# An Experimental Protocol of the Model to Quantify Traction Applied to the Retina by Vitreous Cutters

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**Purpose.** The purpose of this study was to use a novel method to quantify the traction applied to the retina during vitrectomy.

**Methods.** Five 20-gauge electric cutters were used. Fresh porcine eyes were positioned in a specially developed holder and transfixed to the retinal layers with a microwire, and the other end was fixed to the load cell of a strain gauge. The cutter to be assessed was introduced into the eye by a micromanipulator at a 45° angle adjacent to the retina. The traction force was evaluated when the cutter was at 3 and 5 mm from the retina. As control, the experiment was repeated in eyes filled with water, and the results were compared to those when the eyes had vitreous gel.

**Results.** Results from the eyes with vitreous gel indicate that retinal traction increased with increasing aspiration vacuum (7.90 dyn for each 100 mm Hg increased; $P < 0.05$) and proximity to the retina (2.17 dyn; $P < 0.05$) and decreased with increasing cut rate (2.51 dyn for each 500 cuts per minute increased; $P < 0.05$). In all eyes filled with water, traction was not observed.

**Conclusions.** The present study establishes a new reproducible technique to quantify vitreoretinal traction during vitrectomy and demonstrates that the effects of aspiration, distance from the retina, and cut rate are crucial factors in the amount of retinal traction created by vitreous cutters. (*Invest Ophthalmol Vis Sci.* 2010;51:4181–4186) DOI:10.1167/iovs.09-4852

Quantifying the traction applied to the retina by vitreous cutters during vitrectomy is still a challenge for researchers. Some theories about how much force the cutter applies to the retina during pars plana vitrectomy (PPV) and the best cutter design have been reported.[1,2] The vitreous is a semisolid, transparent gel composed primarily of water. Approximately 1% of this gel is composed of other components, such as collagen and hyaluronic acid.[3] The strongest adherence between the vitreous body and the retina occurs at the vitreous base and optic disc and along the retinal vessels.[3] Mechanical posterior vitreous detachment can result in significant damage to the retina[4] and possibly result in retinal detachment related to the surgery[5–8] or in iatrogenic retinal tears.

During vitrectomy, traction is the pulling force that is applied to retinal tissue because of aspiration flow and the pulling of the vitreous that is attached to the retina. Moreover, traction is a complex relationship among aspiration flow, gauge, port geometry, duty cycle (DC), vitreous composition and movement during vitrectomy, and the nature of the vitreoretinal adhesions. Since the advent of closed eye PPV, the instruments have been driven by greater functionality and improved safety.[9–15] Cutter designs allow the surgeon to perform surgeries with speeds of up to 5000 cuts per minute (cpm), and a method to quantify the vitreoretinal traction would be useful for engineers and surgeons to better understand the cutters. In this study, we used a novel method to begin to quantify the traction applied to the retina during vitrectomy.

## Materials and Methods

### Samples

Fresh porcine eyes were obtained from slaughterhouses less than 12 hours after death, during which period the eyeballs were kept at 4°C. After all extraocular structures were dissected and removed, just the sclera was trephined 4 mm from the limbus using a 6-mm Hessburg-Barron vacuum (JEDMED Instrument Co., St. Louis, MO), and the sclera was surgically excised. The cornea, iris, and crystalline lens were then removed en bloc. The eye was positioned in a specially developed holder so that the trephined area was located at the most inferior part of the globe. On the most superior point of the positioned globe (180° to the trephined area), a 1 × 1-cm area of eye wall consisting of sclera, choroid, and retina was removed using surgical scissors. The choroid and retina layer (exposed by scleral trephination) was then transfixed with a hook (Figs. 1A, 1B) made by 0.15-mm stainless steel wire and fixed to the load cell of a strain gauge (Electroforce 3100; Bose Corporation, ElectroForce Systems Group, Eden Prairie, MN; Figs. 1C, 1E). This specific strain gauge can make measurements with a resolution of 0.0006 dyn.[16] We decided to fix the wire in the retina close to the ora serrata area because here the vitreous is most firmly attached at its base.[3]

### Measurement System and Data Acquisition

A specific strain gauge (Electroforce 3100; Bose Corporation) was used to quantify the vitreoretinal force during PPV. The vitrector to be assessed was introduced into the eye by a micromanipulator at a 45°

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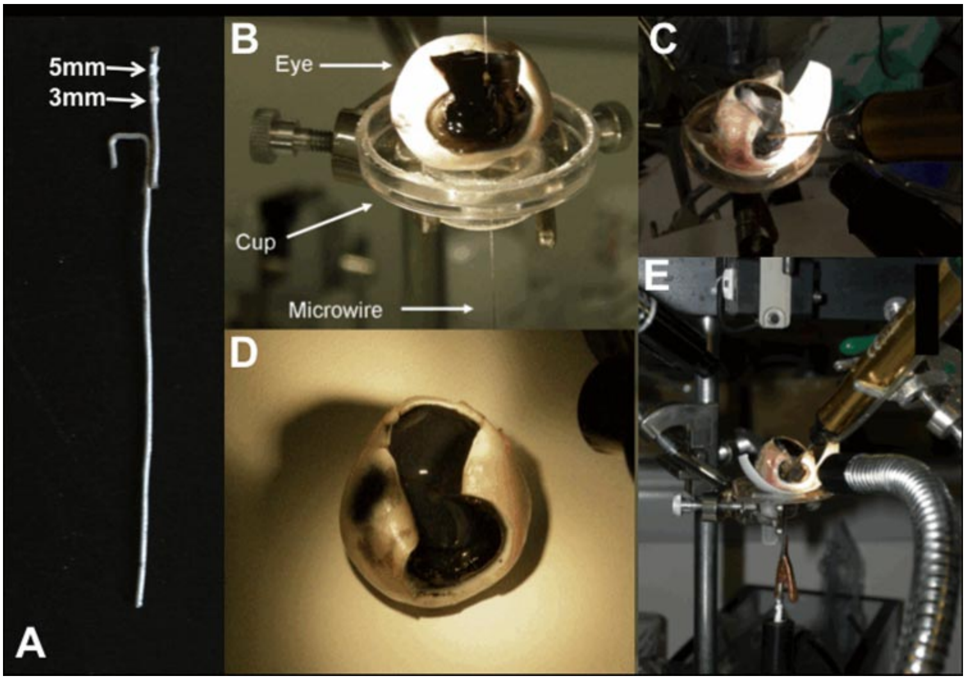


**FIGURE 1.** (**A**) Model of the hook used to fix the retinal layer to the load cell. (**B**) Schematic model of the eye, microwire, and cup used to measure the vitreoretinal traction. (**C**) Position of the eye, cutter, and cup. (**D**) Eye model without vitreous. (**E**) Image of the full setup to measure traction.

angle adjacent to the choroid and retinal layer at the trephination site, and the traction was measured at 3 mm and 5 mm from the retina. To ensure the vitrector was at the right distance, an extension of the wire was made to the vitreous cavity with two marks (3 mm and 5 mm; Fig. 1A), and, with the use of a microscope, it was possible to adjust the cutter in the right position (Fig. 1E). To quantify the vibration effects of the cutter, a setup with cutter *on* and aspiration *off* was used and did not show any traction (Fig. 2).

Data from the strain gauge was outputted to dynamic mechanical analysis (DMA) software, which produces a graph of gram versus time of recording. Once the vitreous cutter is positioned for measurement, the output of the strain gauge is recorded for 10 seconds. For the first 2 seconds, the data are recorded with the vitreous cutting and aspiration turned off. During the next 4 to 6 seconds, data are recorded with the cutting and aspiration turned on. For the last 2 to 4 seconds, data are again recorded with the cutter and aspiration turned off. In this fashion each prepared porcine eye was used only for the testing of one vitreous cutter, per time, in predetermined cut speed, distance, and vacuum rate.

At a select vacuum, the changes in amplitude, as measured by the strain gauge (in grams), helped define the four phases of the cutter (port open, closing, closed, and opening). To analyze the traction, the maximum peak of each evolution in 1 second was evaluated (port open; Fig. 3). For each aspiration rate (150, 250, and 350 mm Hg) and distance from the retina (3 mm and 5 mm), five 20-gauge electrical cutters (Bausch & Lomb, New York, NY) were used at 600, 750, 1000, and 1500 (cpm).

The specific strain gauge (Electroforce 3100; Bose Corporation) quantifies the gram alterations in a single point of area. Equivalent values in force millinewtons are obtained by multiplying the results by

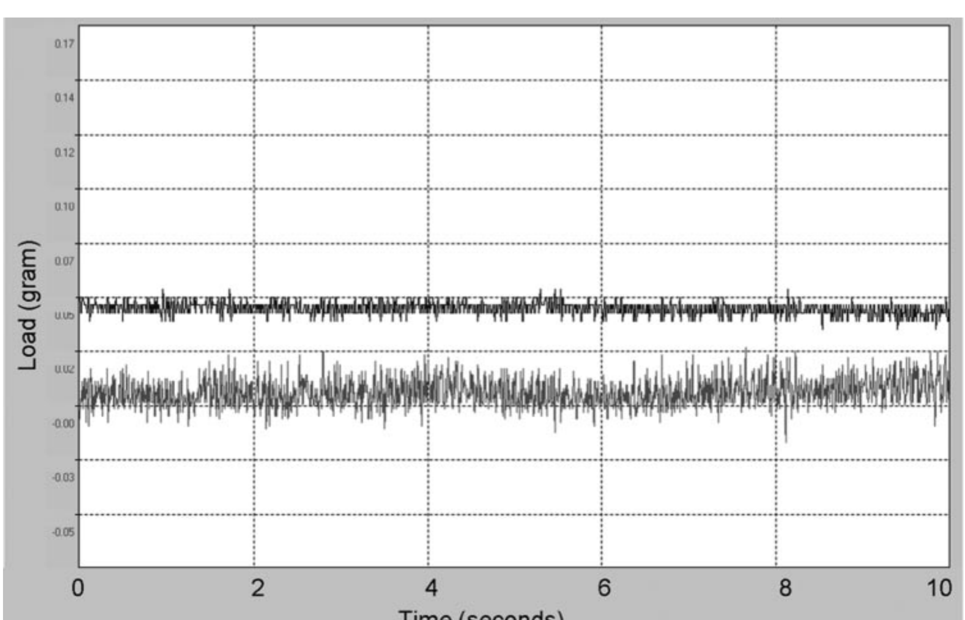


**FIGURE 2.** Graph shows results of the vitreous cutter positioned in the vitreous, with the cutter *on* and aspiration *off*. This shows no measurable change in traction.

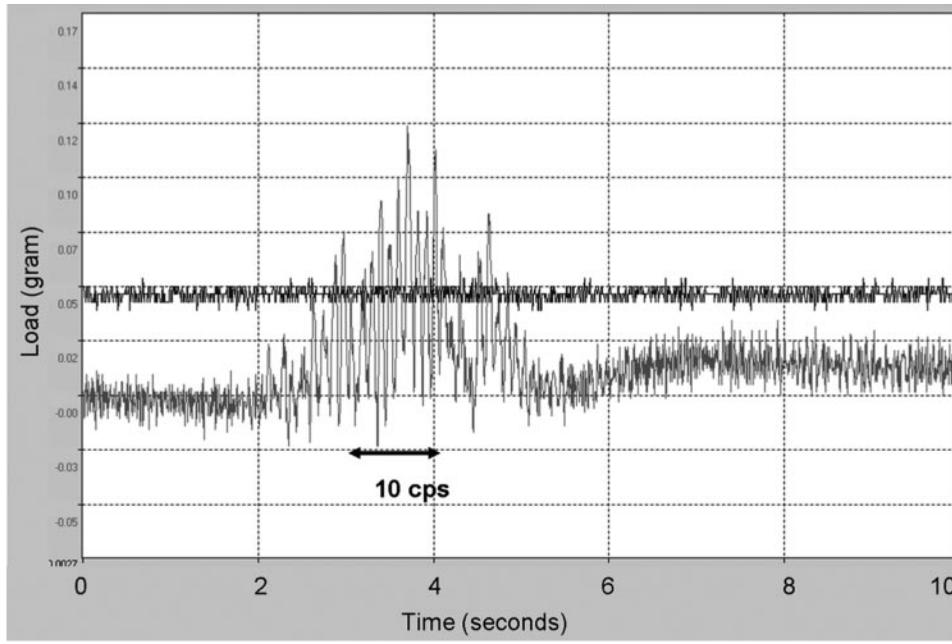


**FIGURE 3.** Eye 1 with vitreous using 150 mm Hg vacuum and 600 cuts/min as parameters. Alterations of the values in amplitude of the graph (in grams) represent the duty cycle (open, closing, closed, and opening). The highest peaks are equal to the highest traction (port open). One dyne is equivalent to 98 grams.

9.8. The value is converted to dynes using a conversion factor of 10 (www.unitconversion.org).[17] Performing the experiment in water as a control was important because water is not attached to the retina; therefore, no pulling force or traction was exerted.

The data were analyzed by vacuum rate, cpm, and distance (3 mm and 5 mm). Paired *t*-tests were used to compare dynes between 3-mm and 5-mm distances and between the lowest and highest cpm, whereas repeated-measures analysis of variance (ANOVA) tested mean dynes across cpm levels. Mixed models with repeated measures were used to obtain regression equations for predicting mean dyne. Programming language (SAS v9.1; SAS Institute, Cary, NC) was used for all analyses. The accepted level of significance for all tests was $P < 0.05$.

## RESULTS

### Traction Results from the Eyes with Vitreous Gel

Before the vitreous gel was removed, in all tests it was possible to identify alterations in the graphic amplitude to depict the cut rates and average vitreoretinal traction at 3-mm and 5-mm distances from the retina (Fig. 3; Table 1).

For all cutters the vitreoretinal traction increased by 7.90 dyn for every 100 mm Hg of vacuum increase ($P < 0.001$), decreased by 2.5 dyn for every 500 cpm increase ($P < 0.001$), and increased by 2.1 dyn at 3 mm from the retina independent of the cut and vacuum rates. The regression equation for predicting mean traction has an $R^2 = 0.94$ (Fig. 4). Because of the increased traction and the already detached condition of the retina, we could not measure the traction force at 3 mm from the retina at 450 mm Hg and 550 mm Hg. In some eyes the aspiration rate was sufficient enough to tear the retina; at this point the graph had enough information to find the exact time of the tear (Fig. 5).

### Traction Results from the Eyes Filled with Water

It was not possible to record traction when the eye was filled with water (Fig. 6). It was impossible to observe peak alterations (e.g., port open, closing, closed and opening) at any cut or vacuum rate. The only alteration observed during the experiment was a slight upward slow drift in the strain gauge values as more water was removed (Figs. 1D, 6).

## DISCUSSION

Traction is a complex relationship between the cutter port geometry, pressure differential, aspiration flow, cut speed, density, and vitreous flow. When surgeons are performing PPV, they automatically control traction by varying the aspiration pressure, cut speed, and distance to the retina. Our previous laboratory procedure describes our methods to measure vitrectomy duty cycle, water and vitreous fluid flow rates, and the

**TABLE 1.** Vitreoretinal Traction of 20-Gauge Electric Cutters at Different Cut Rates, Vacuum, and Distance from the Retina

| Vacuum Level (mm Hg) | Gauge | Cutters Used | Distance from the Retina (mm) | Cut Rate* (cpm) | | | | P (ANOVA) |
|---|---|---|---|---|---|---|---|---|
| | | | | 600 | 750 | 1000 | 1500 | |
| 150 | 20 | 5 | 5 | 5.46 (±0.54) | 4.59 (±0.37) | 3.98 (±0.22) | 3.60 (±0.45) | <0.001 |
| | | 5 | 3 | 7.88 (±0.31) | 7.36 (±0.64) | 5.50 (±0.25) | 4.67 (±0.13) | <0.001 |
| 250 | 20 | 5 | 5 | 11.50 (±1.51) | 11.00 (±1.27) | 9.23 (±2.73) | 8.46 (±1.00) | 0.04 |
| | | 5 | 3 | 15.10 (±1.77) | 13.98 (±1.24) | 12.76 (±1.41) | 12.03 (±0.35) | 0.01 |
| 350 | 20 | 5 | 5 | 17.61 (±2.23) | 16.23 (±3.00) | 13.97 (±1.96) | 13.56 (±0.89) | 0.01 |
| | | 5 | 3 | 26.50 (±2.63) | 23.96 (±2.00) | 23.58 (±0.03) | 21.10 (±2.11) | 0.03 |
| 450 | 20 | 5 | 5 | 31.16 (±5.98) | 27.46 (±5.71) | 24.13 (±4.08) | 21.39 (±2.85) | <0.001 |
| 550 | 20 | 5 | 5 | 41.78 (±9.72) | 38.58 (±7.72) | 34.96 (±5.53) | 31.88 (±2.43) | <0.001 |

* Values represent traction as measured in dynes (±SD).

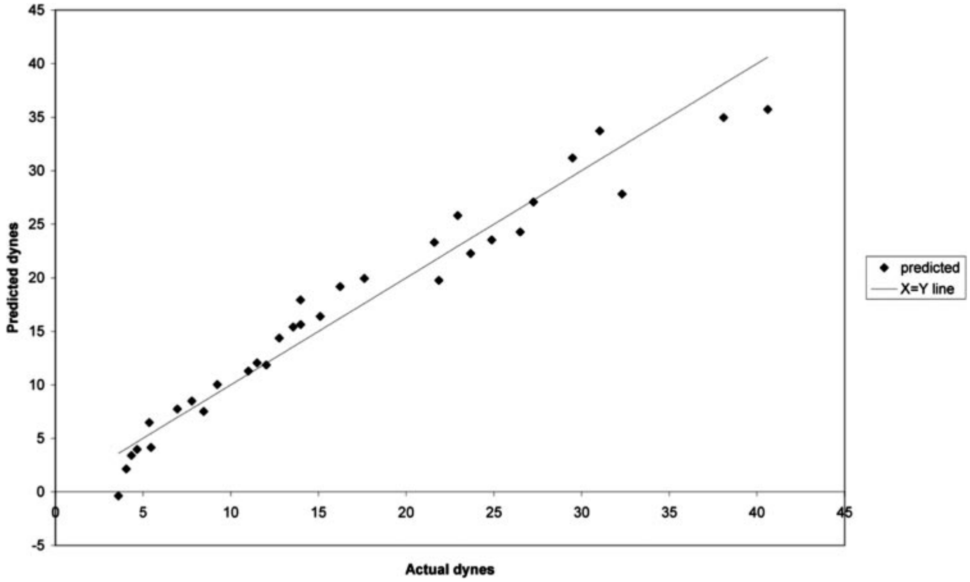


**FIGURE 4.** Prediction indicates traction of 20-gauge electric cutter.

movement of vitreous around the aperture of cutters.[14,18,19] In addition, we recently developed a new method to quantify traction applied to the retina by the vitreous cutter during vitrectomy.

This discovery could contribute to better understanding of the relation between the vitreous and the cutters and could allow comparison of results from different cutters to improve their design.

The specific strain gauge (Electroforce 3100; Bose Corporation) has typical applications in biomechanics, and the DMA software gives the results in grams or millimeters of tissue, elastomers, or other soft materials compared with time. Reproduction of the study in eyes filled with water is important because water is not attached to the retina; hence, there is no pulling force or traction. To quantify the vibration effects of the cutter, a setup with cutter *on* and aspiration *off* was used and did not show any traction or different alteration in the graph (Fig. 2). Those two data increase the accuracy of the results and method.

Our principal goal was to find a way to measure the real traction applied to the retina during vitrectomy. The hook made by microwire was the bridge to fix the retina into the strain gauge. Once the microwire was fixed, it was possible to quantify the pulling force applied to the retina by the vitreous. This method was more accurate because only the point fixed with the microwire contributed to the result. Other models have used theoretical measurements to predict traction but lacked experimental confirmation.[20] Another benefit of our method was the ability to observe the four phases of the cutter cycle (port open, closing, closed, and opening; Fig. 3) and matching the exact value with each phase (e.g., 10 peaks/s using 600 cpm). These two factors demonstrate the accuracy of the method. Outside the tube is a port, and inside the tube is a guillotine that closes the port and cuts the vitreous. The regression equation shows an accuracy of 94% for this cutter; Figure 4 better describes the slope.

Heterogeneity of the vitreous is a complicating factor.[3] Therefore, vitreous flow studies have demonstrated significant variations (DeBoer C, et al. *IOVS* 2006;47:E-Abstract 5254).[10,12,14,18,21] Furthermore, the variability of the recorded traction (Fig. 3) is caused by the movement of the vitreous around the tip, the vitreous deformation, and the possibility of vitreous obstruction. This peak-to-peak variability in traction was observed more frequently at low cut rates than high cut rates (Fig. 7). This result demonstrates that the cut speed is an important factor for decreasing the induced variability in vitreoretinal traction. Higher cut rates fragment the vitreous into smaller pieces, producing less deformation and less obstruc-

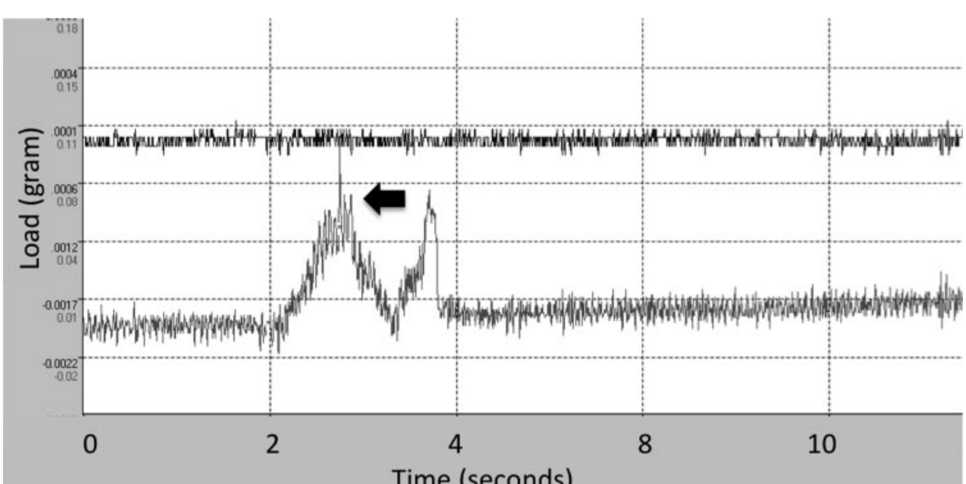


**FIGURE 5.** Graph shows exactly when the cutter tore the retina (*arrow*), between 2 and 4 seconds. The peak declined quickly.

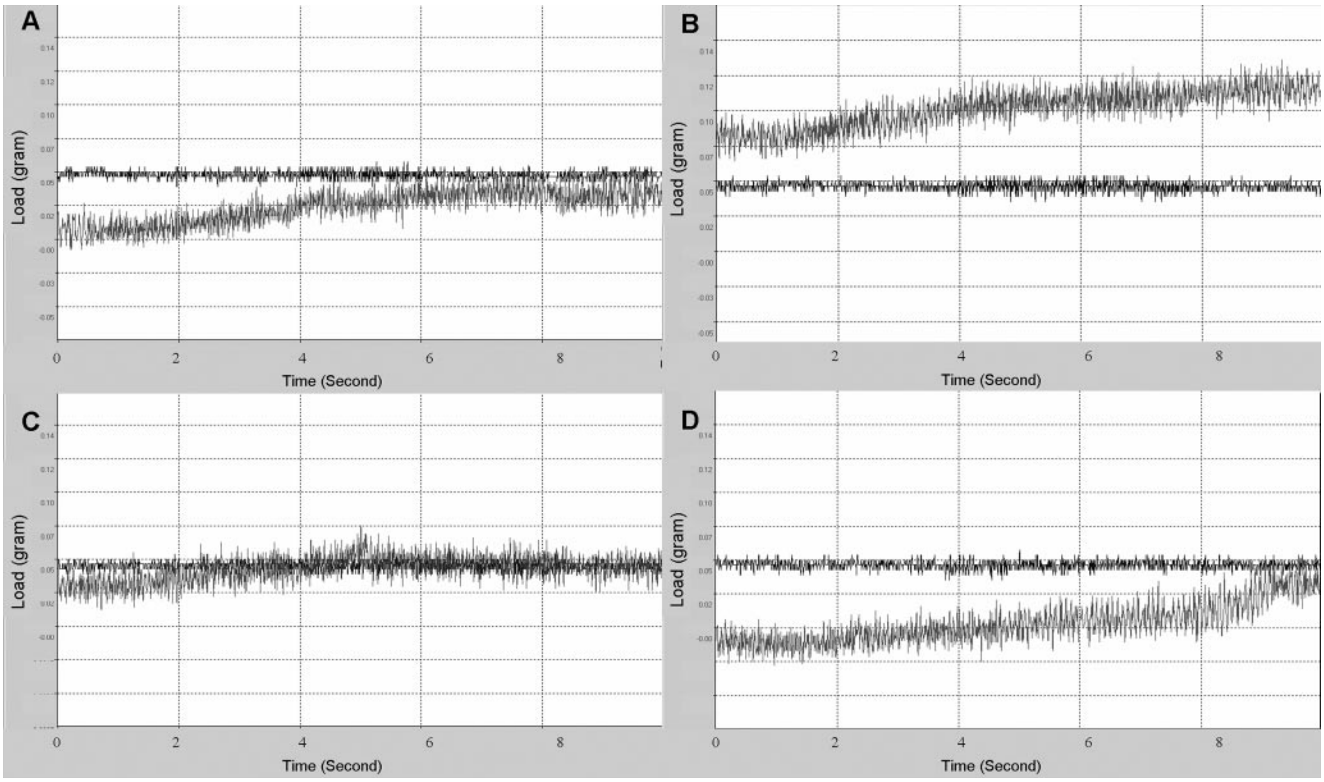


**FIGURE 6.** Eye 1 results without vitreous and with the vitreous cavity filled with water. No evidence of traction peaks. The graphs show a linear trend after the cut and aspiration are *on* from the beginning to the end of the experiment because the cutter removed a certain amount of water during the trial, decreasing the weight of the eye. (**A**) 150 mm Hg at 600 cpm. (**B**) 250 mm Hg at 600 cpm. (**C**) 150 mm Hg at 1500 cpm. (**D**) 250 mm Hg at 1500 cpm.

tion. This same effect on the vitreous of higher cut rates has also been shown to increase the flow rate provided the DC is taken into account.[12,14]

A cutter with 50% duty cycle was chosen because duty cycle has an important influence on flow rate, especially at rapid cutting speeds (DeBoer C et al. *IOVS* 2006;47:E-Abstract 5254).[12] Most pneumatic cutters have a variable DC, with the cutter closed more than open at high cut rates; this variation of the open and closed phases can influence traction.[12,14,18,19,21,22]

Higher aspiration vacuum leads to larger volumes of fluid and vitreous pulled into the port per cut. The driving force for removal is high, and the surrounding tissue experiences a large removal force, corresponding to high traction. When the aspiration vacuum is lower, less volume is pulled with less traction. Our results demonstrate an increase of 7.28 dyn for each 100-mm Hg increase for this cutter.

Reproducing the experiment in a water-filled eye without vitreous demonstrated that traction depends on the removed substance, leading to a better understanding of results. Figure

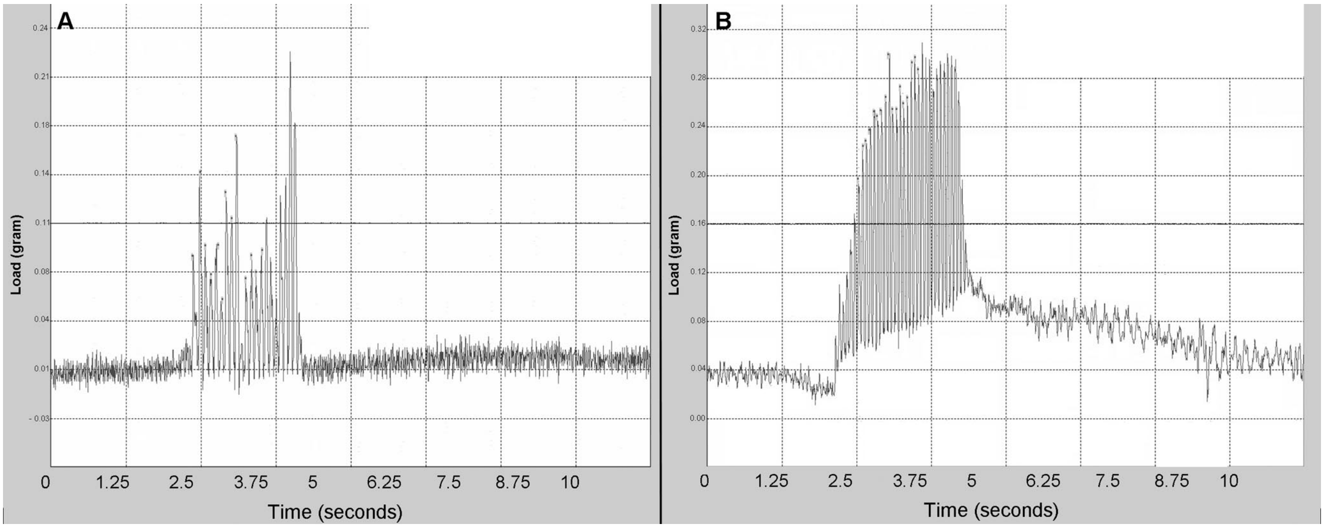


**FIGURE 7.** (**A**) At low cut rate (750 cpm), the graph shows an inconsistent peak trend because of the movement of the vitreous around the tip, vitreous deformation, and the possibility of obstruction. (**B**) Higher cut rate (150 cpm) shows a linear peak trend.

6 shows a slow upward drift from the beginning to the end of the experiment, corresponding to the removal of water during the trial. This graph did not show the high peak-to-peak alterations indicative of tractional forces, as seen when the cutter was in vitreous.

When compared with adhesive forces, traction between the retina and the retinal pigment epithelium (RPE) demonstrates the safety of the vitrectomy procedure. Measurements have shown an attachment force of 100 to 180 dyn/cm between the retina and the RPE.[23,24] This adhesion force is 180% stronger in cats[25] and 140% stronger in monkeys[24] than in the rabbit. This study in freshly enucleated porcine eyes shows that the vitreoretinal traction values are at least 3.6 to 4.34 times lower than the retinal adhesion forces to the RPE at 350 mm Hg and 6 to 20 times lower at reasonable vacuum rates (150–250 mm Hg) in porcine eyes. Hence, these results are important to be aware of when setting parameters for removing the vitreous from a detached retina. However, these tractional forces can result in iatrogenic damage if the retina is already detached. Last, all measurements were made with the cutter fixed with a micromanipulator; the surgeon's movement of cutters within the eye could add tractional forces.

In conclusion, this study establishes a model to test vitreoretinal traction during vitrectomy and demonstrates that vacuum rate, cut speed, and distance of the cutter from the retina are important factors.

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