New Instruments

A NEW VITREOUS CUTTER BLADE ENGINEERED FOR CONSTANT FLOW VITRECTOMY

Tommaso Rossi, MD*
Giorgio Querzoli, PhD†
Carlo Malvasi, DEng‡
Mario Iossa, MD*
Giampiero Angelini, DEng‡
Guido Ripandelli, MD§

*From the *The Eye Hospital of Rome; †Department of Hydraulics and Civil Engineering, Faculty of Engineering, University of Cagliari; ‡Optikon 2000 Inc; and §Bietti Eye Foundation.*

The standard guillotine-shaped vitreous cutter blade (hereafter named Regular Blade [RB]) did not substantially change over the past 40 years, because of its simple and robust design. The asynchronous suction and cutting action, typical of RB blades, determines complete port obstruction generating flow instability and fluid acceleration that results in limited efficiency and eventually retinal traction.

Newer blade shapes allowing residual flow when the port is "closed," have been recently described and shown to yield a more favorable duty cycle, fluid dynamics, and volumetric flow rate.[1]

We herein introduce a further improvement of blade design, named Constant Flow Blade (CFB; Twedge Cutter Blade; Optikon 2000 Inc, Rome, Italy), that maintains the amount of open port surface invariant throughout the duty cycle, achieving a much higher flow while doubling cut rate.

Description

Blade Shape

The CFB outer shaft (compared with the RB in Figure 1) has a slightly enlarged port while the inner cylinder has a rectangular opening and a double beveled blade that slides like a cursor between the 2 ends of the port (Positions A and C in Figure 1). The blade cuts both at the proximal end of its run (Position A) and at the distal end (Position C), leaving the entire port surface open in both cases. Anywhere in between the two ends (Position B), the blade occupies only a fraction of the port, leaving two inversely proportional openings on either side that add up to exactly the same opening surface as the entire port in Positions A and B. The overall free port surface, therefore, remains unchanged and constant regardless of blade position, exactly matching the width of the open RB blade.

The RB, on the contrary, leaves the port completely open only in Position A, whereas closes progressively and eventually completely as the blade slides toward Position C, leaving only half the port open in Position B.

Experimental Setting

The 23-guage probes mounting the above blades (Twedge Cutter; Optikon 2000 Inc) have been connected to the R-Evolution CS phaco-vitrectomy machine console (Optikon 2000 Inc) equipped with double Venturi/peristaltic pump and have been tested under various conditions. Tests have been conducted in a transparent Plexiglas box ($3 \times 5 \times 3$ cm^3 parallelepiped) filled with balanced salt solution (BSS) (Alcon, Fort Worth, TX), egg albumen,[2] or porcine vitreous to simulate both aqueous and vitreous fluidics.[3] Constant flow blade blades (Twedge Cutter) have also been implied in 12 human cases using the same platform.

Fluids have been seeded with triamcinolone crystals (Kenacort; Bristol-Myers Squibb, New York, NY) passed through a 40-μm filter, and motion recorded with high-speed camera (MotionPro; Integrated Design Tools Inc, Tallahassee, FL).[1,2]

Main Outcome Measures

Duty cycle, volumetric flow rate, and kinetic energy, as described elsewhere,[1] have been considered as main outcome measures.

G. Angelini and C. Malvasi are employees of Optikon 2000 Inc. The other authors have any financial/conflicting interests to disclose.

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Reprint requests: Tommaso Rossi, MD, Via Tina Modotti 93, 00142 Rome, Italy; e-mail: tommaso.rossi@usa.net

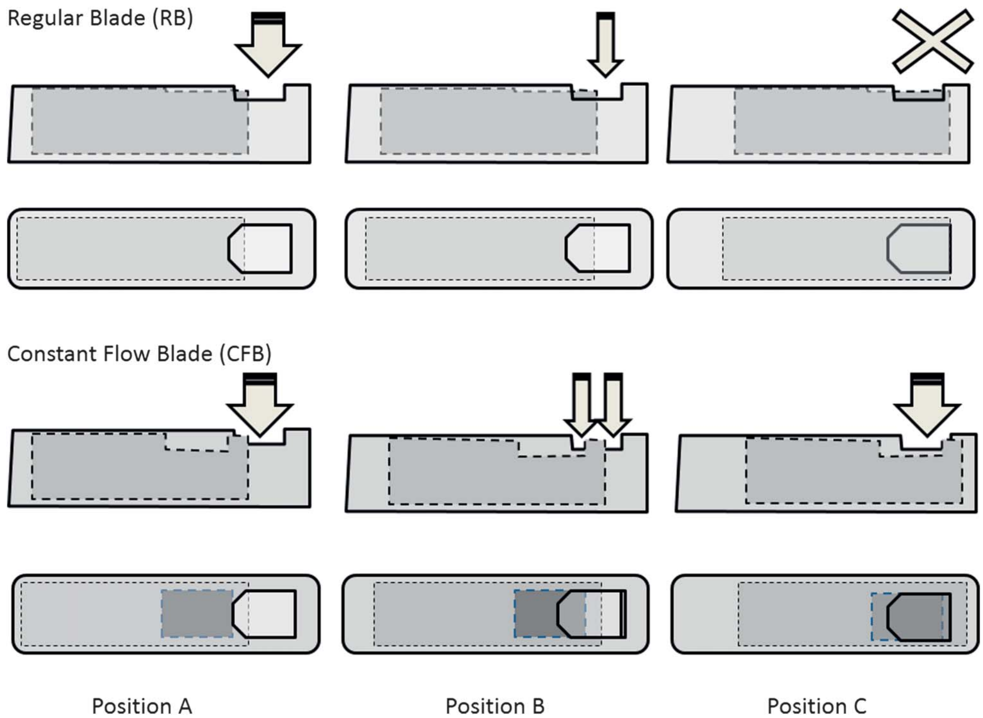

Fig. 1. Schematic drawing of blade shapes. The upper panel shows the RB. The port is completely open only in Position A, while closes progressively in Position B, and is completely obstructed in Position C. The lower panel shows the CFB. The CFB port opening is slightly larger than that of the RB to compensate for the inner blade residual port obstruction in Positions A and C. The double edge blade (proximal and distal) occupies a very limited surface of the port (in Position B) and allows effective cutting action in both Positions A and C doubling de facto the cut rate.

Results

Constant flow blade duty cycle (Figure 2, solid line) shows a remarkably constant opening and a clear advantage when compared with the RB (Figure 2, dotted line) at any considered cut rate. Flow rate (Figure 3) improves accordingly, showing a clear advantage for the CFB regardless of pump type and aspiration setting. More interestingly, the CFB flow rate is invariant to cut rate and its advantage about the RB widens steadily as cut rate increases.

The CFB flow rate in albumen (Figure 4) increases steadily up to 650 cpm to 1,000 cpm when it levels off, remaining constant despite any further cut rate increase. Regular blade also shows a similar pattern of initial rise, although much less pronounced and levels at a much lower flow rate (about ¼ of CFB flow).

Kinetic energy is proportional to squared velocity and its variation with time is a measure of acceleration, and therefore proportional to traction induced by such vitreous cutter[4,5] (since force equals mass times acceleration). Constant flow blade determined much less kinetic energy fluctuation (Figure 3, solid line) both in BSS and albumen and regardless of pump type. Average kinetic energy also was significantly higher for the CFB compared with RB in all cases. Kinetic energy spatial maps are reported in Figure 5 for BSS and albumen; the CFB shows a higher kinetic energy and more localized in proximity of the cutter port.

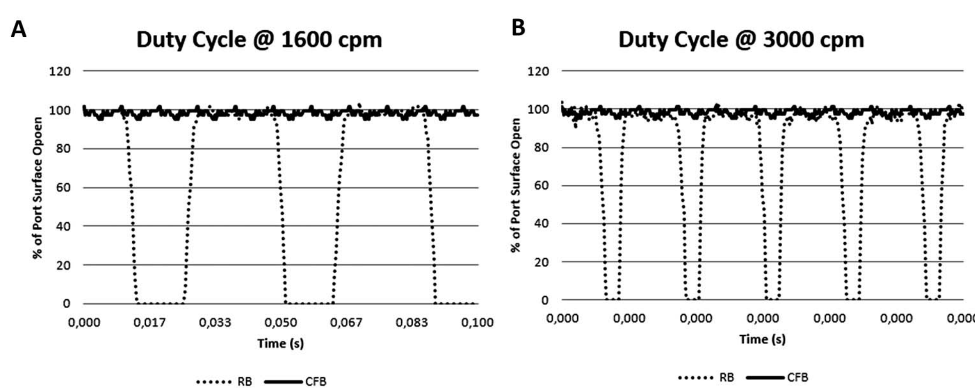

Fig. 2. Duty cycle of RB (dotted line) and CFB (continuous line) defined as percent of open port surface over the cutting cycle at 1,600 cpm (**A**) and 3,000 cpm (**B**). Because of the invariant port surface available for aspiration, CFB duty cycle is the same in Positions A–C, and is consistently close to 100%.

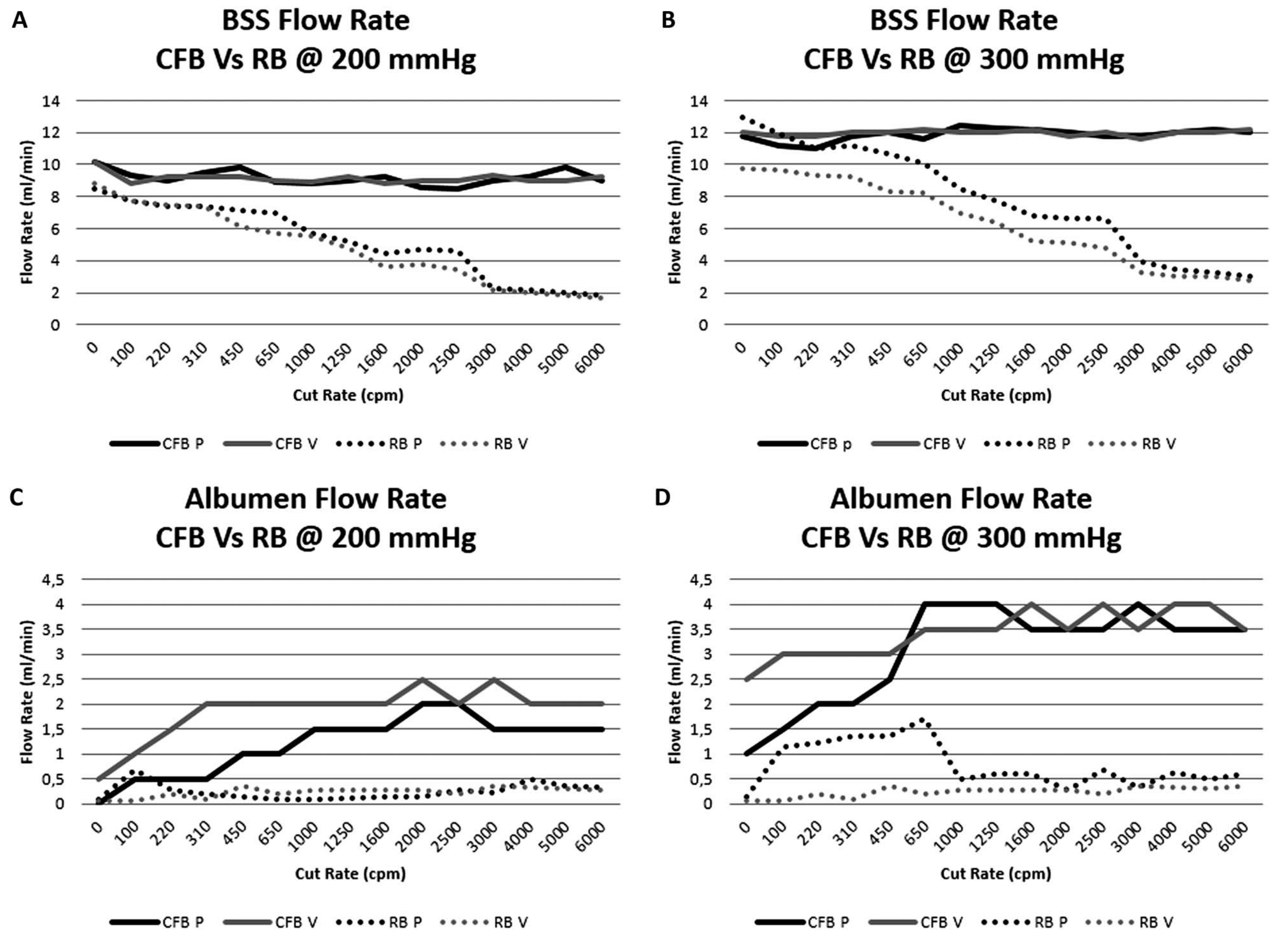

Fig. 3. Volumetric flow rate in BSS (**A** and **B**) and albumen (**C** and **D**) at 200 mmHg (**A** and **C**) and 300 mmHg aspiration (**B** and **D**) for Venturi and peristaltic pump. Note that the BSS flow rate for RB decreases linearly (as an effect of duty cycle reduction) while remains constant for CFB. In albumen (**C** and **D**), all blades show flow increase as the cut rate increases from 0 cpm to ~1,000 cpm (because of the smaller chunks within the inner cutter shaft that tend to simulate a lower viscosity and are more easily aspirated) after which the flow rate plateaus. Constant flow blade levels off at flow values between threefold and fourfold the RB flow rate. P, peristaltic; V, Venturi.

Porcine vitreous vitrectomy videos recorded with a high-speed camera of both CFB and RB are also available (see **Video, Supplemental Digital Content 1**, http://links.lww.com/IAE/A301; see **Video, Supplemental Digital Content 2**, http://links.lww.com/IAE/A302, respectively).

Discussion

Designing blade shapes with invariant flow as cut rate increases, represents a significant improvement of vitrectomy.[2,3] The idea of drilling a hole within the internal blade to allow residual flow when the port is closed was initially proposed by Sussman and Zalesky[4] in 1992 and subsequently revived by Rizzo.[5]

We introduce a further refinement of this same concept through our CFB (Twedge Cutter) that keeps the open port surface constant, optimizing flow, and stabilizing velocity (i.e., kinetic energy per a given mass unit). Constant flow blade duty cycle is by design virtually 100%, and the blade does not obstruct the port but slides in between the 2 ends of it, resulting in a much smoother and continuous cutting and aspiration.

We believe the surgical benefit was clearly felt in the 12 treated eyes (4 puckers, 3 macular holes, and 5 retinal detachment cases) and is also made visible through the high-speed video (see **Video, Supplemental Digital Content 1**, http://links.lww.com/IAE/A301) of triamcinolone-seeded porcine vitreous.

The video demonstrates the reason for the surgical feeling of ease and efficiency: the cutter port aspirates vitreous strands as the double bevel blade smoothly slides back and forth. The flow never interrupts and no sudden vitreous incarceration occurs because the alternating suction on both sides of the blade results in a continuous "tug of war" game where the grasp on vitreous strands is never lost.

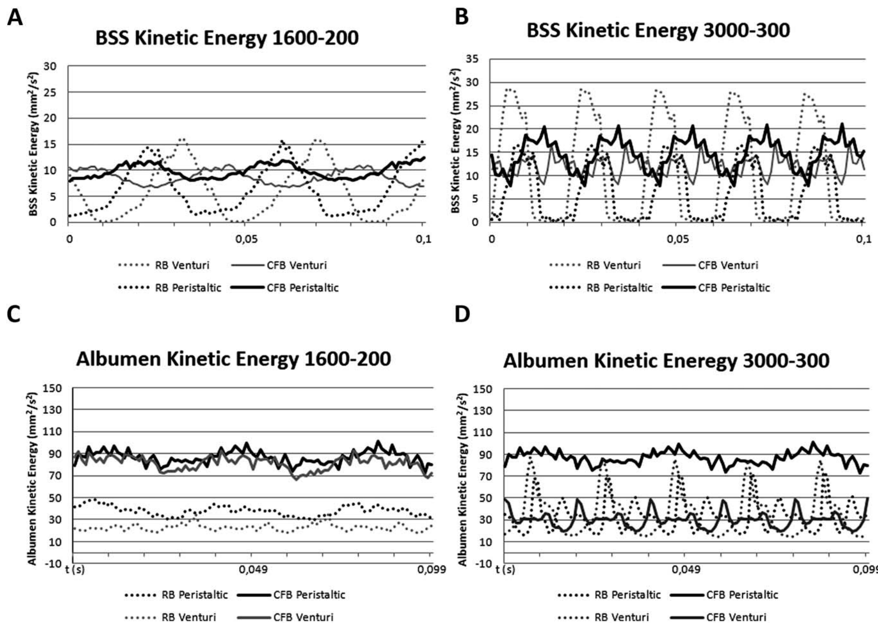

Fig. 4. Balanced Salt Solution (**A, B**) and Albumen (**C, D**) Kinetic Energy; 0.1 seconds averaged for the overall 2 seconds of high speed recording is shown. Regular Blade generates much more kinetic energy fluctuation (dotted lines) than CFB, regardless of pump and aspiration level. Note that the average KE is always higher for the CFB, implying a higher efficiency.

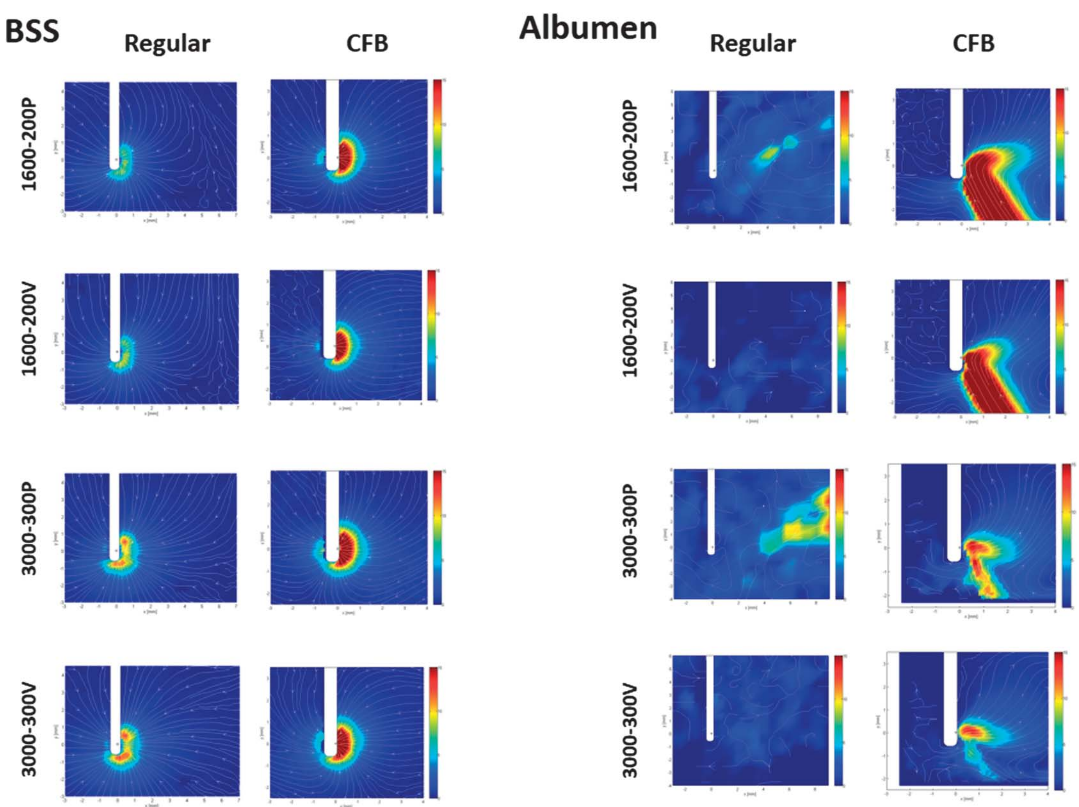

Fig. 5. Spatial map of RB and CFB kinetic energy measured in BSS and albumen. The port is oriented rightward. In BSS (two leftmost columns), the CFB determines a higher kinetic energy regardless of pump and suction level because of the much higher efficiency. In albumen (two rightmost columns), the CFB determines a much wider and sharply demarcated area of perturbation, whereas the RB area of perturbation is much less demarcated, and there is a remarkable difference between peristaltic (second and fourth rows) and Venturi (first and third rows) pump. Note that the CFB determines a much higher mean kinetic energy than the RB. Because spatial maps report the average square of velocity, the RB fluctuates between a higher velocity (for a much smaller time) and zero velocity when the port closes while the CFB fluid velocity remains higher than zero and reasonably constant throughout the cycle. This explains the marked difference between the two. Also noteworthy is the higher kinetic energy allowed by the peristaltic pump as opposed to Venturi pump with either blade. Peristaltic pumps remove a given volume per time unit, and therefore tend to build up pressure more than Venturi pumps; this probably accounts for a higher vacuum that determines partial tubing collapse when the port is obstructed by the blade or viscous fluid, generating adjunctive aspiration as occlusion resolves.

The RB, on the contrary (see **Video, Supplemental Digital Content 2**, http://links.lww.com/IAE/A302) releases vitreous strands at the end of every cutting cycle when the engaged vitreous is severed and aspiration shut down by the closing port. Each subsequent cutting action needs to engage the vitreous before being able to cut and remove material: the RB video (see **Video, Supplemental Digital Content 2**, http://links.lww.com/IAE/A302) shows triamcinolone crystals attracted toward the cutter port by the aspiration when the port is open, rebounding backward as the port closes and suction released. It is conceivable that the need for reengaging the lost material at each subsequent cutting cycle reduces RB efficiency.

Fluid dynamics data also support the surgical impression, because CFB flow remains remarkably constant at any considered cut rate (Figure 3) both in BSS and albumen, while the RB suffers a sharp flow reduction as the cut rate increases (at 6,000 cuts per minute, RB flow is <¼ the CFB flow). More importantly, kinetic energy variation with time was much more pronounced when using an RB, as opposed to the CFB that kept overall energy high (and therefore fluid velocity and volumetric flow), despite minimizing its fluctuations (Figure 4).

It should be noted that also the CFB showed some degree of velocity fluctuation. We believe this is due to blade motion dragging effect that acts as a plunger engaging the microfibril structure of the vitreous that responds as an elastic material.

Minor drawbacks of the CFB include the need for aspiration and flow rate adjustment, especially when working closer to the retina, given the higher efficiency of the cutter and the "open" status of the cutting port. The CFB port, in fact, cannot be closed, whereas the RB port allows both closed and open modality when inactive. When the pedal is released, therefore, aspiration halts and the blade stops in Position A (Figure 1), leaving the port entirely open and possibly engaging vitreous fibrils. This exposes the surgeon to the theoretical risk of pulling uncut vitreous inadvertently engaged.

This did not seem to represent a serious problem during the 12 cases performed, probably because when the aspiration pedal is released, aspiration drops fast while cutting stops abruptly only when the very end of the pedal course is reached. This means that aspiration is almost zero when cutting is still working at the preset value (mostly 2,000–4,000 cuts per minute); should a few uncut fibrils still be engaged, therefore, the residual cutting action is very likely capable of releasing them.

Software modification allowing a few more cuts after suction ends might overcome this problem, although it should be noted that most surgeons work in "open port" modality when using RB blades and face this same scenario every day.

The blade tip was tested to verify concerns about a possible structural weakening due to the presence of a side aperture. Cutters have been working for several hours in BSS and egg white at 6,000 cuts per minute, and none showed malfunctioning or signs of damage in optical microscopy.

To summarize, the CBF blade proved both experimentally and surgically extremely interesting and capable of offering significant advantages over the regular guillotine blade in terms of higher efficiency and safety. Further and extensive testing is warranted before such promising blades can become part of our every day's surgical armamentarium.

Key words: duty cycle, fluid acceleration, human vitreous motion, pars plana vitrectomy, particle image velocimetry, vitreous cutter fluidics, vitreous traction, vitreous acceleration.

References

1. Rossi T, Querzoli G, Angelini G, et al. Fluid dynamics of vitrectomy probes. Retina 2014;34:558–567.
2. Wals KT, Friberg TR. Vitreous substitute removal rates with the Accurus and Millennium vitrectomy systems. Ophthalmic Surg Lasers Imaging 2008;39:174–176.
3. Pitcher JD III, McCannel CA. Characterization of the fluidic properties of a syringe-based portable vitrectomy device. Retina 2011;31:1759–1764.
4. Sussman G, Zalesky E. Surgical Device. US patent 5284472A. Allergan Inc, Feb 8, 1994.
5. Rizzo S. Performance of a modified vitrectomy probe in small-gauge vitrectomy. Retina Today 2011;9:40–42.