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An Armrest Is Effective for Reducing Hand Tremble in Neurosurgeons

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Abstract

Experienced neurosurgeons reduce hand tremble by placing their hand beside the operative field when performing microneurosurgery conventionally. Another solution to reduce hand tremble is an armrest. However, the reduction of hand tremble by using an armrest or finger-placing technique has not been rigorously measured in microneurosurgery. This study was performed to provide a quantitative assessment of the efficacy of an armrest to reduce hand tremble in comparison with the finger-placing technique. Hand tremble was evaluated in 11 board-certified neurosurgeons in a simulated microneurosurgery. The loci of surgical forceps handled by neurosurgeons were measured by a three-dimensional optical coordinate measuring machine. A static task was performed under four conditions: with/without the finger-placing technique and/or an armrest. The radius of an imaginative sphere including 95% of each locus was calculated and reviewed according to the four conditions. Hand tremble was significantly larger when the finger-placing technique was not implemented compared to when the technique was used ($P < 0.05$). The armrest also reduced hand tremble ($P < 0.05$) similar to the finger-placing technique. Non-inferiority was retained between the finger-placing technique and the armrest. Concomitant use of the armrest and the finger-placing technique did not interfere with the efficacy of the technique to reduce neurosurgeon's hand tremble. The finger-placing technique was confirmed to reduce hand tremble. Resting the neurosurgeon's forearm on an armrest also reduced the hand tremble. An armrest is a device that reduces hand tremble in neurosurgeons like the finger-placing technique.

Key words: armrest, hand tremble, microsurgery, three-dimensional optical coordinate measuring machine, tremor

Introduction

Hand tremble in neurosurgeons is a considerable obstacle to precise microneurosurgery. One of the primary causes of hand tremble is tremor. Physiological tremor is present in all normal subjects.[1] Neurosurgeons generally place their finger and/or hypothenar eminence beside the operating field to reduce hand tremble. Neurophysiological studies have demonstrated the efficacy of supporting the hand or wrist in reducing tremors. Burne et al. reported a reduction of hand tremor when the hand was held against a rigid bar.[2] Coulson et al. examined hand tremor in normal subjects and showed that the hand tremor was decreased by a wrist support. They recommended that microsurgeons should consider using wrist supports.[3] Although their experiment did not simulate microneurosurgery, the results supported the efficacy of the finger-placing technique, which reduces hand tremble in neurosurgeons.

Unfortunately, the finger-placing technique cannot always be implemented. If the operating field is shallow or the surgical instrument (e.g., aneurysm clip applier) is too long, the finger would not be able to reach the surface of the patient's head or the head frame. Sugita et al. developed a hand rest for microneurosurgery,[4] however, this hand rest cannot be used in all kinds of surgical approaches. Such lack of support for the neurosurgeon's hand can adversely affect hand stability.

One potential solution to reduce hand tremble is to use an armrest. Armrest is regarded as a helpful

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equipment to reduce neurosurgeon's hand tremble similar to the finger-placing technique.[4] Some armrests have been developed for microsurgery.[5–7] The authors have also developed an intelligent armrest using robotics technology, which is currently in clinical use.[8] However, the effectiveness of armrests during microneurosurgery has been assessed based only on the subjective impressions.[9]

The present study was performed to verify the effectiveness of armrest. Highly accurate three-dimensional (3-D) loci of the tremor during microsurgical simulation was recorded by a highly accurate three-dimensional optical coordinate measuring machine (3-D optical CMM), which was designed to track the 3-D location of an object. This is the first study using such an accurate 3-D optical CMM to record neurosurgeon's hand tremble.

Materials and Methods

Eleven Japanese board-certified neurosurgeons volunteered to participate in the present study. The subject group did not include any of the authors. All of the volunteers were men, and had 7–25 years (mean: 16.4 years) of experience in neurosurgery.

The experimental environment simulating microneurosurgery (Fig. 1A) consisted of an operating table (MOT-5000; Mizuho Corporation, Tokyo), Sugita multipurpose head holder and head frame (Mizuho Corporation), skull and cerebrum models (MMI-FTA; Muranaka Medical Instruments Co. Ltd., Osaka), operator's chair (Micro Chair MC-860; Mizuho Corporation), and an operating microscope (SN MD-6FDc; Nagashima Medical Instruments Co. Ltd., Tokyo). A 5-mm piece of 7-0 nylon suture was placed on the insular cortex of the brain model as a visual target.

A handmade experimental armrest (Fig. 1B) made of a rigid Agathis wood plate 10 mm thick overlaid by a PORON® (Taketoyo, Chita, Aichi) microcellular polymer urethane foam sheet 5 mm thick was used in this study. The armrest was 350 mm in length and 80 mm in width and was mounted on a commercially available tripod (G 1220 MK2; GITZO, Rungis, France) via a camera platform (029; Manfrotto, Cassola, Italy).

Subjects were seated in the operator's chair, which they were allowed to adjust along with the operative

Fig. 1 A: Panoramic photograph of our experimental environment simulating microneurosurgery. Skull and cerebrum models were installed in a Sugita multipurpose head frame and head holder attached to an operating table. The neurosurgeon sits on an operator's chair and observes the cerebrum model through an operating microscope. His right forearm and the hypothenar eminence are placed on an armrest seated beside the operator's chair. B: Handmade experimental armrest. It was designed to support the subject's forearm and hand from the elbow to the hypothenar eminence. The armrest was mounted on a tripod. C: The camera unit of the three-dimensional optical coordinate measuring machine that was used in this study (K600; Nikon Metrology NV, Leuven, Belgium). D: A dedicated infrared light-emitting diode marker of the coordinate measuring system pasted on a pair of surgical forceps.

microscope to obtain the most comfortable posture consistent with their usual posture during microsurgery. The tripod of the armrest was set on the floor beside the operator's chair and adjusted to an appropriate position according to the subject's requirement. Magnification of the operative microscope was maximized (approximately ×19) after preparation.

A static experimental task was designed in which the subjects were asked to keep pointing to the visual target with the tip of a pair of surgical forceps. The duration of the task was approximately 20 s. Each subject performed the task under four different conditions: with finger-placing technique without using the armrest (indicated as "Finger" in Figures), without the finger-placing technique without using the armrest ("Free"), without finger placement but with the armrest ("Armrest"), and with finger placement and with the armrest ("Armrest w/Finger"). All the trials under these four conditions were repeated twice and data were pooled: a total of eight trials were performed for each subject. The order of the trials was rearranged for each subject to control for learning effects between the four conditions.

To compare hand tremble, the loci of the surgical forceps were recorded. A 3-D optical CMM (K600; Nikon Metrology NV, Leuven, Belgium) (Fig. 1C) was used to acquire the loci of the surgical forceps with high temporal and spatial resolution. The frequency of coordinate data acquisition was 200 Hz; the spatial resolution and the relative volumetric accuracy of the 3-D optical CMM were 0.002 mm and 0.02 mm, respectively. The camera unit of the 3-D optical CMM was placed 2.5 m from the experimental operative field. A dedicated infrared light-emitting diode (LED) was pasted on the surgical forceps 20 mm from the tip (Fig. 1D). Another LED was pasted onto the cranial model as a fiducial marker of the coordinate system. These two LEDs were connected to the controller of the 3-D optical CMM via a dedicated strobe/multiplexer. Concurrent 3-D coordinate data of the surgical forceps and the cranial model were obtained every 5 ms during the task. A few time points that included technical acquisition error were skipped. A total of 4,096 (= 2^{12}) time points (20.475 s) were analyzed for each trial. Before data analysis, the coordinate data of the cranial model obtained from the second LED were subtracted from the concurrent coordinate data of the first LED on the surgical forceps to exclude possible shaking of the cranial model.

For quantitative comparison of hand trembles, the authors introduced the concept of "Radius of Tremble," which was measured by a three-step procedure as follows. First, the loci traced by the surgical forceps during one trial were drawn in 3-D space, and the averaged location of the surgical forceps was determined by calculating the mean value of all of the coordinate data during one trial (Fig. 2A). Second, a sphere that included 95% of the loci was imagined (Fig. 2B). Third, the radius of the sphere was calculated and named "Radius of Tremble" (Fig. 2C). The radius is equivalent to the 95th percentile of 3-D displacement of each momentary coordinate for the surgical forceps from the averaged locations of the surgical forceps through one trial. "Radius of Tremble" was calculated for each trial to quantize

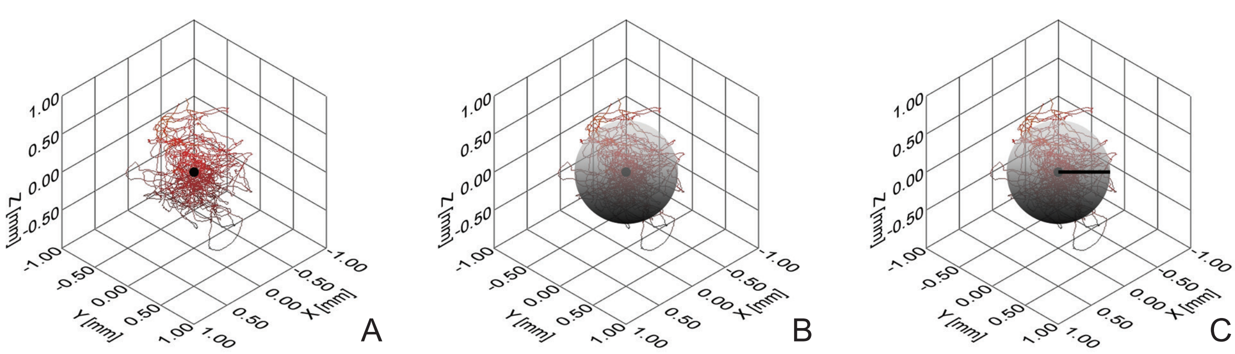

Fig. 2 The authors proposed a representative value named "Radius of Tremble" for quantitative evaluation of hand tremble. The procedures to calculate the "Radius of Tremble" are shown. A: The loci traced by the light-emitting diode (LED) marker during one trial are drawn in a three-dimensional (3-D) frame of reference. The LED marker was pasted 20 mm from the tip of the surgical forceps. The coordinate of the average location of the surgical forceps during one trial is shown as a black dot. B: A virtual spherical body, which includes 95% of the locus, is overlaid on the image. The sphere indicates a space where the LED marker remained during 95% of the trial. C: The radius of the sphere is indicated as a black line. The radius is equivalent to the 95th percentile among all the 3-D distance values between each momentary coordinate and the averaged location of the surgical forceps, and is named the "Radius of Tremble."

and represent hand tremble. These "Radii of Tremble" of all trials were aggregated according to the four conditions and compared. Statistical significance was analyzed by Steel-Dwass test.

Differences of the "Radii of Tremble" between the condition with the finger-placing technique without the armrest and the other three conditions were calculated for each subject. The mean values and 95% confidence intervals for the three conditions were evaluated by non-inferiority test. According to the supplier of the 3-D optical CMM, the coordinate data independently had a standard deviation of 0.02 mm. Consequently, the equivalence margin was determined to 0.04 mm from the metrological accuracy in accordance with the role of additivity of variance.

Results

In all subjects, the largest "Radius of Tremble" among the four conditions was recorded when the finger-placing technique was not implemented and the armrest was not applied, in comparison to other three conditions (Fig. 3, left).

The mean values of "Radius of Tremble" among all 11 subjects were: 0.32 ± 0.15 mm [mean ± standard deviation (SD), respectively] with the finger-placing technique without the armrest, 1.21 ± 0.53 mm without the finger-placing technique and without the armrest, 0.36 ± 0.13 mm without the finger-placing technique but with the armrest, and 0.26 ± 0.06 mm with both finger-placing technique and the armrest (Fig. 3, right). Comparison among these four conditions indicated that the mean value of "Radius of Tremble" was significantly decreased in each of the three conditions with the finger-placing technique and/or the armrest compared to the condition without the finger-placing technique and without the armrest ($P < 0.05$). There was no statistical significance of mean differences between the condition with the finger-placing technique without the armrest and the condition without the conventional finger-placing but with the armrest ($P > 0.05$). Addition of the finger-placing technique to the armrest made no significant difference compared to the condition without the finger-placing technique with the armrest ($P > 0.05$). Addition of the armrest to the finger-placing technique made no significant mean difference in comparison to the finger-placing technique ($P > 0.05$).

In accordance with the non-inferiority test (Fig. 4), the "Radii of Tremble" in the condition without the finger-placing technique without the armrest were inferior to the condition with the finger-placing technique without the armrest. The non-inferiority of the armrest against the finger-placing technique was retained. The "Radii of Tremble" in the condition with the finger-placing technique with the armrest were not inferior to those in the condition with the finger-placing technique without the armrest.

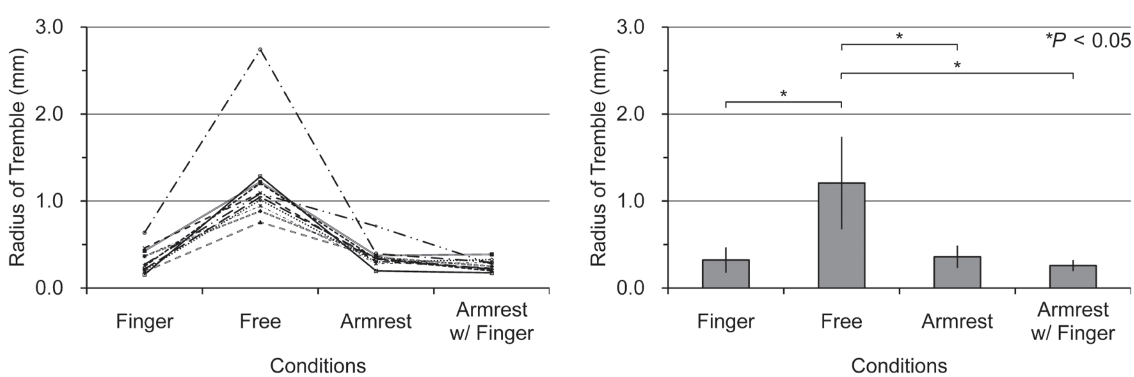

Fig. 3 Left: A graph showing the distribution of "Radius of Tremble" for all subjects and changes in the "Radius of Tremble" according to four conditions. The y-axis indicates the 95th percentile of distances between momentary and averaged location of the surgical forceps ("Radius of Tremble"). When neither finger-placing technique nor the armrest was applied, the "Radii of Tremble" were the largest among the four conditions in all subjects. Right: Bar graph showing the mean values and their standard deviations of "Radius of Tremble" according to the conditions. When neither finger-placing technique nor the armrest was applied, the "Radius of Tremble" was significantly larger than that with the finger-placing technique ($P < 0.05$). There was no significant mean difference between use of the finger-placing technique and the armrest ($P > 0.05$). Addition of the armrest to the conventional technique had no significant effect compared to the finger-placing technique itself ($P > 0.05$). In each of the three conditions with the finger-placing technique and/or armrest, the mean value of "Radius of Tremble" was significantly smaller than that without the finger-placing technique without the armrest ($P < 0.05$). Addition of the finger-placing technique to the armrest had no significant effect compared to the armrest itself ($P > 0.05$).

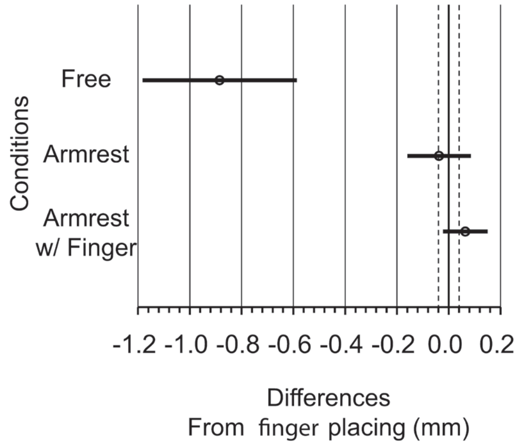

Fig. 4 Non-inferiority test of the difference of "Radius of Tremble" between the finger-placing technique (indicated as "finger placing" in this figure) and the other three conditions. Broken lines indicate the equivalence margin (0.04). The non-inferiority of the armrest compared to the finger-placing technique was retained. Use of the armrest together with the finger-placing technique was not inferior to the condition with the finger-placing technique without the armrest.

Discussion

Physiological tremor is considered to consist of central neurogenic oscillation and mechanical oscillation in sensorimotor loops.[10] Many recording modalities have been proposed to understand physiological tremor.

Electromyography has been widely used to study the neurogenic aspect of the oscillation.[11,12] Electromyography has been useful to understand tremor, however, electromyography could not directly measure the actual magnitude or 3-D amplitude of the tremor.

The physical aspect of physiological tremor has also been studied using various measuring modalities. Lippold recorded the force and displacement of physiological tremor using a strain gauge and moving coil transducer.[13] Elble and Randall used a force transducer and electromyography.[11] Accelerometry has also been widely used.[2,14] Although accelerometry and its spectral analysis permitted investigators to measure the mechanical aspects of physiological tremors, it was not sufficient to quantize the magnitude or 3-D amplitude of neurosurgeon's hand tremble. Acceleration data must be integrated twice to determine the position data. Accumulated errors produced by the repeated integral computation are not negligible. Recently, an image-based motion analysis method was introduced to evaluate surgeon's hand tremor during microsurgery.[15,16] This method enabled visual evaluation of the amplitude of tremor. However, this method could not provide data on the true spatial amplitude of the tremor because the video recordings were not 3-D but projected onto a two-dimensional plane.

In contrast to a previous study in which maximal displacement values were adopted to represent the amplitude of surgeon's tremor,[16] the authors evaluated neurosurgeon's hand tremble using the mean 95th percentile values of distances between the momentary and averaged location of the surgical forceps. We named the representative as "Radius of Tremble." In actual clinical situations, whether a microscopic maneuver is carried out well or not is dependent not on maximal displacement but on how long a surgeon can control the surgical instrument within an appropriate location. Therefore, maximal displacement is not regarded as an ideal representative to describe neurosurgeon's hand tremble. Furthermore, the maximal values can be easily disrupted by contingent factors. Maximal displacement can be considered to include outliers that do not reflect the nature of microsurgical maneuverability. Therefore, the authors compared hand tremble by analyzing the 95th percentile values.

Our result confirmed that the finger-placing technique reduced neurosurgeon's hand tremble and the armrest can be applied along with the finger-placing technique. Even if the finger-placing technique cannot be implemented, an armrest can reduce hand tremble. Neurosurgeons can select either of them in accordance with the situation. Simultaneous use of the armrest and the finger-placing technique had sufficient efficacy in reducing hand tremble compared to the finger-placing technique alone. Even in situations where the finger-placing technique is used, an armrest can be used.

This study had some limitations. First, we did not examine whether use of an armrest can reduce fatigue in neurosurgeons during an operation. However, it is reasonable to speculate that a well-designed armrest would reduce such fatigue. It is not easy to make a scientific assessment of neurosurgeon's fatigue, but further studies are warranted.

Another limitation is that the shape, size, and setting of the armrest were not investigated. The armrest was designed as a simple flat rectangular plate to exclude any effect of the particular configuration of the armrest and to determine only the essential effectiveness of its use. The dimensions (350 mm in length and 80 mm in width) of the armrest were set to adequately support the neurosurgeon's forearm and hand from the elbow to the hypothenar eminence. This study did not make reference to the appropriate shape and size of the armrest.

An optimally designed armrest would enhance its effectiveness. The appropriate position and angle of the armrest were decided according to each subject's preference. Each subject was permitted to adjust the hand and armrest to the most comfortable setting, which was appropriate to determine the essential effectiveness of the armrest without any other factors that would affect hand tremble. The effectiveness of the armrest can be modified by changing its angle and position. The efficacy of the armrest may be enhanced if the design and setting are optimized based on the results of further investigations.

The final limitation was due to the "static" task design. A static task was designed because static evaluation of the surgeon's hand was considered a prerequisite for smooth and accurate microscopic maneuvers. Fine microscopic maneuvers are achieved by smooth and accurate hand control of the surgeon. The setting of an armrest must be changed to fit the ever-changing situation in actual clinical situations. Further investigations with dynamic tasks are needed to determine the whole efficacy of armrest use during microscopic maneuvers.

In many clinical situations, armrests may have to be adjusted frequently, and this is inconvenient with existing armrests so they are insufficient for continuous operation. Further development of both statically optimized and dynamically sufficient armrests is necessary. Appropriate use of such armrests will benefit many neurosurgeons by reducing hand tremble.

The efficacy of the finger-placing technique to reduce neurosurgeon's hand tremble during microscopic tasks was confirmed in an experimental environment simulating microneurosurgery. An efficacy of an armrest to reduce hand tremble was quantitatively confirmed. It was proven that those two devices did not conflict. While awaiting the development of more functional and convenient armrests, armrests can be a helpful equipment during microneurosurgery.

Acknowledgments

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Conflicts of Interest Disclosure

The authors have no conflicts of interest concerning the materials or methods used in this study or in the findings presented in this article. All authors have registered online self-reported conflicts of interest disclosure statement forms through the website for the Japan Neurosurgical Society members.

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