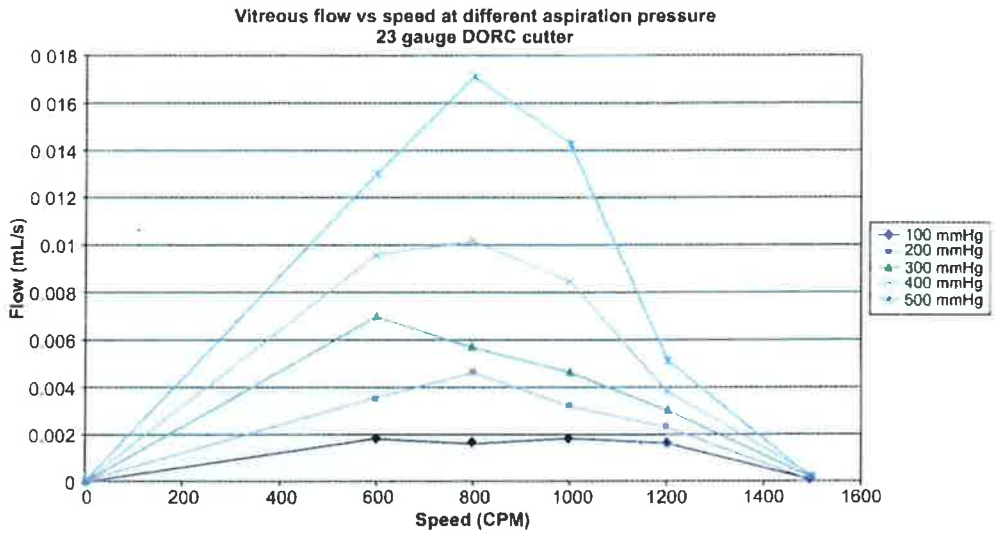

FIGURE 14-2: The same 23-gauge cutter illustrated in Figure 14.1 demonstrates a different curve when flow is measured in vitreous

Vitreous Cutting Efficiency and Duty Cycle

Studies in our 'Eye Concepts Laboratory' showed that duty cycle is important in maximizing vitreous flow rate. Duty cycle can be defined for vitreous cutters as the ratio of the time the cutter port is open to the time it is closed. By performing high speed video analysis of the opening and closure of vitreous cutters, we confirmed that electric cutters have a constant duty cycle and that spring return pneumatic cutters have a variable duty cycle. Electric cutters use an electric motor to open and close the cutter blade and the duty cycle is a constant 50%. Pneumatic cutters rely on pulses of air to close the port and a return spring to reopen the port. As the cutting rate increases, the spring constant behaves in a non-linear fashion resulting in different duty cycles at different cut rates (i.e. time port is open or closed) and at high cut rates this can lead to the port being closed for most of the time and therefore dramatically effecting the flow of vitreous **(Figure 14.3)**. The ports of some first generation pneumatic cutters are completely closed at cutting rates of 2500 cuts per minute.

CAN THIS DETRIMENTAL EFFECT ON DUTY CYCLE OF PNEUMATIC VITRECTOMY AT HIGH CUTTING RATES BE OVERCOME BY ENGINEERING?

We evaluated a second generation pneumatic spring return vitreous cutter engineered to maintain a high duty cycle at high cutting rates **(Figure 14.4)**. A lower pneumatic pulse pressure is used to drive the cutter and the pulse itself has been shaped. The cutter is designed to operate at 2500 cuts per minute a rate far higher than currently commercially available cutters. We confirmed not only the improved ability to move vitreous at higher cutting rates compared to first generation vitreous cutters but a 25 gauge version of this cutter was able to move more vitreous than some first generation 20 gauge cutters **(Figure 14.5)**.

Vitreous Flow Related to Cut Rate

Increasing the cutting rate is another easy way to increase this vitrectomy efficiency. Experimental work in our lab illustrated the dramatic effect of increasing cutting rate on increasing efficiency of

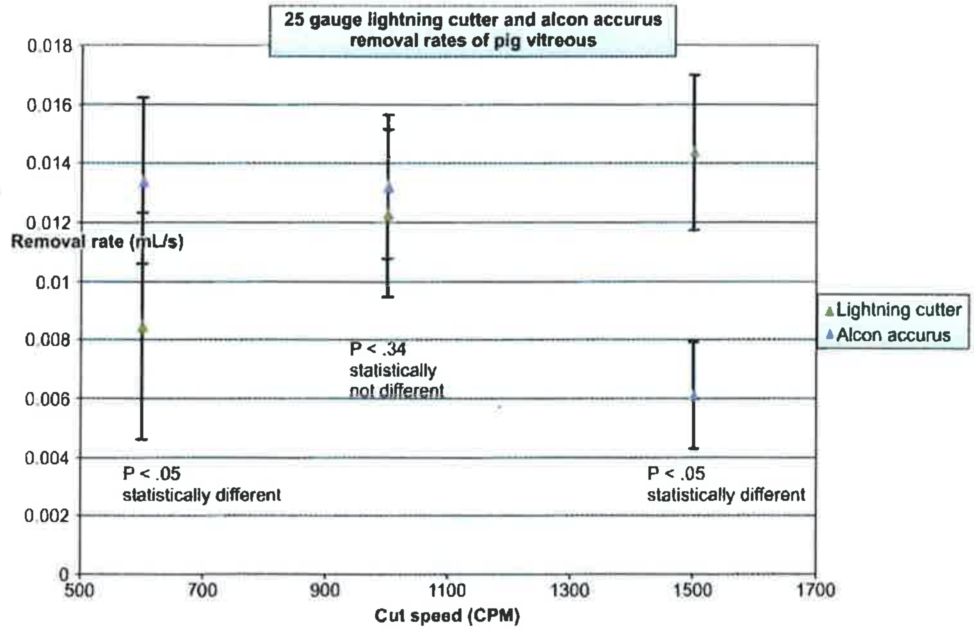

FIGURE 14-3: The effect of duty cycle on vitreous flow is pronounced above 1000 cpm where the flow through the cutter with fixed duty cycle is superior to the cutter with a variable duty cycle

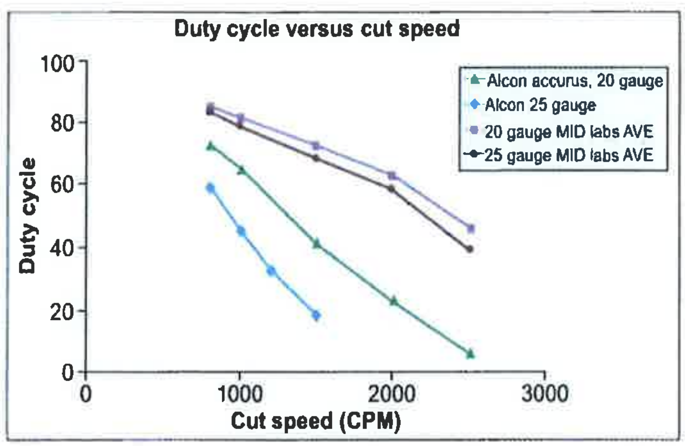

FIGURE 14-4: A second generation pneumatic cutter has been successfully engineered to maintain a higher duty cycle at high cut rates compared to a first generation pneumatic cutter

cutting **(Figure 14.6)**. This is explained by the inefficiency of vitreous cutting as revealed by high speed video analysis. We added triamcinolone acetonide or microspheres to porcine vitreous to enhance its visibility. We recorded the movement of vitreous at the tip of vitreous cutter using a high speed camera capable of capturing 700 frames per second. With this camera each cut of a cutter run at 1500 cuts per minute could be captured by 28 frames. We observed that vitreous cutting is neither smooth nor efficient, but in fact is a discontinuous process. There are times when the cutter is activated and no vitreous is moving into the port. At other times there is even reversal of flow. There are varying velocities of vitreous flow through the aperture with a single cycle, on opening of a pneumatic cutter there is a slow movement of vitreous into the port and as the port opens wider,

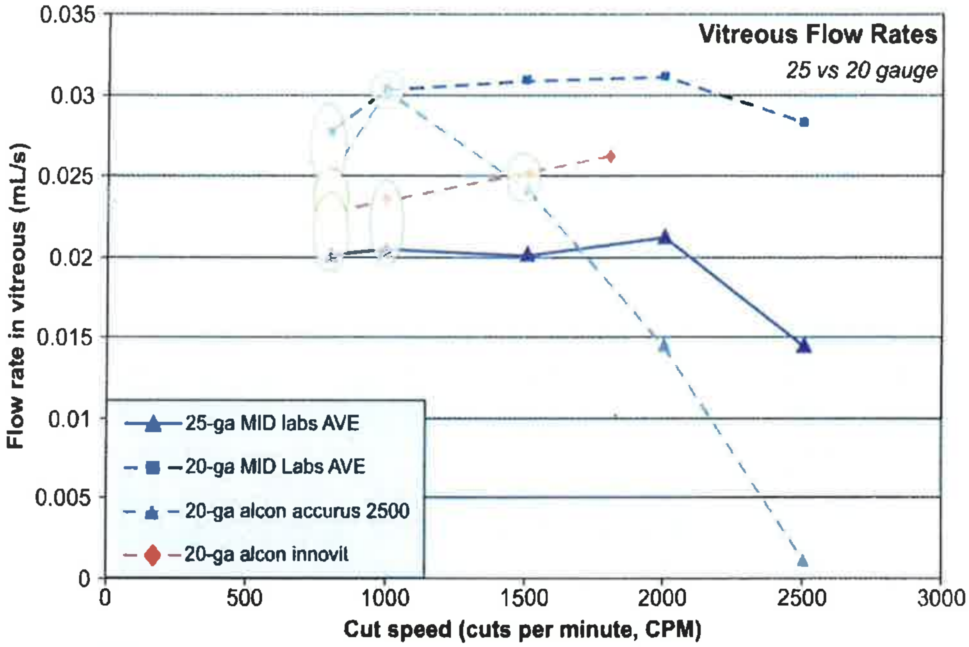

FIGURE 14-5: A second generation 25-gauge cutter moves more vitreous than a first generation pneumatic cutter above 2000 cpm

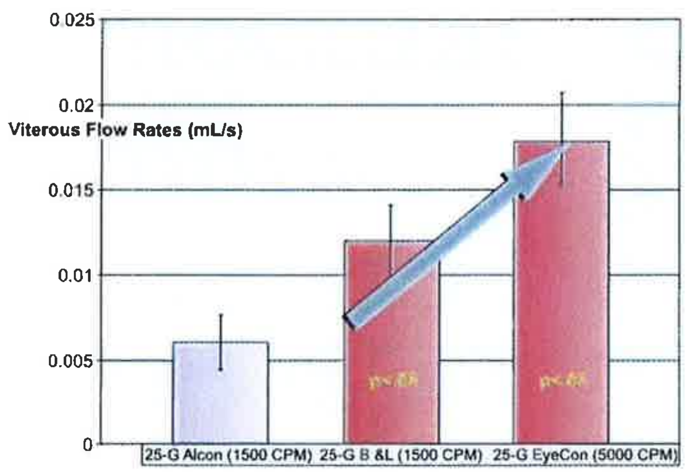

FIGURE 14-6: Increasing cut rate substantially increases vitreous flow through a cutter

there is a faster movement of vitreous. The effect of increasing cutting rate is similar to the effect of increasing the number of swings of using a dull axe.

There is little doubt that automated closed eye vitrectomy has come a long way in 37 years and has been a major breakthrough in the management of retinal diseases. However, further development of vitrectomy instrumentation especially in small gauge needs additional study and understanding of fundamental mechanics of vitreous cutting and vitreous flow. Moreover, these studies need to use much more quantitative assessment in addition to the qualitative assessment techniques. In our 'Eye Concepts Laboratory' we have applied both quantitative and qualitative techniques and by doing so we have and plan to continue to improve vitreous surgery and meet the challenges of our ever evolving field.

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References

1. Machemer R, Buettner H, Parel JM. Vitrectomy, a pars plana approach. Instrumentation. Mod Probl Ophthalmol 1972;10:172-77.
2. Magalhaes O Jr, Chong LP, DeBoer C, Bhadri PR, Lescoulie J, McCormick J, Barnes A, Humayun M. Improved understanding of vitrectomy, qualitative high speed video analysis of vitreous movement around the aperture of vitreous cutters. Invest Ophthalmol Vis Sci (ARVO Supplement) 2006; 2688:127.
3. DeBoer C, Barnes A, Lescoulie J, Fang S, Magalhaes O Jr, Bhadri P, McCormick M, Chong L.P, Hassan T, Humayun M. Vitreous removal rates and high-speed video analysis of 25-gauge vitrectomy cutters. Invest Ophthalmol Vis Sci (ARVO Supplement) 2006;5254/B669:244.
4. Magalhaes Jr O, Chong LP, Deboer C, Bhadri PR, McCormick M, Fang S, Kerns R, Barnes A, Humayun M. Vitreous dynamics, the new solid development concept. Vitreous flow analysis in 20, 23 and 25 gauge cutters. Invest Ophthalmol Vis Sci (ARVO Supplement) 2007; 2243/B852, 110.
5. Magalhaes Jr O, Chong LP, Deboer C, Bhadri P, Kerns R, Barnes A, Fang S, Humayun H. Vitreous dynamics: vitreous flow analysis in 20-, 23-, and 25-gauge cutters. Retina 2008;28:236–41.
6. Magalhaes Jr O, Barnes A, DeBoer C, Humayun M, Chong LP, Bhadri P, Fang S. Guillotine performance: duty cycle analysis of vitrectomy systems. Retinal Cases and Brief Reports (in press).