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# Safety of a water lift system during maxillary sinus floor elevation —An experimental study using sinus membrane elevation model—

**Takahito Uwazumi[1], *Kenzo Morinaga[2], Isumi Toda[3], Yuki Teranishi[2], Yasushi Nakajima[2], Kaoru Kusano[2] and Shunsuke Baba[2]**

*[1]Graduate School of Dentistry (Department of Oral Implantology), [2]Department of Oral Implantology and [3]Department of Anatomy, Osaka Dental University, 8-1 Kuzuhahanazono-cho, Hirakata-shi, Osaka 573-1121, Japan*
**E-mail: morinaga-k@cc.osaka-dent.ac.jp*

**Currently, studies on the safety of maxillary sinus floor elevation involving the application of water pressure to detach and elevate the sinus membrane are limited. In this study, we created an eggshell model to elevate the sinus membrane and evaluated its effects on the shape of the elevating part, and the effects of flow rate and the implementation of a starting point (SP) on the elevation; 12 groups were compared based on the combinations of the shape of the lifting part, presence or absence of SP, and flow rate (300, 600, 1200 mL/h). We visually observed the state of the eggshell membrane during lifting, and a pressure gauge was used to detect pressure changes. In the case of with SP, no significant difference was observed in shape or flow rate, and stable lifting was possible. In the case of without SP, the maximum pressure increased significantly ($p < 0.05$); however, no significant difference was observed in shape or flow rate. To safely and accurately elevate the sinus membrane using water pressure, bone morphology and flow rate are crucial factors. Additionally, implementing SP at the elevation site is essential. (J Osaka Dent Univ 2024; 58: 173-182)**

**Key words: Maxillary sinus floor elevation; Water pressure; Eggshell; Water lift system; Sinus membrane elevation model**

## INTRODUCTION

Dental implant placement in the maxillary molar region is challenging because there is a lack of bone to embed the implant due to alveolar bone resorption and the presence of the maxillary sinus. To overcome this challenge, Boyne and James[1] devised the lateral window technique for maxillary sinus floor elevation, and Tatum[2] and Summers[3] devised the alveolar crest approach, which has been used in clinical practice. Notably, the success rate of maxillary sinus floor elevation is generally over 90%, and surgery is the primary treatment approach.[4-8] Comparatively, the lateral window technique is more invasive and technical than the crestal approach; with the available treatment options, it is essential to adopt a safe and minimally invasive surgical technique.

Regarding the alveolar crest approach for maxillary sinus floor elevation, a method in which water pressure is used to detach and elevate the sinus membrane has been devised; several studies have indicated this approach is relatively minimally invasive and safe.[9-13] However, most of these are case reports, and how much water pressure is to be applied when the sinus membrane is elevated, how water pressure changes depending on the shape of the elevating part, and how it is raised depending on the shape of the maxillary sinus floor is unknown. Studies evaluating the safety of maxillary sinus floor elevation are few, and there is currently a lack of scientific evidence. Kim *et al.*[14] conducted a sensory test on multiple dentists who had performed maxillary sinus floor elevation using water pressure; although this method was useful, there were limitations as it did not provide information on the required water pressure and lifting level.

Recently, chicken eggs have been used as a training model for maxillary sinus floor elevation. Chicken eggs are composed of an eggshell and a membrane on its inner surface,[15, 16] demonstrating structural similarity with the alveolar bone and maxillary sinus membrane. Rampalli *et al.*[17] pasted collected eggshell membranes into the human maxillary sinus and used them as a training model for maxillary sinus floor elevation, and reported that eggshell membranes were useful as a training model. Therefore, we used the eggshell membrane as a model to study various parameters, such as water pressure at the floor of the maxillary sinus.

In this study, we used an eggshell as a model to elevate the sinus membrane and investigated the shape and flow rate of the elevating part and the effects of providing sinus membrane detachment as SP on the elevating mode.

## MATERIALS AND METHODS

### Experimental materials

A total of 120 commercially available eggs were used. All chicken eggs used were brown, measuring 5.5-6 cm in length and 4.0-4.5 cm in width, and weighing MS size (52-58 g) (Fig. 1).

### Experimental conditions

### Experimental techniques and water pressure measurements

A hole with a diameter of 3.6 mm was formed at the top of the eggshell by cutting only the eggshell using an ultrasonic cutting instrument (Sonic Surgeon 310L, Donil Technology, Korea). In with SP group, the eggshell membrane was detached as SP using a mucosal peeler (Sinus All kit, Neo Biotech Co., Seoul, Korea) prior to lifting the eggshell membrane (Fig. 2). Using an automatic syringe pump (Terufusion syringe pump, Terumo, Japan), 5 mL of physiological saline solution was injected at a constant flow rate. During injection, the eggshell membrane was lifted using water pressure using a surgical kit (Sinus All kit, Neo Biotech Co., Seoul, Korea). The behavior of water pressure during eggshell membrane elevation was recorded using a pressure gauge (Disposable Pressure Sensor −DPS Series−, Surpus, Japan). The pressure gauge was connected to a software (Sensor viewer kit −V-kit−, Surpus, Japan), and pressure values were recorded (Fig. 3). Next, the state of the eggshell membrane was visually observed during lifting, and pressure changes were monitored using a pressure gauge. Based on the obtained results, we evaluated the influence of each factor.

### Comparison based on the shape of the elevated part

Two groups, including group I (which assumed a

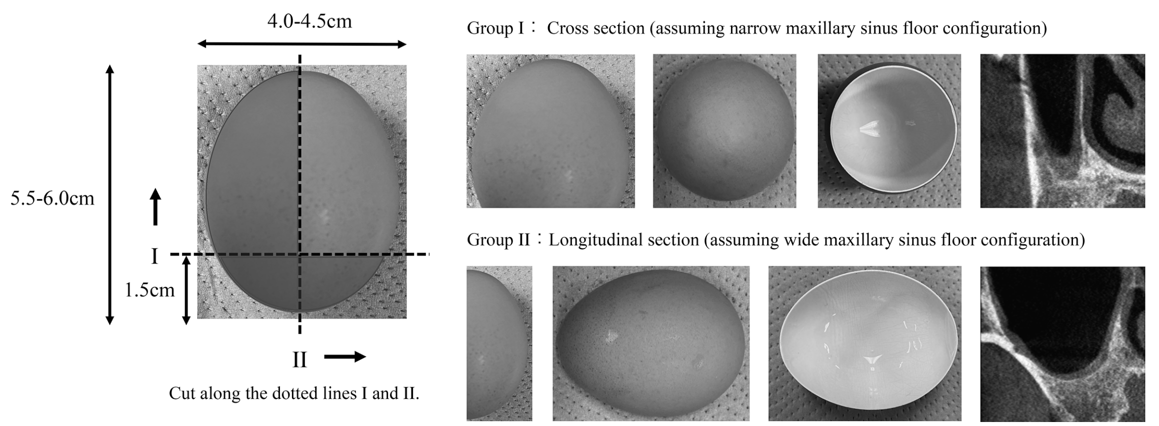


**Fig. 1** Shape of an eggshell. Cutting the eggshell relative to the shape of the maxillary sinus.

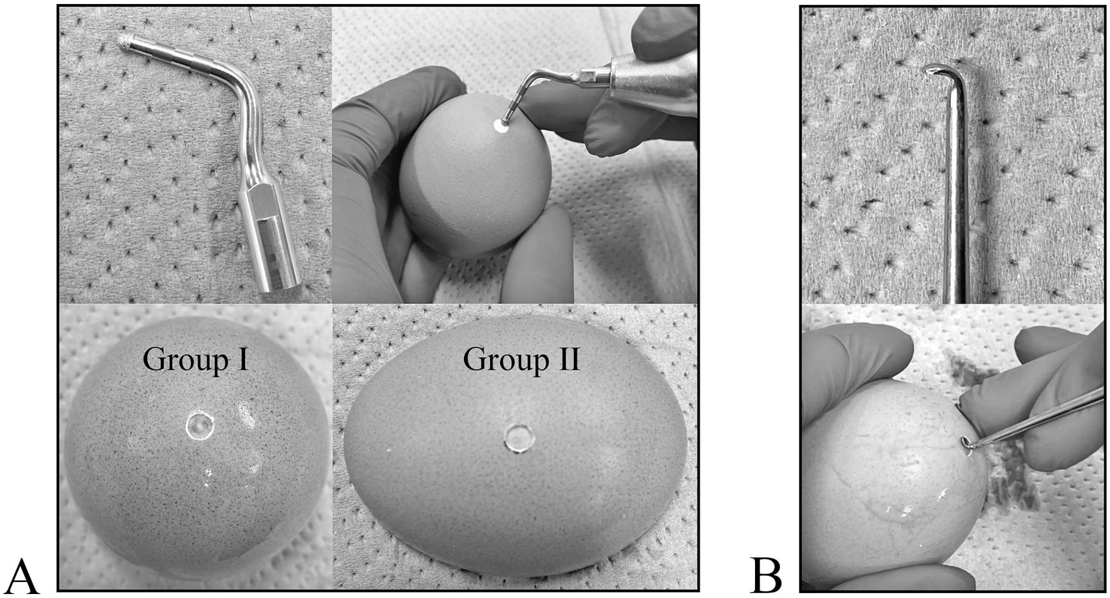


**Fig. 2** (A) Cutting only the eggshell using Piezosurgery to avoid damaging the eggshell membrane. (B) Detachment of eggshell membranes using a mucosal peeler in the group with SP.

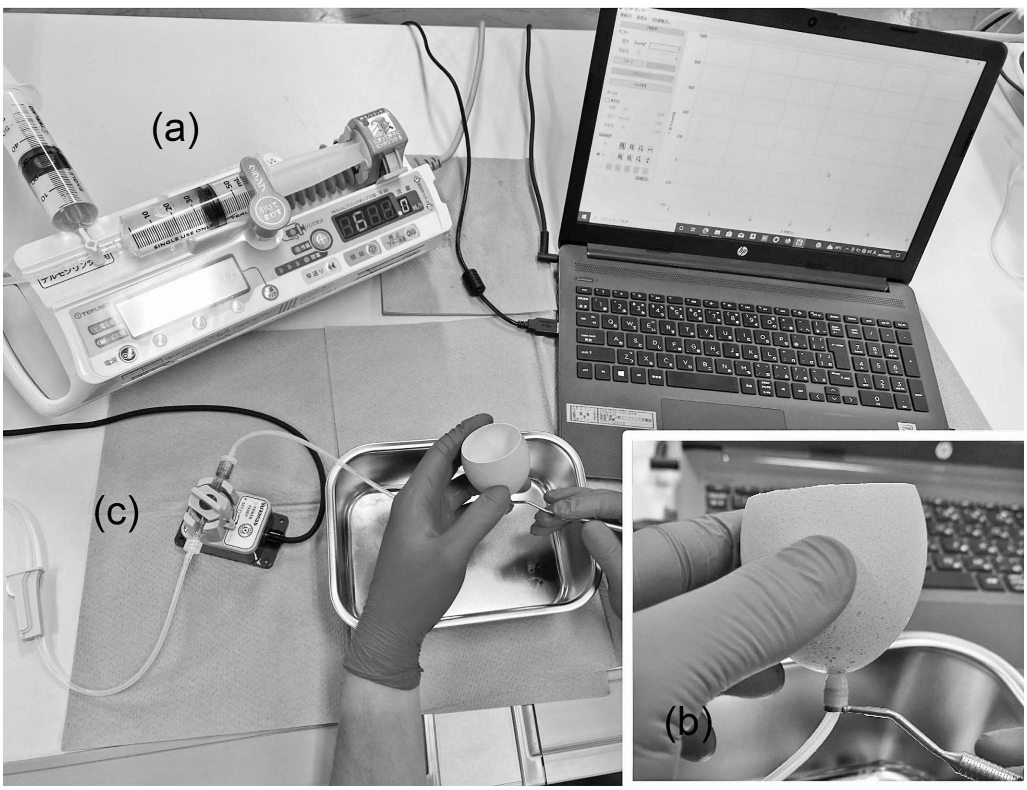


**Fig. 3** (a) Infusion of saline at a constant rate using an automatic syringe pump. (b) Elevation of the eggshell membrane using Sinus All Kit. (c) Measuring water pressure with a pressure gauge.

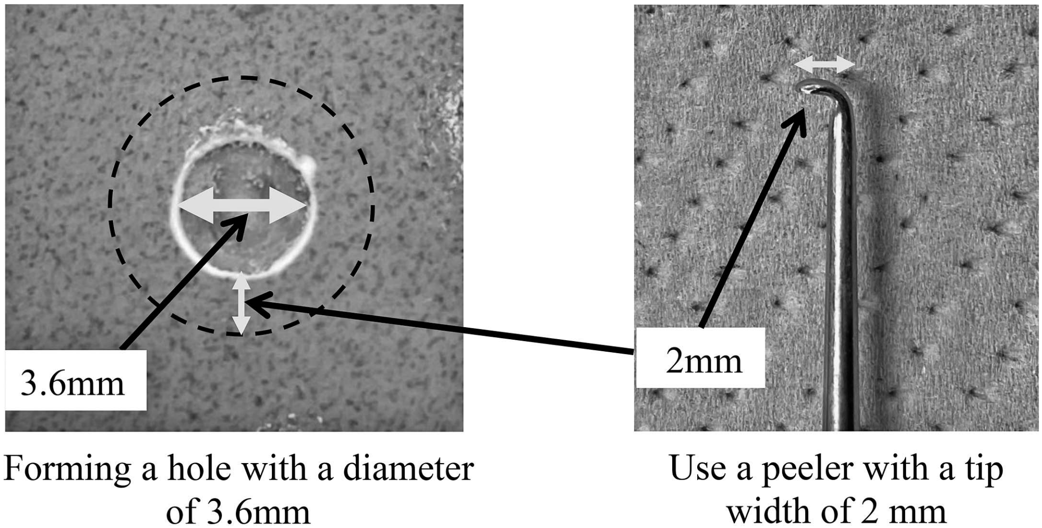


**Fig. 4** Formation of holes in eggshells and provision of detachment as SP.

narrow maxillary sinus floor configuration) and group II (which assumed a wide maxillary sinus floor configuration), were evaluated to compare the morphology of the elevated part. For group I, the acute end of the eggshell was used, which was cut 1.5 cm from the floor of the fossa along the long axis of the egg, and for group II, the side of the eggshell was used, which was cut longitudinally at the center of the short axis of the egg (Fig. 1).

### Comparison according to flow rate

To compare the flow rates, a syringe pump (Terufusion Syringe Pump Model 35, Terumo Corporation, Japan) was used, and the flow rates were set to three groups: 300, 600, and 1200 mL/h, and 5 mL of physiological saline was injected at a constant flow rate in each case.

### Comparison with and without sinus membrane detachment as SP

The subjects were divided into two groups depending on the presence or absence of membrane detachment as SP at the elevation; a mucosal peeler (Sinus All kit, Neo Biotech Co., Seoul, Korea) was modified, the tip was shaved down to 2 mm, and detachment was performed within 2 mm of the outer circumference of the 3.6 mm diameter hole in the group with SP (Fig. 4).

A total of 12 groups were created by combining these conditions, and 10 eggshells were used in each group.

### Statistical analysis

The mean and standard deviation of each parameter were calculated for each group and compared using the Student's *t*-test and one-way analysis of variance using statistical software (Statcel 4; OMS Publisher, Tokorozawa, Japan). A $p$-value of $<0.05$ was considered significant.

## RESULTS

### Measurement of water pressure during eggshell membrane elevation

Fig. 5 illustrates a water pressure waveform during eggshell membrane elevation. Point a on the waveform is the point where water pressure begins to be applied. From there, the pressure increases until the eggshell membrane begins to lift to its peak, point b. Once the eggshell membrane begins to lift, the pressure drops rapidly, and the membrane begins to lift continuously, which is point c. From there, lifting continues at a constant pressure, and the point at which measurement ends is point d. In this study, we calculated the maximum pressure at point b and the average pressure between c and d from this waveform. Table 1 shows a list of the maximum pressure and average pressure of the 12 groups measured in this study.

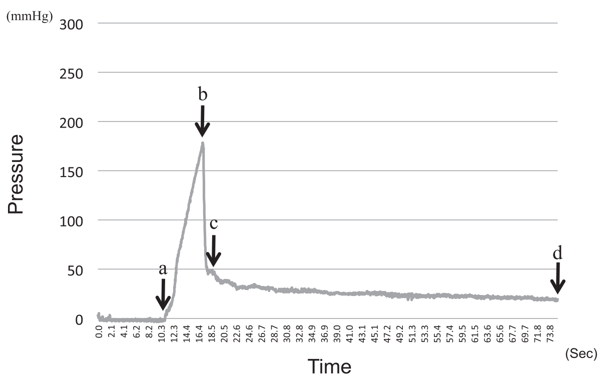


**Fig. 5** Pressure waveform during eggshell membrane elevation. (a) Point at which we started to apply water pressure. (b) Point at which the membrane begins to lift (maximum pressure). (c) Point at which the membrane begins to lift continuously. (d) End point of measurement.

**Comparison of morphology and flow rate within the group with SP**

Comparing the shapes, at a flow rate of 1200 mL/h, the maximum pressures in groups I and II were 144.7±25.9 mmHg and 151.1±55.5 mmHg, and the average pressures were 19.6±6.0 mmHg and 22.0±6.9 mmHg, respectively (Table 1, Fig. 6). At a flow rate of 600 mL/h, the maximum pressures in groups I and II were 133.1±50.1 mmHg and 143.0 ±40.6 mmHg, and the average pressures were 15.7±5.4 mmHg and 22.1±9.8 mmHg, respectively. At a flow rate of 300 mL/h, the maximum pressures in groups I and II were 137.6±26.0 mmHg and 141.9±35.5 mmHg, and the average pressures were 19.2±6.6 mmHg and 18.4±4.9 mmHg, respectively. Although there was no significant difference in maximum pressure and average pressure between the two groups due to the differ-

**Table 1** Maximum and average pressure during eggshell membrane elevation

| | | 300ml/h | | 600ml/h | | 1200ml/h | |
|---|---|---|---|---|---|---|---|
| | | Maximum pressure (mmHg) | Average pressure (mmHg) | Maximum pressure (mmHg) | Average pressure (mmHg) | Maximum pressure (mmHg) | Average pressure (mmHg) |
| Group Ⅰ Cross section | Without SP | 368.3±90.1 | 17.9±5.9 | 385.8±115.3 | 21.2±4.1 | 461.3±92.6 | 18.5±3.4 |
| | With SP | 137.6±26.0 | 19.2±6.6 | 133.1±50.1 | 15.7±5.4 | 144.7±25.9 | 19.6±6.0 |
| Group Ⅱ Longitudinal section | Without SP | 287.4±108.8 | 20.5±5.2 | 391.7±117.3 | 17.5±4.2 | 394.6±127.3 | 19.4±3.2 |
| | With SP | 141.9±35.5 | 18.4±4.9 | 143.0±40.6 | 22.1±9.8 | 151.1±55.5 | 22.0±6.9 |

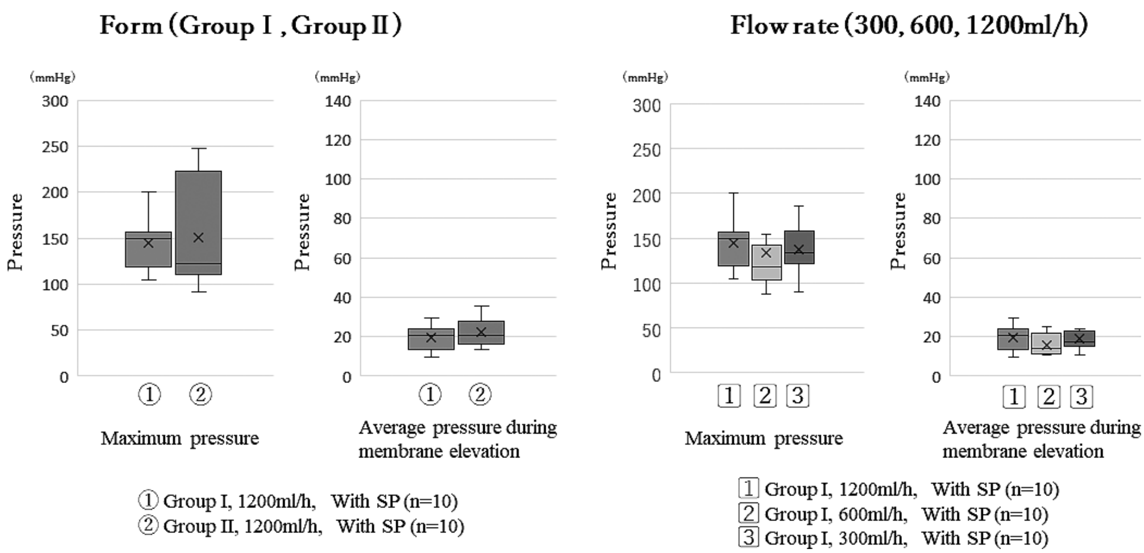


**Fig. 6** Comparison of morphology and flow rate within the group with SP.

ence in morphology, there was variation in maximum pressure in group II. Furthermore, despite the variation in the flow rate, the maximum pressure and average pressure of each group showed similar values, and no significant difference was observed between the groups (Table 1, Fig. 6).

**Comparison of morphology and flow rate with and without SP**

Fig. 7 compares the waveforms with and without SP. Comparing the presence and absence of SP at a flow rate of 600 mL/h, the maximum pressures for the group with SP and the group without SP were 133.1±50.1 mmHg and 385.8±115.3 mmHg, and the average pressures were 15.7±5.4 mmHg and 21.2±4.1 mmHg, respectively. When comparing the results with and without SP, the maximum pressure in the group without SP was approximately 3-5 times higher than in the group with SP ($p < 0.05$). Comparatively, the maximum pressure in the group without SP was higher ($p < 0.05$), and the results showed significant variation; however, the average pressure was the same as that in the group with SP, and no significant difference was observed (Table 1, Fig. 7).

**Comparison of morphology and flow rate within the group without SP**

The results showed that the maximum pressure was significantly higher in the group without SP ($p$

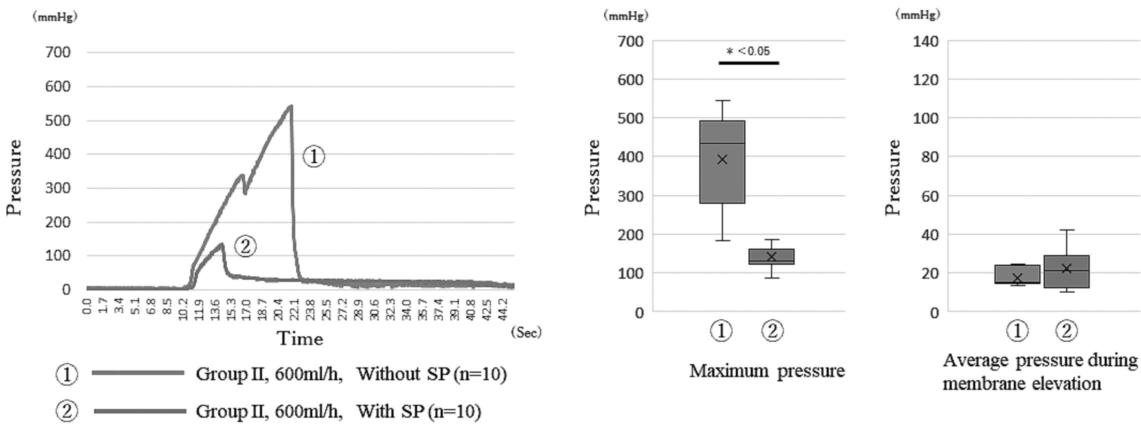


**Fig. 7** Waveforms and pressure comparisons with and without SP.

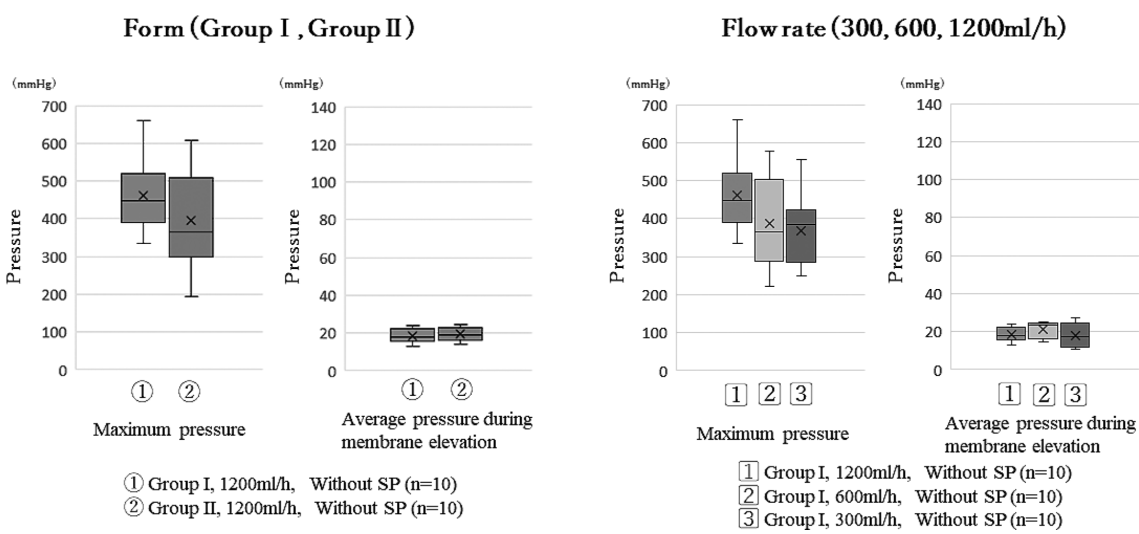


**Fig. 8** Comparison of morphology and flow rate within the group without SP.

＜0.05); notably, the maximum pressure within the group without SP varied widely, ranging from approximately 157.7-660.2 mmHg under morphological and flow rate conditions. In addition, although there was a tendency for the maximum pressure to increase at high flow rates, there was no significant difference in the maximum pressure. Furthermore, once lifting began, the average pressure in the group without SP was the same as that in the group with SP, and no significant difference was observed between both groups (Table 1, Fig. 8).

### Water pressure waveform and eggshell membrane rupture rate with and without SP

The groups with and without SP were compared under the same conditions; the group with SP showed almost the same waveforms and stable eggshell membrane elevation was achieved. Conversely, the waveform during elevation in the group without SP showed varied characteristics despite being under the same conditions, and the elevation of the eggshell membrane was unstable. In the group with SP 7/60 eggshell membranes (11.6%) broke during lifting. In the group without SP, 18/60 eggshell membranes (30%) broke. Similar to the waveform during lifting, the rate of breakage was higher in the group without SP compared to the group with SP (Fig. 9).

### Deflection in the lifting direction of eggshell membranes

When observing the lifted area of the eggshell

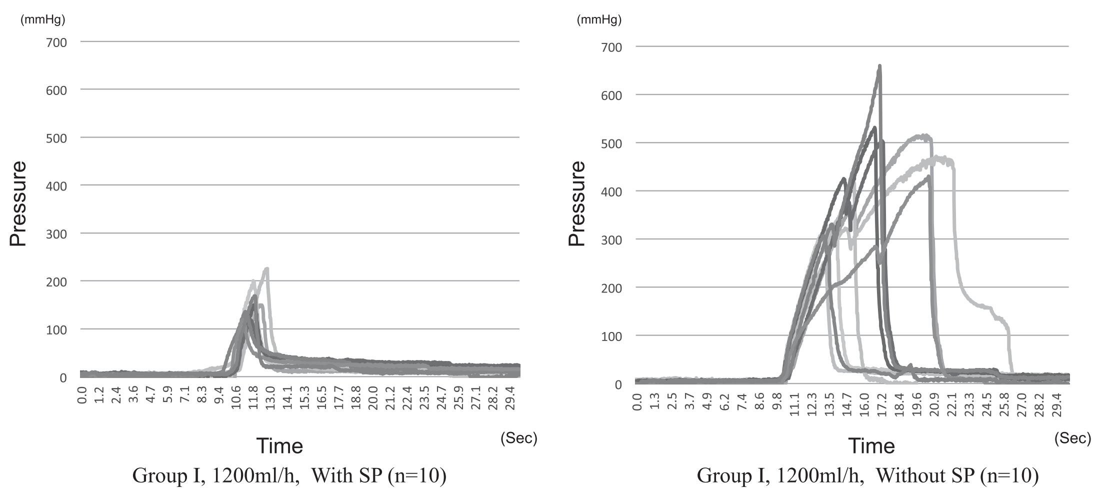


**Fig. 9** Comparison of water pressure waveforms with and without SP.

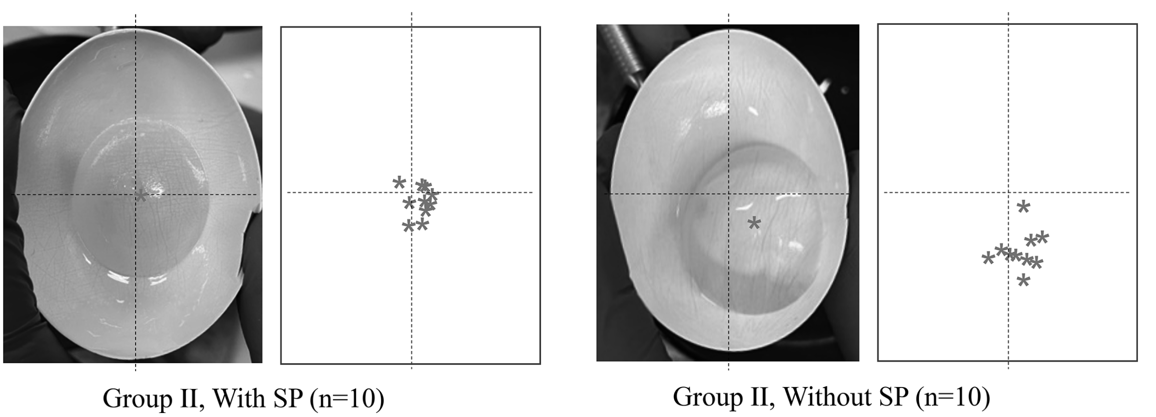


**Fig. 10** Deflection in the lifting direction of eggshell membranes.

membrane, in the group with SP, it is lifted concentrically with respect to the center of the raised area; however, in the group without SP, it is lifted in a deflected manner rather than in a concentric circle. This tendency was more pronounced in the longitudinal section (Fig. 10).

## DISCUSSION

### Water pressure and waveform

In this study, the water pressure during the lifting of the eggshell membrane was measured in real-time. Based on the obtained waveforms, the pressure applied to the eggshell membrane when it was lifted was detected. Ro *et al.*[18] performed maxillary sinus floor elevation using water pressure in human maxillary sinuses and measured water pressure; the pressure applied to the human maxillary sinus membrane during elevation was 25.0 ± 13.0 kPa, which was approximately equal to that used in our study. Furthermore, regarding the waveform of pressure during membrane elevation, the waveform was similar to the waveform obtained from our study. This suggests that although there are differences between the human maxillary sinus membrane and eggshell membrane,[19-22] it was an effective model for measuring water pressure. The characteristic point of the waveform obtained is that the water pressure reached the maximum pressure before lifting started, and once lifting started, the membrane could be lifted with relatively light pressure; this suggests that safely performing surgery depends on how the initial maximum pressure is suppressed.

### Maxillary sinus morphology and water pressure

In this study, we compared two patterns using an eggshell model: a wide maxillary sinus and a narrow maxillary sinus. Notably, no significant difference was observed between the two regarding morphology. Eggshell models were used to measure water pressure; therefore, the morphology was uniform for each group. However, the morphology of human maxillary sinuses varies and is further complicated by anatomical requirements such as tooth roots and septa.[23-25] Notably, in this study, the cavity was formed in a flat area of the eggshell; however, it is essential to form a cavity in an area where the floor of the maxillary sinus is sloped.[26] In such a case, the application of water pressure becomes more complicated; it is crucial to consider these factors in further studies.

### Flow rate and water pressure

Notably, no significant difference in water pressure was observed regarding the flow rate. However, when lifting without SP, the pressure tended to increase as the flow rate increased. When detachment was performed, stable lifting was achieved regardless of the flow rate, suggesting that as long as detaching is performed, the flow rate is not a significant concern. Furthermore, physiological saline was injected at a constant flow rate using a syringe pump. In current clinical applications, the surgeon injects by applying pressure to the syringe with fingertips[27]; however, excess pressure may cause perforation of the membrane. In a preliminary experiment in which physiological saline was injected using a finger-feel sensation, we observed cases of damage to the eggshell membrane. Therefore, it is crucial to develop a device to safely inject at a constant rate.

### Presence or absence of detachment as SP and water pressure

In this study, a significant difference in maximum pressure was observed depending on the presence or absence of detachment as SP. When detachment was not performed, the maximum pressure was 3-5 times higher than when detachment was performed, and the waveform after detaching the membrane was not stable. Furthermore, the rate of breaking of the eggshell membrane during lifting was high, suggesting that the presence or absence of detachment as SP significantly affects the maximum pressure and that providing SP is essential to achieve safe lifting. Perforation of the maxillary sinus membrane significantly affects prognosis.[28-30] Nolan *et al.*[28] reported that the implant failure rate was 11.3% in cases with sinus membrane perforation, compared to 3.4% in cases without perforation. However, there are no differences in success rates of with or without perforation procedures,[31, 32] and bone resorption occurs due to perforation.[5] Although it has been suggested that providing SP is crucial to prevent perforation, this phenomenon has not been incorporated into the protocol of the currently used maxillary sinus floor elevation system using water pressure; it is essential to consider amending the protocol in this regard.

### Deflection of the lifting area

In this study, the lifting area expanded concentrically and evenly in the group with SP; however, it expanded in a biased manner in the group without SP; this could be due to the detaching progressing preferentially in the direction in which it first started when the maximum pressure was reached. Cho *et al.*[33] reported the results of a study in which maxillary sinus floor elevation was performed using water pressure on the maxillary sinus in pigs; there were variations in the elevation pattern of the sinus membrane, which was significantly influenced by the morphology of the maxillary sinus. Furthermore, lifting was performed without SP. Notably, our study, which revealed that the elevation progresses with deflection toward the part that is first detached, can guide surgeons in controlling the area of elevation according to the morphology of the maxillary sinus.

Although there are differences in the properties and strength of ablation between eggshell membranes and human maxillary sinus membrane, this study revealed factors determining the safety of maxillary sinus floor elevation using water pressure. In conclusion, bone morphology and flow rate are crucial factors in achieving safe and accurate elevation of the sinus membrane using water pressure. Notably, it is essential to implement membrane detachment as SP at the elevation site.

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**Conflicts of interest**
The authors declare no conflicts of interest associated with this study.

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