· Basic Research ·

A new tube chamber system for evaluation of anterior chamber pressure during phacoemulsification tested in porcine eyes

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Abstract

● **AIM:** To measure the optimal anterior chamber pressure (ACP) for safe phacoemulsification using a new tube chamber system with internal pressure measurement function in the porcine eye.

● **METHODS:** The 20-gauge and 21-gauge straight tips with yellow and orange sleeves, respectively, were covered by a test chamber combined with a pressure sensor for measuring ACP. This was measured for 20s from 10s after starting aspiration in the linear mode using vacuum levels of 200 and 150 mm Hg with a 20-gauge tip, and 300 and 250 mm Hg with a 21-gauge tip. Using a porcine eye, a pressure sensor fixed with a 0.9 mm corneal incision measured ACP. For the posterior capsule contact assay, porcine eyes were treated as described above, and the ultrasonic needle tip was held at the height of the iris and aspirated for 30s in linear mode at a vacuum of 200 and 150 mm Hg for the 20-gauge tip, and 300 and 250 mm Hg for the 21-gauge tip. The bottle height at which the posterior capsule accidentally contacted the ultrasonic tip was recorded, and the estimated ACP was calculated.

● **RESULTS:** The internal pressure of the new tube chamber system and ACP from the porcine eye closely matched proportional changes at vacuum levels of 200 and 150 mm Hg with 20-gauge tips. Similarly, proportional changes at vacuum levels of 300 and 250 mm Hg with the 21-gauge tip were nearly equal. The bottle height at which the posterior capsule contacted with the tip and estimated ACP were 57.5±12.6 cm (20.2±7.9 mm Hg) at 200 mm Hg with a 20-gauge tip, 35.0±10.0 cm (16.6±6.3 mm Hg) at 150 mm Hg with a 20-gauge tip, 47.5±12.6 cm (18.7±8.7 mm Hg) at 300 mm Hg with a 21-gauge tip, and 32.5±5.0 cm (15.7±3.5 mm Hg) at 250 mm Hg with a 21-gauge tip.

● **CONCLUSION:** A comprehensive understanding of this chamber system's characteristics and usage can resolve anterior chamber instability caused by changing preoperative settings on the phaco machine.

● **KEYWORDS:** test chamber; cataract surgery; settings; anterior chamber stability

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INTRODUCTION

Advances in cataract surgery, particularly in phacoemulsification, have enhanced the safety of this procedure[1]. However, surgical complications, including endophthalmitis, suprachoroidal hemorrhage, retinal detachment, and posterior capsule breakage, can still occur[2]. Posterior capsule breakage is a relatively common cataract surgery complication, has an incidence of approximately 0.5%-4.7%[3-4], potentially leading to cystoid macular edema[5-6], endophthalmitis[7-8], and severe inflammation or rhegmatogenous retinal detachment. This complication necessitates additional surgical interventions due to vitreous dropped lens fragments. A significant proportion (59.6%) of posterior capsule breakages have been reported to occur during phacoemulsification[9].

To prevent accidental posterior capsule breakage, a thorough understanding of phacoemulsification fundamentals, including ultrasound power modulation and fluidics, is essential[10-11]. Phacoemulsification settings significantly impact procedure safety and visual outcomes[12]. Various factors have crucial roles in maintaining the anterior chamber during cataract surgery. To maintain the stability of the anterior chamber during phacoemulsification surgery, fluidics, which refers to the balance between fluid inflow and outflow, should be regulated. Inflow fluid from the irrigation bottle travels through a plastic tube to the ultrasonic needle and flows into the eye's anterior chamber. While some phaco devices utilize a forced injection system, many rely on a gravity-based fluidic system based on bottle height to maintain proper anterior chamber pressure (ACP)[13-14]. After entering the anterior chamber, outflow fluid was suctioned into the ultrasonic needle and returned to the phaco machine pump through a plastic tube. The outflow fluid is regulated by the vacuum level created by the pumps, which are categorized as Venturi and peristaltic pumps. A Venturi pump maintains a constant vacuum level regardless of tip occlusion[15], while a peristaltic pump applies a vacuum level by closing the tip[16]. The fluid outflow was also affected by the diameter of the phaco tip[16]. The balance between inflow and outflow preserves the ACP intraoperatively[11]. However, few experimental reports have described ACP stability. In the conventional method, real-time measurement of human eye ACP requires inserting a measuring instrument directly into the eye.

We developed a new tube chamber system that can assess ACP in a non-occluded aspirate state with various phaco machine settings. In this study, we calculated the relationship between ACP and bottle height in phacoemulsification system with Venturi pump mode and recommended a safe setting range that would not cause posterior capsule breakage. This method can potentially enable an analogy of ACP without invading the patient's eye and to propose recommended safe internal pressures in a non-occluded aspirate state.

MATERIALS AND METHODS

Ethical Approval IRB/ethics committee of Yamaguchi University approval was not required as eyes that would be discarded at the meat market were used. All surgeries were conducted after eye nucleation, following the guidelines in the Statement for the Use of Animals in Ophthalmic and Visual Research.

Materials This study utilized a WHITESTAR SIGNATURE PRO phacoemulsification system in Venturi pump mode (Johnson & Johnson Surgical Vision, Santa Ana, CA, USA) along with a pressure sensor (AP-V80; KEYENCE, Tokyo, Japan) and data recorder (NR-600; KEYENCE, Tokyo, Japan). A chamber for obtaining pressure measurements was established by combining the pressure sensor with a test chamber [DUAL PUMP PACK (OPO73), Johnson & Johnson Surgical Vision, Santa Ana, CA, USA]. Considering the remaining bottle and cassette wear, cassettes and bottles were exchanged in each experiment. The height of the porcine eye, pressure sensors, and ultrasonic needle tip were set at 85 cm from the ground, aligning with previous reports[17].

Intrachamber and Anterior Chamber Pressure Measurements The 20-gauge and 21-gauge straight tips with a yellow and orange sleeves, respectively, were covered by the test chamber combined with a pressure sensor for measuring intrachamber pressure. In linear mode, the intrachamber pressure was measured for 20s from 10s after initiating aspiration using vacuum levels of 200 and 150 mm Hg with a 20-gauge tip and 300 and 250 mm Hg with a 21-gauge tip. It was measured at 10-cm and 1-cm intervals bottle height intervals when the internal pressures in the non-occluded aspirate were 5-25 mm Hg and approximately 0 mm Hg, respectively. Each experiment was repeated four times, and the average value was calculated.

Porcine eyes were obtained from a local abattoir (Hiroshima Meat Makket Co., Ltd., Hiroshima, Japan). Surgery involved a superior 2.4-mm corneal incision, followed by continuous curvilinear capsulorrhexis, hydrodissection, and nuclear resection. To prevent iris contact, a pressure sensor was secured *via* an inferior 0.9-mm corneal incision. A 20-gauge straight tip with a yellow sleeve and a 21-gauge straight tip with an orange sleeve were used for the ultrasonic needle. ACP was measured for 10s from 10s after initiating aspiration in the linear mode using vacuum levels of 200 and 150 mm Hg with a 20-gauge tip and 300 and 250 mm Hg with a 21-gauge tip at the bottle height, which was lowered from 80 to 10 cm. Each experiment was duplicated using two porcine eyes, and the average value was calculated.

Posterior Capsule Contact Assay Porcine eyes were treated as described previously. Ultrasonic needle procedures utilized 20-gauge and 21-gauge straight tips with yellow and orange sleeves, respectively. The ultrasonic needle tip was positioned at the iris level, and aspiration was applied for 30s at vacuum levels of 200 and 150 mm Hg with a 20-gauge tip, and 300 and 250 mm Hg with a 21-gauge tip in linear mode. The bottle height was decreased by 5 cm increments, and the height at which the posterior capsule accidentally contacted the ultrasonic tip was recorded. Each experiment was repeated ten times using ten porcine eyes.

Indicator Values Calculation The intrachamber pressure at the height of the posterior capsule in contact with the tip was calculated from approximately straight lines and bottle heights obtained from ACP measurement assay and posterior capsule contact assay, respectively. The calculations involved substituting the bottle height into approximately straight lines.

RESULTS

Intrachamber and Anterior Chamber Pressure Measurements The internal pressure in the non-occluded aspirate state with various phaco machine settings was

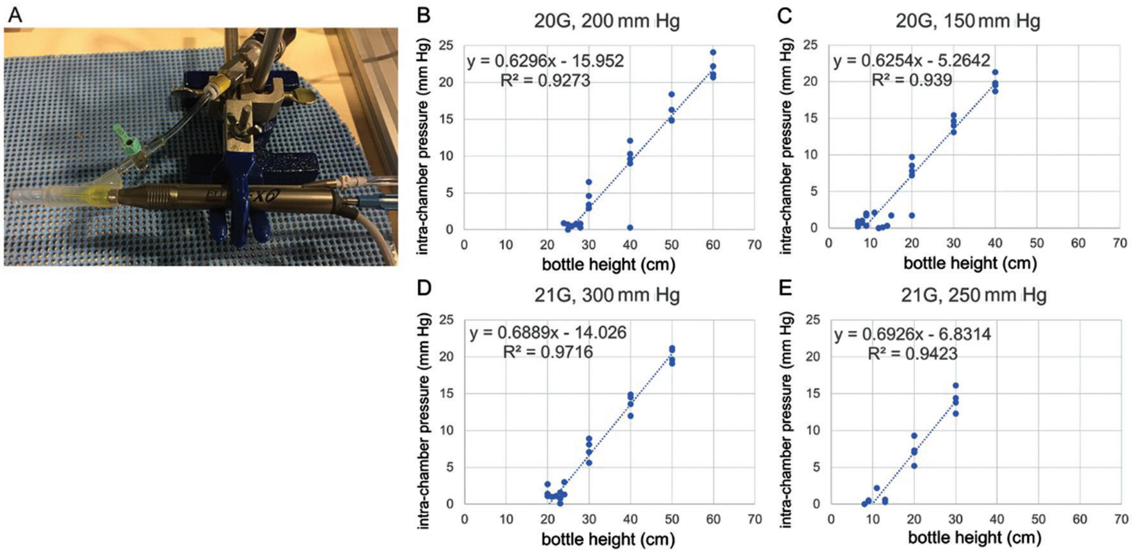

Figure 1 Changes in internal pressure with various phaco machine settings in the tube chamber A: The average internal pressure in the non-occluded aspirate state with various settings for 20s from 10s after initiating aspiration in the linear mode was measured using the tube chamber. The internal pressure was measured at 10-cm bottle height intervals during internal pressures of 5-25 mm Hg in the non-occluded aspirate, and at 1-cm intervals during internal pressures of approximately 0 mm Hg in the non-occluded aspirate. Each experiment was repeated four times. B: The distribution of internal pressure at a vacuum level of 200 mm Hg with a 20-gauge tip was linear and may be represented by an approximate straight line (y=0.6296x-15.952, R^2=0.9273). C: The distribution of internal pressures at a vacuum level of 150 mm Hg with a 20-gauge tip was linear and may be represented by an approximate straight line (y=0.6254x-5.2642, R^2=0.939). D: The distribution of internal pressures at a vacuum level of 300 mm Hg with a 21-gauge tip was linear and may be represented by an approximate straight line (y=0.6889x-14.026, R^2=0.9716). E: The distribution of internal pressures at a vacuum level of 250 mm Hg with a 21-gauge tip was linear and may be represented by an approximate straight line (y=0.6926x-6.8314, R^2=0.9423).

investigated using a tube-chamber system with intrachamber pressure measurements (Figure 1A). Internal pressures were recorded at vacuum levels of 200 mm Hg with a 20-gauge tip (Figure 1B), 150 mm Hg with a 20-gauge tip (Figure 1C), 300 mm Hg with a 21-gauge tip (Figure 1D), and 250 mm Hg with a 21-gauge tip (Figure 1E). Proportional changes using vacuum levels of 200 and 150 mm Hg with a 20-gauge tip were almost equal (Figure 1B, 1C). Similarly, proportional changes at vacuum levels of 300 and 250 mm Hg with a 21-gauge tip were almost equal (Figure 1D, 1E).

The ACP in the non-occluded aspirate state with various phaco machine settings was also investigated using porcine eyes and pressure sensor (Figure 2). ACP was recorded at vacuum levels of 200 mm Hg with a 20-gauge tip (Figure 2A), 150 mm Hg with a 20-gauge tip (Figure 2B), 300 mm Hg with a 21-gauge tip (Figure 2C), and 250 mm Hg with a 21-gauge tip (Figure 2D). Proportional changes using vacuum levels of 200 and 150 mm Hg with a 20-gauge tip were almost equal (Figure 2A, 2B). Likewise, proportional changes using vacuum levels of 300 and 250 mm Hg with a 21-gauge tip were almost equal (Figure 2C, 2D).

Settings for Preventing Posterior Capsule Contact with The Tip To identify the settings wherein accidental aspiration of the posterior capsule occurred, the height of ultrasonic needle contact with the posterior capsule was measured at vacuum levels of 150 and 200 mm Hg for the 20-gauge tip or 250 and 300 mm Hg for the 21-gauge tip (Figure 3B, 3C). The 20-gauge tip touched the posterior capsule at a bottle height of 57.5±12.6 cm with vacuum level of 200 mm Hg and at bottle height of 35.0±10.0 cm with vacuum level of 150 mm Hg (Figure 3B). Meanwhile, the 21-gauge tip touched the posterior capsule at a bottle height of 47.5±12.6 cm with vacuum level of 300 mm Hg and at bottle height of 32.5±5.0 cm with vacuum level of 250 mm Hg (Figure 3C).

Table 1 Intrachamber pressure at the bottle height when the posterior capsule was in contact with the tip

Setting for phaco machine	Bottle height (cm)	Intrachamber pressure (mm Hg)
200 mm Hg with 20-gauge tip	57.5±12.6	20.2±7.9
150 mm Hg with 20-gauge tip	35.0±10.0	16.6±6.3
300 mm Hg with 21-gauge tip	47.5±12.6	18.7±8.7
250 mm Hg with 21-gauge tip	32.5±5.0	15.7±3.5

Indicator Values Calculation of Safe Internal Pressure In this study, the minimum indicator values of intrachamber pressure are summarized (Table 1).

The intrachamber pressure at the bottle height when the posterior capsule was in contact with the tip was calculated from each approximate straight line (Figure 2) and bottle height at which the posterior capsule was in contact with the tip (Figure 3).

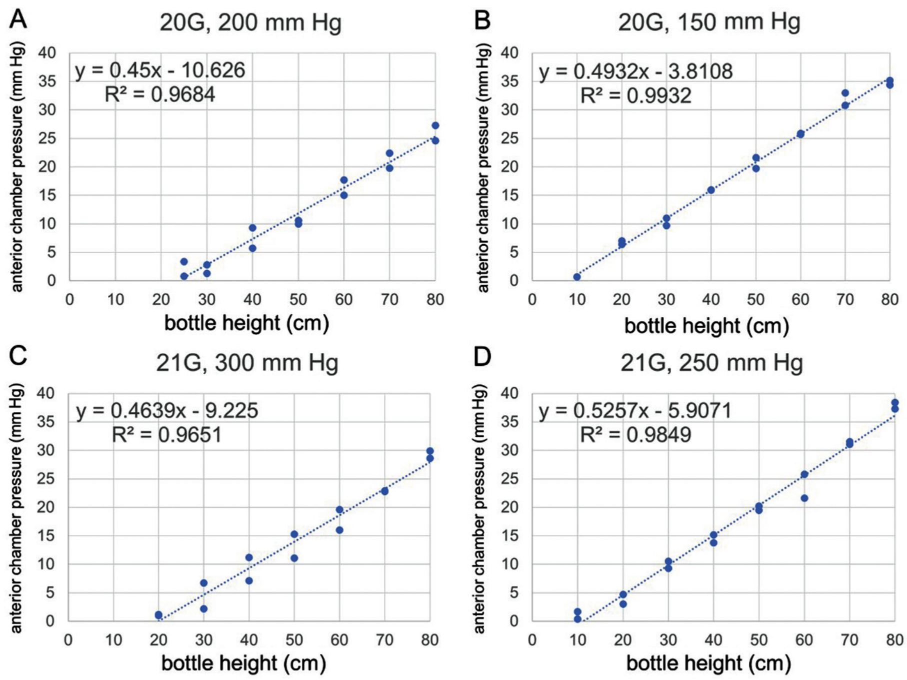

Figure 2 Changes in ACP with various phaco machine settings in porcine eyes The average ACP in the non-occluded aspirate state with various phaco machine settings for 10s from 10s after initiating aspiration in the linear mode was measured using the porcine eyes. The ACP was measured at 10-cm bottle height intervals from 80 to 10 cm. Each experiment was duplicated with two porcine eyes. A: The distribution of ACPs at a vacuum level of 200 mm Hg with a 20-gauge tip was linear and may be represented by an approximate straight line (y=0.45x -10.626, R^2=0.9684). B: The distribution of ACPs at a vacuum level of 150 mm Hg with a 20-gauge tip was linear and may be represented with an approximate straight line (y=0.4932x-3.8108, R^2=0.9932). D: The distribution of ACPs at a vacuum level of 300 mm Hg with a 21-gauge tip was linear and may be represented by an approximate straight line (y=0.4639x-9.225, R^2=0.9651). D: The distribution of ACPs at a vacuum level of 250 mm Hg with a 21-gauge tip was linear and may be represented by an approximate straight line (y=0.5257x-5.9071, R^2=0.9849). ACP: Anterior chamber pressure.

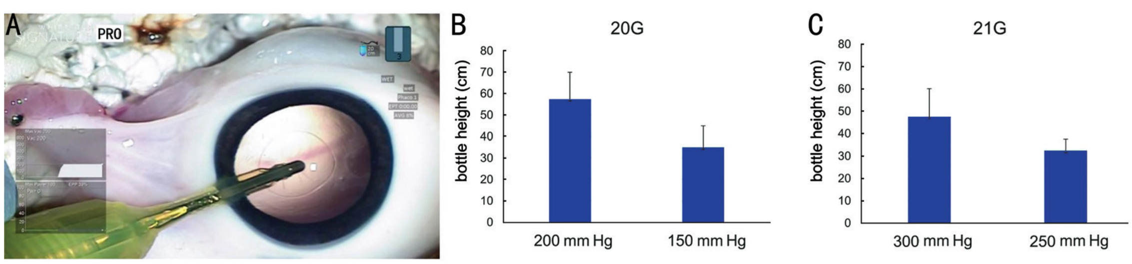

Figure 3 Bottle height at which the posterior capsule came into contact with the tip The ultrasonic needle tip was held at the iris level, and vacuum was applied with various phaco machine settings for 30s in the linear mode using porcine eyes. The bottle height was lowered in 5-cm steps, and the bottle height at which the posterior capsule accidentally came into contact with the ultrasonic tip was recorded. A: Posterior capsule folds were confirmed upon touching the posterior capsule with the ultrasonic tip. B: The contacting bottle heights at vacuum levels of 150 and 200 mm Hg for the 20-gauge tip are presented as mean±SD from 10 independent experiments. C: The contacting bottle heights at vacuum levels 250 and 300 mm Hg for the 21-gauge tip are presented as mean±SD from 10 independent experiments.

DISCUSSION

A tube chamber system was constructed with internal pressure measurements to verify safety and improve anterior chamber instability during phacoemulsification. Using this tube chamber system, target internal pressures for a non-occluded aspirated state in phacoemulsification system with Venturi pump mode was investigated. The propertiers of the tube chamber system were also confirmed by comparison with porcine eyes.

The ACP can be calculated using the following equation: pressure (mm Hg)=bottle height (cm)×10/13.6, where the densities of mercury and water are 13.6 g/cm^3 and 1 g/cm, respectively[13]. Thus, in the occluded state, the internal pressure is proportional to the bottle height in the gravity fluid system. In this study, the proportional relationship between internal pressure and bottle height at various settings was apparent, even in the non-occluded aspirate (Figure 1). Similar to the assay using the tube chamber, proportional relationships between ACP and bottle height at various settings were also observed in porcine eyes (Figure 2). However, under similar conditions, the rate of change in pressure in the assay using the chamber was greater than that in the assay using porcine eyes. This may be attributed to the stiffer material of the chamber as compared to the porcine eye.

In the assay using the chamber, the rate of change in internal pressure with bottle height remained constant, regardless of vacuum level (Figure 1). However, in the assay using porcine eyes, the rate of ACP change decreased as the vacuum level increased (Figure 2). The volume flow rate was calculated using the following equation: Volume flow=cross-sectional area × mean flow velocity[18]. The volume reduction of the porcine anterior chamber due to aspiration, which is the reduction in the cross-sectional vector area, was considered to increase the flow velocity to maintain the volume flow velocity. Consequently, the pressure was presumed to decrease with an increase in flow velocity following Bernoulli's principle[19].

The human cornea is stiffer and less elastic than porcine eye[20]. Since this chamber system may be stiffer than the porcine eye, it may exhibit changes in ACP more similar to the human eye. Hence, further studies on stiffness are necessitated to comprehend the differences between this chamber system and that of the human eye.

In this study, the internal pressure in the nonoccluded aspirate state was evaluated. However, in clinical practice, occluded and non-occluded states of the nucleus occur intermittently during phacoemulsification. Khng *et al*[13] reported the following: fluctuations in the ACP of 25.7-41.7 mm Hg, average ACP of 39.9-94.3 mm Hg, and maximum IOP of 66.1-196.6 mm Hg during nuclear removal. Kreutzer *et al*[21] reported that the mean ACP during nuclear removal was 36.5-40.1 mm Hg. Zhao *et al*[22] reported that the maximum IOP during nuclear removal was 52-74 mm Hg. However, constructing a system that mimics the occluded state caused by nuclear fragments is challenging. Therefore, we assessed the target internal pressure using this chamber system to develop a system that measured the internal pressure in the non-occluded aspirate state.

In phacoemulsification cataract surgery, venturi pumps are efficient systems that reduce fluid use, case time, and energy[23]. On the other hand, they have problems with surges and anterior chamber stability[24]. There have been reports on anterior stability of peristaltic pump using similar test chambers[25], but none on Venturi pump. In this study, we used originally test chamber and porcine eyes to determine the relationship between safe ACP and bottle height under Venturi pumps. In addition, a posterior capsule contact assay was performed assuming a posterior capsule failure model (Figure 3), and showed a surgical setting that could maintain anterior stability. A safe surgical setup with this chamber system may overcome the disadvantages of Venturi pumps, such as anterior chamber instability.

Limitations of this study are the lack of a large sample size and of inclusion in the study of various factors that contribute to anterior chamber stability, such as anterior chamber size, lens thickness, posterior chamber pressure, and surge after occlusion. Further studies involving these factors with more samples are needed to clarify the role of these factors.

Using this chamber, the ACP could be estimated without invading the patients' eyes. For reference, the minimum indicator values in this chamber system was summarized (Table 1). Safer settings were confirmed by checking the intrachamber pressure preoperatively. Therefore, this tube chamber system may assist in preventing posterior capsule breakage.

This study revealed that this tube chamber was less influenced by changes due to vacuum level settings than porcine eyes and recommended safe internal pressures in a non-occluded aspirate state. A thorough understanding of the characteristics and appropriate usage of this chamber system may resolve anterior chamber instability due to variations in preoperative settings of the phaco machine.

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