



Effect of a new phacoemulsification and aspiration handpiece on anterior chamber stability

Hisaharu Suzuki, MD, PhD, Tsutomu Igarashi, MD, PhD, Hiroshi Takahashi, MD, PhD

Purpose: To evaluate the responsiveness of 3 phacoemulsification and aspiration (PEA) systems and a new handpiece to occlusion break by measuring anterior chamber depth (ACD) and intraocular pressure (IOP).

Setting: Zengyo Suzuki Eye Clinic, Kanagawa, Japan.

Design: Experimental study.

Methods: ACD change during intentional occlusion breaks was observed and evaluated using the slit side view (SSV) method and IOP measurement with the Centurion Vision System (Group 1), Centurion Vision System with Active Sentry (Group 2), Infiniti Vision System (Group 3), and Constellation Vision System (Group 4). 5 eyes were included per group. Occlusion breaks were triggered at IOP of 30 mm Hg, vacuum limits of 550 mm Hg, and aspiration rate of 40 mL/min. ACD change ratio, surge duration, and

surge volume were analyzed from videos of SSV and IOP measurement.

Results: The smallest ACD change was observed in Group 2 with SSV. ACD change ratios in Groups 1 to 4 were $17.5\% \pm 3.9\%$, $7.3\% \pm 1.2\%$, $35.7\% \pm 9.5\%$, and $74.1 \pm 7.7\%$, respectively. Surge duration and surge volume were calculated only for Groups 1 and 2 and were significantly lower in Group 2 than in Group 1 (0.32 ± 0.03 vs 1.17 ± 0.07 seconds; 18.91 ± 4.70 vs 45.70 ± 0.83 μ L). In these 2 groups, ACD change ratio correlated with surge volume.

Conclusions: This study evaluated the responsiveness of 3 PEA systems and a new handpiece to occlusion breaks by measuring IOP and ACD. The Active Sentry system was useful for maintaining the ACD even during occlusion breaks.

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For safe phacoemulsification and aspiration (PEA) cataract surgery, it is important to understand fluid dynamics in the anterior chamber and how they impact the stability of the anterior chamber depth (ACD). In conventional PEA systems, an irrigation solution is supplied passively from a bottle hung at an appropriate height. In this gravity-based fluidic system, the flow rate of the irrigation fluid depends on the height of the bottle. Surgeons often need to place the bottle higher and increase the pressure to relieve anterior chamber fluctuations. However, high pressure can easily damage intraocular tissues such as the cornea, iris, and optic nerve.¹ Lowering the irrigation bottle during surgery significantly reduced corneal endothelial damage.² However, the ACD can easily become unstable with lower irrigation flow, particularly when occlusion breaks occur. Anterior chamber instability from occlusion break surge results in

anterior chamber shallowing and complications such as posterior capsule rupture and vitreous loss.^{3,4}

The Centurion Vision System (Alcon Vision LLC; hereafter Centurion) introduced in 2012 features the Active Fluidics technology, which compresses or decompresses the balanced salt solution fluid bag with 2 metal plates and adjusts the perfusion flow in time to maintain intraocular pressure (IOP) to compensate for flow losses.^{5,6} This technology provides active IOP control during surgery, which is especially important in a lower IOP setting. Centurion also passively mitigates surges using appropriate, low-compliant suction tubing.^{5,7} The Active Sentry handpiece (Alcon Vision LLC; hereafter, Active Sentry) was recently introduced.^{8–10} This new handpiece incorporates an irrigation pressure sensor that quickly detects IOP changes in the anterior chamber and stabilizes IOP during surgery.

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From the Zengyo Suzuki Eye Clinic, Kanagawa, Japan (Suzuki); Department of Ophthalmology, Nippon Medical School, Chiba Hokusoh Hospital, Chiba, Japan (Igarashi); Department of Ophthalmology, Nippon Medical School, Tokyo, Japan (Takahashi).

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Corresponding author: Hisaharu Suzuki, MD, PhD, Zengyo Suzuki Eye Clinic, 1-22-11 Zengyo, Fujisawa City 251-0871, Kanagawa, Japan. Email: s5054@nms.ac.jp.

Few previous studies have shown that anterior chamber stability can be maintained with PEA systems by measuring changes in aqueous volume and IOP after occlusion breaks, but no study has visually observed or quantitatively evaluated the change in the ACD during occlusion break.^{8–10} In addition, no study has reported on the relationship between ACD and IOP change as postocclusion surge volume during surgery. Since 2017, we have recommended and used the slit side view (SSV) method to visually evaluate fluid flow within the anterior chamber during surgery as it clearly provides better volumetric view of the chamber compared with any other method.¹¹ SSV also enables the visualization of changes in the ACD during surgery. In this study, we observed changes in the ACD using 3 PEA systems and a new handpiece using the SSV method and evaluated their responsiveness to occlusion break by measuring changes in the ACD and IOP.

METHODS

Ethical Considerations

Because extracted porcine eyes obtained from a local abattoir were used in this study, this is outside the scope of the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research. The ethics committee ruled that approval was not required for the study.

Porcine Eyes

Twenty fresh porcine whole eyes enucleated from animals were purchased from Tokyo Shibaura Entails Ltd. and stored in a controlled laboratory environment. The eyes used in this study were delivered to the laboratory within 1 day of preservation. Porcine eyes without corneal clouding, vitreous leakage, or obvious ocular damage were selected. The eyes were divided into 4 groups, with 5 eyes per group.

Phacoemulsification and Fluid Dynamics Configurations

The PEA systems used were as follows: Centurion with Active Fluidics and OZil handpiece (Group 1) (Alcon Vision LLC), Centurion with Active Fluidics and Active Sentry (Group 2), Infiniti Vision System (Alcon Vision LLC; hereafter Infiniti) and OZil handpiece (Group 3), Constellation Vision System (Alcon Vision LLC; hereafter Constellation), and OZil handpiece (Group 4). Centurion and Infiniti use a peristaltic pump to control aspiration flow, whereas Constellation uses a Venturi pump. Infiniti and Constellation use gravity-based fluid systems. To minimize variations among the experiments, a 0.9 mm mini-flared 45-degree Kelman aspiration bypass system phaco tip and UltraSleeve (Alcon Vision LLC) were used for all tests.

Study Maneuver

Under an ophthalmic microscope (LuxOR Revalia; Alcon Vision LLC), a 2.4 mm corneal incision was first created in the porcine eye. A cohesive ophthalmic viscosurgical device (Provisc; Alcon Vision LLC) was injected through the incision. To measure changes in the ACD, the central part of the cornea was marked with oil-based ink, and the center of the anterior capsule of the lens was marked with a 27G needle.

The porcine eye was transferred to the slitlamp microscope stand where the eye was stabilized and set up such that a 2.4 mm corneal incision could be made at the 12 o'clock position, as previously reported.^{11,12} A phaco tip was inserted through a corneal incision and stabilized over the iris surface. Changes in the anterior chamber were observed using a slitlamp microscope BI900 (Haag-Streit, Koeniz, Switzerland). We named this procedure the SSV.^{11,12}

Intraoperative IOP was measured using a device consisting of the following 4 parts: a 25G needle, a pressure transducer, a universal pressure meter (IX-TA-220 Recorder with Integrated Sensors; iWorx, Dover, NH, USA), and a monitor. Figure 1 shows

a schematic diagram of the test setup. Before starting the measurements, the pressure transducer was calibrated using a digital manometer M-382 (AS ONE Corp., Japan). The 25G needle tip of the pressure transducer was inserted from the limbus into the anterior chamber at the 3 o'clock position. The pressure transducer was placed at the same height as the porcine eye to eliminate head height errors. The IOP was recorded continuously during the procedure. The slit light was then aligned with the needle insertion area. The corneal diameter of the area exposed to slit light was measured to set the base value when measuring the ACD.

Phacoemulsification was performed in porcine eyes using each PEA system. The procedure was performed via a superior 2.4 mm corneal incision. The PEA handpiece and eyeball were fixed on a fixed table to minimize leakage from the incision and stabilize conditions so that incisional leakage would not affect changes in the ACD and IOP. Groups 1 and 2 were tested using a target IOP setting of 30 mm Hg. Gravity-based PEA systems (Groups 3 and 4) were tested at a bottle height of 41 cmH₂O, which is equivalent to 30 mm Hg. In preliminary experiments, each PEA system was tested for its responsiveness to occlusion break at an IOP of 20 mm Hg with a high vacuum pressure setting. However, at an IOP of 20 mm Hg, the ACD of gravity-based fluidic systems could not be measured because the anterior chamber collapsed. Therefore, in this experiment, the IOP was set to 30 mm Hg. All PEA systems were tested with an aspiration rate of 40 mL/min, vacuum limit of 550 mm Hg, ultrasonic oscillation setting of 0%, and IOP setting of 30 mm Hg.

After pressing on a foot pedal to remove the ophthalmic viscosurgical device by aspiration, the irrigation-only state was maintained to stabilize IOP. The aspiration tube was pinched with pliers, occluded for 3 seconds, and released after 3 seconds. This procedure was repeated 4 times. During the intentional occlusion break surge event, IOP changes and SSV images were continuously recorded. Waveforms representing IOP before and after the occlusion break are shown in Figure 2.

Examination

ACD changes during occlusion break were observed using the SSV method and recorded. The ACD distance between the marked corneal apex (P1) and anterior lens capsule on screen (P2) was measured using an image analysis software from DITECT Image Processing Products (DITECT), and the ACD change ratio after the occlusion break was calculated (Figure 3). The corneal diameter was used for calibration. After defining the marked corneal apex and anterior lens capsule on screen, changes in the distance between the 2 points were measured. The percentage change in the ACD after the occlusion break was calculated for each group. The IOPs obtained from the postocclusion break surge testing were analyzed using LabScribe 3 (iWorx), and baseline IOP, reduction rate, surge duration, and surge volume were evaluated.

Data Conversion and Analysis

The baseline IOP, minimum IOP, and surge duration for each eye during the postocclusion surge were extracted from the recorded IOP waveforms using LabScribe 3 software. The mean and standard deviation were calculated for each group. The mean reduction rate from baseline was calculated as $([\text{baseline IOP} - \text{minimum IOP}] / \text{baseline IOP}) \times 100\%$ in each group.

The mean surge volume for each PEA system was calculated from the IOP and surge duration using the conversion equation of Dyk et al.^{8,13} In addition, the correlation between ACD and surge volume was evaluated.

Statistical Analysis

In this experiment, the Mann-Whitney *U* test and the Kruskal-Wallis test were used to compare the groups. Correlation analysis of ACD and surge volume was performed using the Pearson product-moment correlation (*r*). Statistical significance was set at *P* < .05. All data were analyzed using Excel 2019 software (Microsoft Corp.).

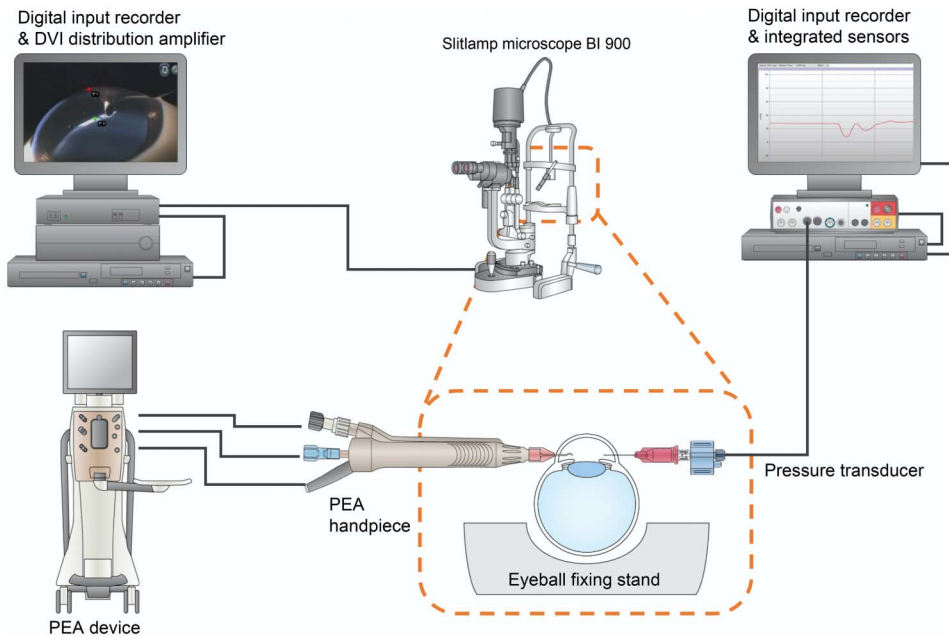


Figure 1. Components of the IOP and SSV experimental test setup. PEA = phacoemulsification and aspiration; SSV = slit side view

RESULTS

Observation of ACD Using SSV

The changes in the ACD in the 4 PEA systems observed with the SSV are shown in Figure 3. In Group 1, when the foot pedal was depressed, the ACD was visually stable. After the occlusion break, the ACD slightly changed and quickly recovered. In Group 2, which included an Active Sentry, the system had a perfusion pressure sensor integrated into the ultrasonic handpiece. When the foot pedal was depressed, the ACD was visually stable and remained stable, even when an occlusion break occurred. In Group 3, when the foot pedal was depressed, the ACD became shallow. The ACD recovered when the aspiration tube was occluded; however, once the aspiration tube was released and the occlusion break surge occurred, the ACD changed significantly and did not recover. In Group 4, the anterior chamber collapsed soon after the foot pedal was depressed. The ACD recovered when the aspiration tube was occluded; however, the anterior chamber collapsed once the aspiration tube was released.

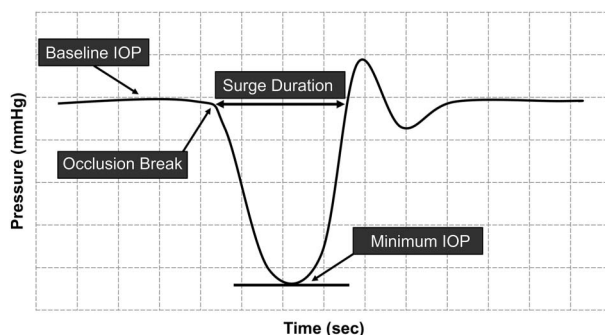


Figure 2. Definition of waveforms in changes in IOP before and after an occlusion break.

Change Ratio in ACD

The ACD change ratio for each PEA system is shown in Figure 4. The ACD change ratios in Groups 1, 2, 3, and 4 were $17.5\% \pm 3.9\%$, $7.3\% \pm 1.2\%$, $35.7\% \pm 9.5\%$, and $74.1\% \pm 7.7\%$, respectively. There was a significant difference among the 4 groups in the ACD change ratio ($P = .00047$ Kruskal-Wallis test). There was a significant difference

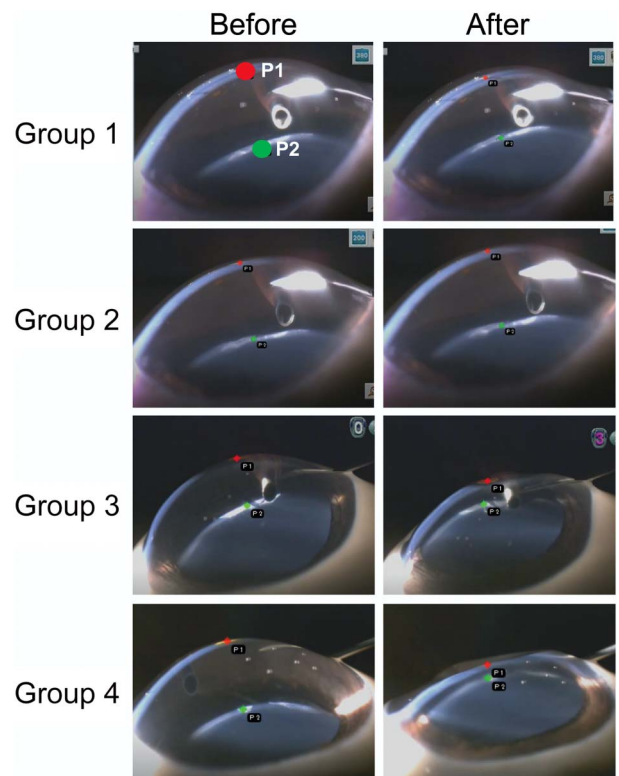


Figure 3. Photograph of anterior chamber change before and after the occlusion break using slit side view.

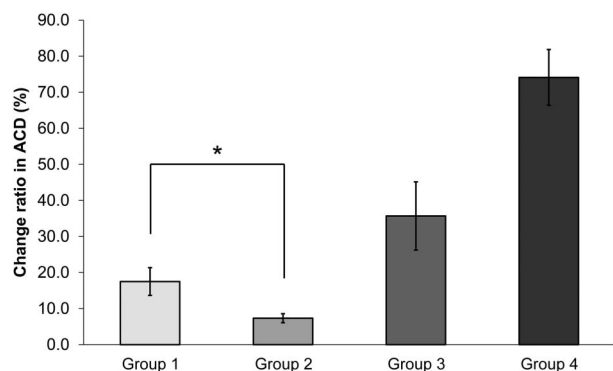


Figure 4. Change ratio in ACD. $P < .05$, Kruskal-Wallis test; * $P < .05$, Mann-Whitney U test. ACD = anterior chamber depth

between Groups 1 and 2 ($P = .02646$ Mann-Whitney U test).

Baseline IOP, Reduction Rate and Surge Duration, and Surge Volume

There was no significant difference in baseline IOP and reduction rate among Groups 1, 2, and 3 ($P = .40529$ and $P = .53259$, respectively, Kruskal-Wallis test) (Table 1). The baseline IOP and reduction rate were not detected accurately in Group 4. The surge duration (0.32 ± 0.03 seconds) and surge volume ($18.91 \pm 4.70 \mu\text{L}$) were also significantly lower in Group 2 than in Group 1 (1.17 ± 0.07 seconds and $45.70 \pm 0.83 \mu\text{L}$, with $P = .02646$ and $P = .03745$, respectively, Mann-Whitney U test), but were not detected accurately in Groups 3 and 4 (Table 1).

Correlation Between ACD and Surge Volume

In Groups 1 and 2, the ACD change ratio correlated with the surge volume ($r = 0.7494$, $P = .01258$) (Figure 5). In Groups 3 and 4, changes in IOP could not be measured accurately because of anterior chamber collapse after the occlusion break.

DISCUSSION

There are many advantages of cataract surgery with low IOP considering the damage to the corneal endothelium or glaucomatous optic neuropathy.^{2,14,15} However, instability of the ACD can be a problem with low IOP cataract surgery, particularly when an occlusion break occurs. To prevent surges, there is also a method of performing surgery at high IOP. However, because low IOP surgery is considered to be less invasive to the eyeball, we selected an IOP setting of

30 mm Hg in this experiment. In the current study, we evaluated the responsiveness of a new handpiece and 3 PEA systems based on the change in the ACD during occlusion break at low IOP settings. We found that the responsiveness of Active Sentry was qualitatively and quantitatively superior to that of other PEA systems with conventional handpieces.

The pump mechanisms of the PEA systems tested in this study are different. In Group 4 (Constellation), the change in the ACD with occlusion break was the largest, resulting in anterior chamber collapse, and it was not possible to measure IOP changes during the surge. Constellation (Group 4) uses a Venturi pump system, in which the suction pressure correlates with the perfusion pressure, making it difficult to maintain the ACD with a low perfusion pressure. Infiniti (Group 3) uses a peristaltic pump in which the suction pressure is independent of the perfusion pressure. However, the change in the ACD with occlusion break was also large, resulting in anterior chamber collapse. This is due to the delayed recovery of the ACD caused by the insufficient fluid supply from the passive perfusion pressure of gravity or the inability to mitigate the vacuum demand after the occlusion break without fluid outflow from the eye. Thus, cataract surgery with low IOP using these systems would be difficult to perform safely.

The Centurion with Ozil handpiece (Group 1) is equipped with Active Fluidics, which uses a variable input pressure and can actively supply fluid into the anterior chamber to mitigate flow losses and deliver consistent IOP. Even when an occlusion break occurs, the fluid outflow is minimized due to the higher resistance and lower compliance tubing, and the ACD is maintained. However, the IOP sensor is installed in the main body of the PEA machine. Therefore, the response can be delayed, that is, the surge event will have already passed before the system can react to mitigate the surge. In contrast, Centurion with Active Sentry (Group 2) could measure the perfusion pressure in real time with an ultrasonic handpiece and quickly send a digital signal to the PEA system, allowing the system's vent valve to briefly vent and reduce the vacuum demand, resulting in reduced amount of fluid outflow from the anterior chamber. Therefore, the change in the ACD, even with an occlusion break, was very small.

The ACD change ratios and their SDs with Centurion with Ozil handpiece (Group 1) and Centurion with an Active Sentry (Group 2) were significantly smaller than those of the gravity-based fluidic systems, Infiniti (Group 3) and Constellation (Group 4) (Figure 4). Clearly, the new fluid

Table 1. Analysis data of the IOP sensor for each item

	Baseline (mm Hg) Mean $\pm$ SD	Reduction rate (%) Mean $\pm$ SD	Surge duration (s) Mean $\pm$ SD	Surge volume (μL) Mean $\pm$ SD
Group 1	30.38 $\pm$ 1.42	79.56 $\pm$ 7.07	1.12 $\pm$ 0.07	45.70 $\pm$ 0.83
Group 2	31.95 $\pm$ 4.59	85.53 $\pm$ 10.42	0.32 $\pm$ 0.03*	18.91 $\pm$ 4.70*
Group 3	29.96 $\pm$ 0.87	79.56 $\pm$ 4.47	—	—
Group 4	—	—	—	—

* $P < .05$, Mann-Whitney U test.

$P < .05$ Kruskal-Wallis test

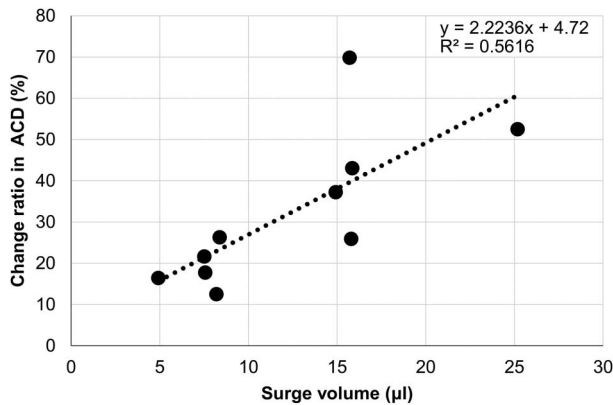


Figure 5. Correlation diagram of change ratio in ACD and surge volume. ACD = anterior chamber depth

dynamics technology provides consistent ACD stability. To the authors' knowledge, this is the first report to evaluate anterior chamber stability based on the change in the ACD.

Differences in response latency between the Centurion with Active Sentry (Group 2) and that without Active Sentry (Group 1) were confirmed by the surge duration and surge volume (Table 1). The speed at which the IOP recovers to its baseline level after an occlusion break indicates how fast any fluidic system responds to changes in IOP. Centurion with an Active Sentry (Group 2) recovered to the baseline IOP 0.8 seconds faster than Centurion without an Active Sentry (Group 1), indicating a greater sensitivity and response to the surge of Active Sentry. Similarly, Vasavada et al. showed in rabbit eyes that Centurion with Active Sentry has a faster recovery to baseline IOP than Centurion without Active Sentry by calculating the rate of IOP increase after occlusion break.⁸ In addition, some studies have evaluated the aqueous volume changes after occlusion breaks.^{5,7,9,10} This is because the volume change associated with an occlusion break is clinically important. Andrew et al. reported that Centurion with Active Sentry has lower percentage aqueous volume loss than Centurion without Active Sentry after an occlusion break using human eye model.¹⁰ Our result is consistent with the previous report. Furthermore, in Groups 1 and 2, the surge volume and ACD change ratio were significantly correlated, suggesting that minimizing surges over a short period is important to stabilize the ACD (Figure 5).

This study has some limitations. The ACD of the porcine eye is different from that of the human eye. Furthermore, real surgery involves operating on the eyeball inside the orbit; however, for this study, the porcine eyes were extracted. Therefore, these potential study limitations should be considered when interpreting the results of this study.

In conclusion, this study evaluated the responsiveness of a new handpiece and 3 different PEA systems to occlusion breaks by measuring IOP and ACD. Consequently, we were able to show the ACD change ratio and the relationship between ACD and surge volume. Also, Active Sentry, a new fluid dynamics mechanism, greatly contributes to ACD stability even when occlusion occurs, suggesting its usefulness in

cataract surgery with low IOP. Using Active Sentry, it is possible to reduce complications such as corneal endothelial damage and posterior capsule rupture. There have been remarkable advances in the development of cataract surgery devices. It is of utmost importance to understand these devices to safely perform surgeries.

WHAT WAS KNOWN

- Keeping IOP low during surgery protects the corneal endothelial cells.
- Active Fluidics Technology provides enhanced IOP control during the procedure compared with gravity-fluid systems.
- The newly introduced Active Sentry handpiece incorporates an irrigation pressure sensor that quickly detects IOP changes in the anterior chamber and stabilizes IOP during surgery.

WHAT THIS PAPER ADDS

- Efficient surgery with low IOP is difficult with the Venturi pump phacoemulsification and aspiration machine.
- The small changes in anterior chamber depth and small surge volume in Centurion with Active Sentry make it possible for surgeons to perform safe and stable cataract surgery at low IOP.

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**First author:**

Hisaharu Suzuki, MD, PhD

Zengyo Suzuki Eye Clinic, Kanagawa, Japan