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Three Dimensional Motion Analysis of Hand Tremors During Endoscopic Ear Surgery

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ABSTRACT

Background Endoscopic surgery is developing in various clinical specialties. During ear endoscopic surgery, a surgeon has to hold an endoscope with one hand and operate the surgical instruments with another hand. Therefore, the stability of the surgeon's hand affects the field of surgical view and quality of the surgery considerably. There are few techniques which are used during surgery to stabilize the endoscope. However, no study has evaluated the efficacy of such techniques in detail. This study examined the three dimensional movement of an endoscope to compare and evaluate the effect of various stabilization techniques to reduce the hand tremor while using the endoscope.

Methods A non-randomized controlled trial involving 15 medical students was conducted in Tottori University, Japan. Subjects held an endoscope with their non-dominant hand and manipulated it using three different stabilization techniques i.e. with resting the elbow on the table, resting the endoscope on the ear canal, both with the elbow on the table and endoscope on the ear canal. For the control, subjects were made to use the endoscope without any stabilization technique. The endoscopic movement was measured with and without using the stabilization techniques.

Results The results obtained in this study indicated that manipulating the endoscope with resting the elbow on the table restrains both vertical (Y-axis) and optical axis (Z-axis) direction of tremor, and manipulating the endoscope by resting it on the ear canal restrains both vertical (Y-axis) and horizontal axis (X-axis) direction while the combined use of both the techniques reduces the endoscope movement in all the three X, Y and Z axes.

Conclusion In conclusion, concomitant use of both techniques appears to be clinically beneficial in endoscopic ear surgery.

Key words endoscopy; otologic surgical procedure; tremor

Endoscopic surgery is developing in various clinical specialties. Recently, endoscopes have been used to perform ear surgeries that are conventionally performed under the microscope.[1, 2] Intra-operative use of endoscopes in middle ear surgery has opened up new perspectives in ear surgery. In future, endoscopic ear surgery (EES) will become an indispensable adjunct to microscopic ear surgery.[3, 4] One of the important benefits of an endoscope over the microscope is the wide-field view of the middle ear, enabled by the light source located at the tip of the instrument and the availability of angled lenses. Furthermore, middle ear procedures using an endoscope can reduce the need for drilling in the operative field.[2, 5–7] Obtaining a sufficiently clear view in an endoscopic surgery is important not only for reducing the operator's burden but also for better clinical outcomes and patients' safety. Although incorporating endoscopic ear surgery into otologic practice is challenging, a graduated and stepwise introduction of EES is recommended to ensure safe and successful implementation.[8] In laparoscopic surgery, usually an assistant is required to manipulate the endoscope with both hands in order to get a desirable view. But the field of view in middle ear surgery is extremely limited as compared to laparoscopic surgery. Therefore, it is difficult for an assistant to stand near the operator and manipulate the endoscope. Moreover, the operator has to perform the surgery from the external auditory canal (EAC), which is very limited space. If an assistant is there to manipulate the endoscope, the assistant's arm would interfere with the operator's arm. Therefore, the operator has to perform ear surgery by himself, holding the endoscope with the non-dominant hand.[3]

It is important to hold the endoscope in a stable position; otherwise, the endoscope can cause direct

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Abbreviations: 3D, 3-dimentional; EAC, external auditory canal; EES, endoscopic ear surgery

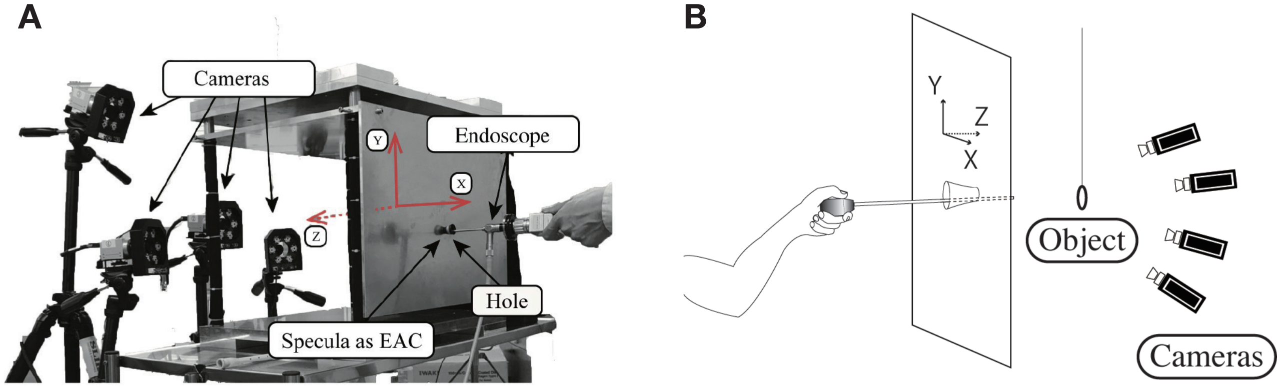

Fig. 1. The pictorial representation of endoscopic setup. The three directions of endoscopic movement with respect to visual axis (X, Y and Z- axes) are shown in solid red lines (**A**). The object is behind the board (**B**). EAC, external auditory canal.

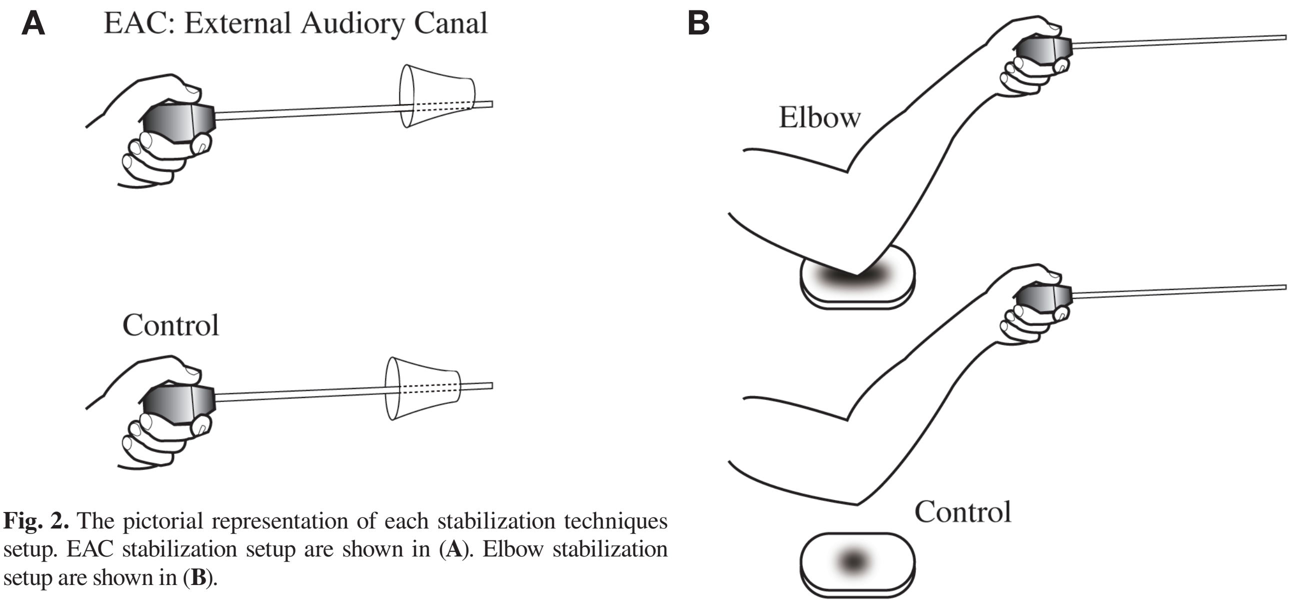

Fig. 2. The pictorial representation of each stabilization techniques setup. EAC stabilization setup are shown in (**A**). Elbow stabilization setup are shown in (**B**).

injury to the EAC or middle ear. The tremor from the non-dominant hand adversely affects the field of view of endoscopic surgery, and it puts the patient's safety at risk. Some techniques are used to stabilize the endoscope—for example, with the elbow on the table, or with the endoscope on the EAC.[9,10] But only few studies have been reported that analyze the efficiency of such endoscope stabilizing techniques or analyze the hand tremor itself. Also, the intraoperative monitors are 2-dimensional, which makes it difficult to measure the displacement of the endoscope due to hand tremors during surgery. In this study, for the first time we have investigated the 3-dimentional (3D) movement of the endoscope with and without the use of endoscope stabilization techniques in order to find the most appropriate method of achieving the most stabilized and clear fields of view during EES.

MATERIALS AND METHODS

The original study population consisted of 15 medical students (eight females and seven males) who agreed to participate in a hand tremor reduction study conducted at Tottori University, Japan between May and July 2016. All of them were right handed. An inclusion criterion for the subjects was no prior experience manipulating an endoscope.

A simple experimental setup shown in Fig. 1. was made using a speculum as an EAC and a ring-shaped clip as an "object" to measure the movement of the endoscope. Each experimental procedure was conducted after calibration using a 70-milimeter stainless cube with grid spacings of 2 mm × 2 mm for preparative quality control: all the cameras captured rectangular coordinates on three axes (ordinate, X; abscissa, Y; and optical axis distance, Z, shown in Fig. 1) and the tremors were calculated as difference between maximum - minimum observed measurements. A thin board with a small hole was used to place the speculum to see the object suspended at a distance of 4 cm from the hole. The smallest diameter of the speculum was 8 mm, and the endoscope was 180 mm in length and 4 mm in diameter.

Subjects were made to sit on a chair and hold an endoscope with their non-dominant hand. The subjects were told to keep the endoscope stable by manipulating it using three different techniques: i) resting their non-dominant elbow on the table, ii) resting the endoscope on the EAC, and iii) both with the elbow on the table and the endoscope on the EAC (Elbow + EAC) (Figs. 2A and B). During the control measurement, the subjects did not use any stabilization technique. Displacement of the endoscope was measured using 3D motion-capture software (Dipp-Motion V™; Ditect Co., Tokyo, Japan). Four high-speed cameras were placed around the experimental setup, facing the tip of the endoscope from various directions. The 3D movement of the endoscope tip was recorded in three directions with respect to the visual axis: horizontally (X-axis); vertically (Y-axis); and parallel to the ear canal (Z-axis) (Fig. 1). The maximum value of the displacement was evaluated in millimeters (mm).

Study subjects were divided into two groups based on the endoscopic displacement without any stabilization technique less than or above the 50th percentile of the endoscope movement. The two groups were compared for reduced hand tremor using different stabilization techniques, and the obtained results were analyzed using unpaired and paired *t*-tests to test the significance of mean differences. Continuous values were presented as mean (SD) Comparisons of mean values of continuous data were performed using Fisher's exact test. In each group, we evaluated the influence of three stabilization techniques using ANOVA followed by the Scheffe's test. A regression analysis was used to estimate the association among three different conditions. We considered $P < 0.05$ as a statistically significant difference.

Study protocols were approved by our Institutional Review Board 1608A078 and were in accord with the Declaration of Helsinki. Participants were informed about the aims, procedures and risks associated with the protocols, and signed a written informed consent.

RESULTS

There were two groups made on the basis of endoscope displacement out of the total 15 subjects taken in the study. The subjects in the high dexterity group (n = 8) showed endoscopic displacement less than 7.5 mm along any axes without using any stabilization technique, whereas low dexterity group (n = 7) showed endoscope displacement more than 7.5 mm (Fig. 3).

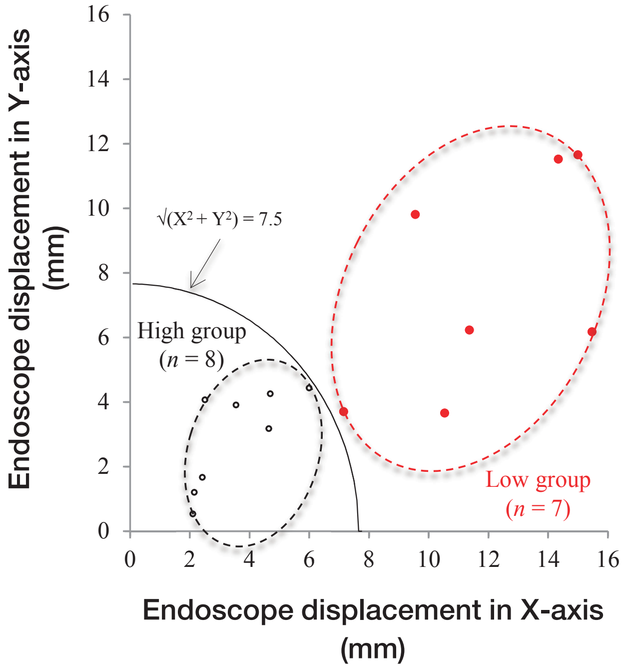

Fig. 3. Distribution of subjects in high and low dexterity groups. Study subjects (n = 15) were divided into two groups by displacement less than (high dexterity group, black dots, n = 8) or above (low dexterity group, red dots, n = 7) the 50th percentile of the endoscope movement (= 7.5 mm, presented as quarter circle in black filled line).

The mean displacement recorded (mm units) in the low dexterity group along the X-axis, Y-axis and Z-axis was (11.9, 7.52, 5.58) in the Controls and (6.68, 3.58, 3.00) while using Elbow; (1.05, 0.92, 2.32) while resting on the EAC; and (1.45, 1.03, 1.87) using Elbow + EAC as stabilization techniques. The mean displacement recorded in the high dexterity group was (3.15, 2.69, 1.57) in the Controls; (3.49, 2.25, 1.13) using the Elbow; (1.13, 0.83, 2.64) resting on the EAC; and (1.29, 1.07, 1.70) using Elbow + EAC techniques along X-axis, Y-axis and Z-axis respectively.

Figure 4 summarizes the mean endoscope displacement and standard deviation along X- and Y-axes in both the groups (low and high dexterity) as a function of control as well as the three stabilizing techniques used. Similarly, Figure 5 shows the displacement along the Z-axis.

In the X-axis direction (Fig. 4a), there was no significant difference between the Elbow stabilization and controls in the high dexterity group. However, the horizontal component of hand tremor in EAC as well as

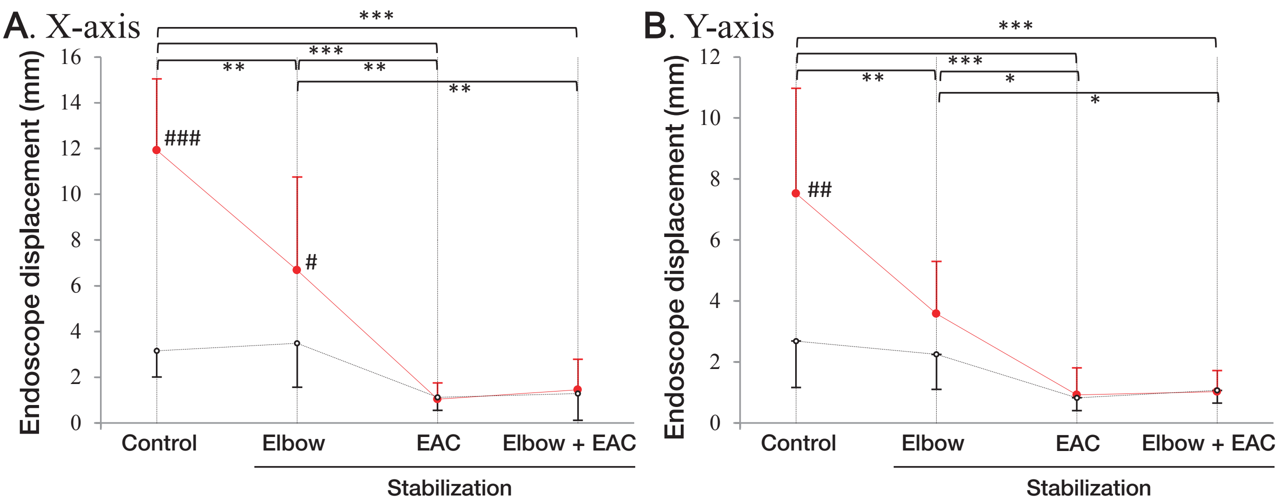

Fig. 4. Position displacement of the endoscope in X-axis (**A**), in Y-axis (**B**) as a function of control and three stabilizing techniques. Vertical dashed lines indicate, from left to right, the control data without any stabilization, elbow stabilization, EAC stabilization, and both elbow plus EAC stabilization. In panels **A** and **B**, high dexterity group (High group, filled black line, $n = 8$, $\sqrt{(X2 + Y2)} < 7.5$) displays unchanged slope from control to all three stabilizations, when compared with low dexterity group (Low group, filled red line, $n = 7$, $\sqrt{(X2 + Y2)} \geq 7.5$) after stabilization of EAC and Elbow + EAC (**A**). Details are described in the text.
Definitions: Closed circles = mean endoscope displacement; Vertical bars = standard deviation of mean values of displacement at control, Elbow, EAC and Elbow + EAC. *$P < 0.05$; **$P < 0.005$; and ***$P < 0.0005$. #$P < 0.05$; ##$P < 0.005$; and ###$P < 0.0005$. * represents intra-group difference and # represents intergroup difference. EAC, external auditory canal.

EAC + Elbow techniques was lower as compared to the control ($P = 0.0001$) of the same group. On comparing the three stabilization techniques to the control in the low dexterity group along the X-axis, all the three stabilization techniques were useful in reducing the hand tremor, with $P = 0.0043$ for Elbow and $P = 0.0001$ for EAC and EAC + Elbow. It was also observed that EAC and EAC + Elbow techniques were statistically significant in reducing the hand tremor as compared to Elbow alone in the same group (P <0.05). However, there was no significant difference between EAC and EAC + Elbow techniques in both low and high dexterity groups.

A similar trend was observed in the Y-axis direction (Fig. 4b) as that of the X-axis. There was no significant difference between the Elbow stabilization and controls in the high dexterity group. However, using EAC as well as EAC + Elbow techniques significantly lowered this vertical component of hand tremor as compared to the control ($P < 0.0005$) of the same group. On comparing the three stabilization techniques to the control in the low dexterity group along the Y-axis, it was found that all three stabilization techniques were useful in reducing the hand tremor, with $P < 0.005$ for Elbow and $P < 0.0005$ for EAC and EAC + Elbow. It was also found that EAC and EAC + Elbow techniques were statistically significant in reducing the hand tremor as compared to Elbow alone in the same group ($P < 0.05$). On the other hand, the difference between EAC and EAC + Elbow

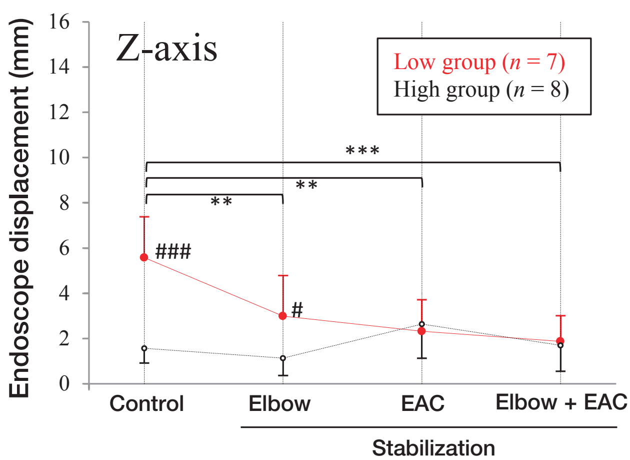

Fig. 5. Position displacement of the endoscope in Z-axis as a function of control and three stabilizing techniques. High dexterity group (High group, filled black line, $n = 8$) displays unchanged slope from control to all three stabilizations, when compared with low dexterity group (Low group, filled red line, $n = 7$) after stabilization of EAC and Elbow + EAC. Details are described in the text.
Definitions: See Fig. 4. *$P < 0.05$; **$P < 0.005$; and ***$P < 0.0005$. #$P < 0.05$; ##$P < 0.005$; and ###$P < 0.0005$. * represents intra-group difference and # represents intergroup difference. EAC, external auditory canal.

techniques was not statistically significant.

There were interesting results found in the Z-axis direction (Fig. 5). The performance using the endoscope and the effect of stabilization techniques in reducing the endoscope displacement in the optical axis of the user was very different and unique in the two groups. In the high dexterity group, none of the stabilization techniques could significantly reduce the endoscope displacement ($P \geq 0.05$). However, in the low dexterity group, the optical axis component of hand tremor with Elbow as well as EAC techniques was significantly reduced compared to that of the control ($P < 0.005$). Interestingly, combining both stabilization techniques further reduced the endoscope displacement significantly as compared to the control ($P < 0.0005$).

DISCUSSION

In an endoscopic ear surgery, obtaining a clear field of surgical view with a 2-dimensional monitor is strongly affected by the hand tremor, especially along the visual axis. There are important anatomical structures like facial nerves, auditory ossicles, semicircular canals, etc., located in the direction parallel to visual axis which, if damaged, would evoke severe complications. Therefore, controlling tremor in this direction becomes important for obtaining a good field of surgical view and ensuring patient safety.[7]

The constant use of the endoscope by oto-surgeons has significantly increased the potential to control middle ear diseases like cholesteatoma by enabling a view of hidden areas that would otherwise not be visible through mini-invasive approaches. Traditional microscopes have unquestionable merits, primarily 3-dimensionality of the operative field and bimanuality; but the endoscopic technique provides a new instrument to understand the etiopathogenesis of cholesteatoma, decisively contributing to a detailed description of recesses of the middle ear, where cholesteatoma more frequently relapses.[11] Endoscopic eradication of the cholesteatoma or epithelial tissue from hidden areas after removal by microscope of all visible cholesteatoma improves the quality of surgery. This in turn significantly decreases the frequency of canal wall-down procedures and posterior tympanotomy requirements with acceptable residual cholesteatoma rates. Transcanal EES has been found to be an acceptable and safe technique for the exposure and eradication of middle ear and/or attic cholesteatoma.[12, 13]

A study by Mürbe revealed that two-handed endoscopic manipulation yields significantly smaller tremor amplitudes than one-handed manipulation; though, in clinical otological surgery, operators basically manipulate the endoscope with one hand and surgical instruments with the other.[9] Neudert analyzed the hand tremor of students during 28 days of surgical training of tympanic membrane reconstruction using both hands but did not find any significant reduction of hand tremor.[14] Their results indicated that the success of the first microsurgical skill acquisition does not depend on the measured tremor. This may be an indicator that reducing hand tremor without any techniques is difficult and requires additional stabilization approaches.

Ovari *et al*. quantified the hand movement accuracy of 14 otorhinolaryngeal surgeons with various levels of surgical experience in middle ear surgery. They found that experienced surgeons have significantly better positioning accuracy than novice ear surgeons in terms of mean displacement values of marker trajectories. The instrument support and the two-handed instrument holding techniques significantly reduce surgeons' tremor.[15]

Although Elbow stabilizations are widely used in general EES procedure using the operation bed as the elbow fixing stand, there is no optimized base for EAC stabilization in the real world. We believe that these experimental results benefit both clinicians and medical equipment providers by improving the existing elbow base and/or device stand for future clinical safety during EES. We found that while using the EAC stabilization technique, there is no need to apply force to the endoscope in the vertical axis direction. Using the EAC as a contact point and the endoscope as a fulcrum reduced the tremors along the horizontal axis. Similar findings reported by Coulson *et al*. show that supporting the wrists significantly decreases the amplitude of the tremor.[16] Surgeons should consider using wrist supports when performing parts of operations that require a high degree of accuracy. One more study showed that tremor can be reduced approximately tenfold during microsurgical operations by fixing the fingertips that hold the operating instruments.[17] On the other hand, because the elbow is unstable, if no stabilization technique is used, subjects cannot avoid moving the endoscope while relying on the elbow alone; therefore, they have to adjust both elbow and wrist movement. When the subjects use the elbow as a contact point and the table as a fulcrum when they put their elbow on the table, it is easy to stabilize the tremor in vertical and visual axis directions because those two directions are on the same plane as the arm and endoscope axis. However, this arm and endoscope plane is orthogonal to horizontal axis direction, so the elbow technique does not affect horizontal axis stabilization.

Although there are few studies that analyze hand tremor, there is no report that examines 3D movement of the endoscope. The results obtained in this study indicate that manipulating the endoscope by putting the elbow on the table restrains both vertical and visual axis direction of the tremor, and manipulating the endoscope by putting the endoscope on EAC restrains both vertical and horizontal axis directions. Concomitant use of these stabilization techniques restrain hand tremor in all the directions of endoscope movement, though there is no multiplier effect along any of the directions.

In conclusion, the present study has demonstrated that both of the tremor stabilization techniques—resting the elbow on the table, and resting the endoscope on the EAC—are useful for reducing endoscopic displacement due to hand tremor. It appears that using both techniques is useful for getting a clear view of the surgical field as well as for ensuring patient safety.

LIMITATION

A limitation of this study is that the hypothetical EAC was a drilled hole on a vertical plate, so the angle to which surgeons inserted the endoscope is different compared to a practical operation.

The authors declare no conflict of interest.

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