Quantitative Evaluation of Phonomicrosurgical Manipulations Using a Magnetic Motion Tracking System

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Objectives/Hypothesis: To present and evaluate the magnetic-based phonomicrosurgery instrument tracking system, a novel and objective method of acquiring instrument position data during simulated phonomicrosurgery. The position data can be used to compute quantitative motion metrics. This system was used to objectively evaluate the motion performance of novice and expert surgeons during phonomicrosurgical simulations and determine the differences between these groups.

Study Design: Prospective cohort study.

Methods: A magnetic-based phonomicrosurgery instrument tracking system was developed, including a workbench, independent task, motion metrics, and computer program. Based on this system, three experts’ and six novices’ motion data were collected and analyzed.

Results: Experts demonstrated significantly better motion smoothness along the y-axis for the dominant hand. For the nondominant hand, experts demonstrated better motion smoothness along all three axes, shorter path length, and better depth perception (P < .05). Experts also demonstrated higher quality of operation (P < .001). No significant difference in time was noted (P = .671).

Conclusions: Parameters derived from magnetic-based motion tracking were able to differentiate between expert and novice surgeons. These parameters have the potential to be used in phonomicrosurgical training as feedback to enhance the training process.

Key Words: Phonomicrosurgery, motion tracking, magnetic based, surgical training, surgical simulation.

Level of Evidence: 4

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INTRODUCTION

Laryngeal diseases affect millions of people in the world, having a significant impact on quality of life. Voice disorders impact individual’s ability to communicate, which can impact job performance and cause social isolation.1–3 Phonomicrosurgery is one of the most common medical interventions used to restore normal voicing function. Hirano proposed the body-cover model to describe the role of each vocal fold layer in vibration. The cover is of particular interest, because it plays a significant role in mucosal wave propagation and normal vibratory function.4 Changes to its composition can greatly affect the vibratory parameters of the vocal folds. For these reasons, a delicate and accurate surgical approach is necessary to preserve or restore normal vibratory function. However, despite the technically demanding nature of phonomicrosurgery, there is a lack of simulative teaching apparatus and objective evaluation of surgical skills that can differentiate between expert and novice users.5

Traditionally, surgeons are trained in an apprenticeship style by observing and performing procedures on patients under expert supervision. This method of training has a long learning time and high cost, and it is the patients who absorb much of the cost and risk of training new surgeons.6 Therefore, a simulative training set-up would benefit public health, allowing new surgeons to develop the necessary skills before practicing on patients. It has been shown that surgeons with previous training on simulators demonstrate more skill and make fewer errors than those who did not undergo simulation training.7 In addition, the ability to objectively evaluate and provide feedback to surgeons would enhance the consistency of surgical education.8

The key to successful phonomicrosurgical manipulation is considered to be the maintenance of motion smoothness and the minimization of tremor,9 as in other areas of microsurgery.10 In laparoscopic surgery, surgeons consider the following factors as key to a
successful operation: compact and continuous spatial motion of the tip of an instrument, smooth motion, good depth perception, a good sense of orientation, and coordination of two hands.\textsuperscript{11} These factors may also be key to successful phonomicrosurgery. Therefore, we derived formulas to quantify the characteristics of phonomicrosurgical motion from this information.

Our goal with this study was to evaluate the use of a magnetic tracking system to characterize surgical skill. Here we compare novice and expert surgeons using a magnetic-based motion tracking system. By allowing comparison of motion metrics during a surgical task, we hypothesize that this system will successfully differentiate between experts and novices. Doing so will enable the development of objective evaluation methods to quantify surgical skill, providing valuable feedback to surgeons to enhance training.

**MATERIALS AND METHODS**

**Phonomicrosurgery Simulation Bench**

The phonomicrosurgical simulation bench used in this study was comprised of 1) a laryngeal dissection frame developed at the University of Wisconsin\textsuperscript{7}; 2) a floor-stand microscope (OPMI 1-H; Zeiss, Oberkochen, Germany); 3) right turn triangle forceps and upturned laryngeal microscissors (Pilling; Teleflex Medical, Research Triangle Park, NC); and 4) a surgeon’s chair with arm support boards (Fig. 1) that was designed to achieve a maximum comfort level for the operator.\textsuperscript{10} This equipment was used to complete the surgical tasks detailed below.

**Motion Tracking System**

The peripheral component interconnect (PCI) bus-based direct current magnetic position and orientation tracking system, microBIRD (Ascension Tech Ltd, Burlington, VT) is used to track the path of the tip of the surgical instruments within the surgical field (Fig. 2). The microBIRD’s sensors (0.5 mm in diameter and 3 mm in length) are attached to the tip of the instruments and measure the strength of the applied magnetic fields (Fig. 3). These data are processed by the PCI card, and the distance from the transmitter to the sensor, as well as the orientation angle, are calculated on x-, y-, and z-axis (Fig. 4). Detection occurs at 68.3 Hz, with a minimal position resolution of approximately 0.5 mm. The default factor between the displacement of the sensor and on-computer movement was calculated as $1.59 \text{ mm in the } x \text{ direction (8 mm), } 1.01 \text{ mm in the } y \text{ direction (8 mm), and } 0.28 \text{ mm in the } z \text{ direction (7.75 mm).}$ This factor was used to calibrate for the following investigations.

**Simulative Task**

A paper task was designed that requires the operator to make vertical cuts similar to the microflap technique used in laryngeal microsurgery. The paper consists of 3 mm $\times$ 3 mm square grids and a centered circle of 25 mm in diameter. This paper is fixed on a hollow tubular bracket with an inner diameter of 25 mm. Within the circle are two red rows that contain...
three squares each that are sequentially cut along their vertical grid lines (Fig. 5). The working distance was a constant 38 cm, and the laryngoscope was fixed at a 42° angle with the x-y plane.11 The tubular bracket was adjusted under the microscope light until the far end projection of the laryngoscope was overlapped with the yellow border of the triangle to ensure that the angle and the operation field were the same in every trial.

The microscissors were held in the dominant hand, and the microforceps were held in the nondominant hand. Timing started when the two surgical instruments were steadied within the laryngoscope and ended when the last square was removed. A successful operation requires coordination of both hands and eyes, and fine control of movement and strength. The quality of operation was evaluated through scoring based on the ratio of the area being cut off to the standard square area (see Supporting Information, Appendix Figures 1 and 2, in the online version of this article).

**Parameter Development**

Key factors for technical success during laparoscopic surgery have previously been identified, which include motion smoothness, precise depth perception, accurate sense of direction, and two-hand coordination.12 Because both laryngeal microsurgery and endoscopic surgery involve instrument tip movement similar to laparoscopic surgery, these parameters are utilized in this motion tracking system. Based on the kinematic characteristics of laparoscopic instruments, Cotin et al.13 developed parameters to quantitatively analyze surgical motion.

In this study comparing five expert surgeons’ and 20 novice surgeons’ performance on laparoscopic motion, these parameters appropriately characterized surgical skills. Data collected through this motion tracking system provide kinematic information including: the position of the tip of an instrument in three-dimensional space, the direction and degree of rotation of an instrument along three main axes, and the time needed to perform a task. These data can be used to establish similar parameters and develop a scoring system to evaluate the quality of task completion.13 These same kinematic parameters are used here to describe and evaluate motion during this simulated laryngeal microsurgery task. Additionally, operation precision was scored, which is employed as a quality parameter. Details are described as follows:

**Time (T):** This is the total time in seconds (s) taken to complete the task, starting when the instruments are placed into the endoscope and steadied over the task, and ending when the last cut is made.

**Motion smoothness (S):** This characterizes the overall smoothness of the instrument’s movement. It is based on the measure of jerk, or the instantaneous change in acceleration $j = d^3v/dt^3$.14 The entire equation represents the time-averaged integrated squared jerk:

$$S = \frac{1}{T} \sqrt{\frac{1}{2} \int_0^T j^2 dt}$$

The higher the $S$ value, the more significant the tremor is. Here, $j$ is measured along the three axes, $x$, $y$, and $z$, separately.
Path length (P): This parameter is the total distance traveled by the tip of the instrument. A shorter path length corresponds to a more skillful surgical maneuver. It is measured in millimeters and calculated as follows:

\[ P = \sum_{0}^{T} \sqrt{(dx)^2 + (dy)^2 + (dz)^2} \]

Depth perception (D): This is the total distance travelled by the tip of the instrument along the instrument’s own axis. With the laryngoscope fixed at a 42° angle with the x-y plane, \( D \) is measured in millimeters and can be calculated as follows (Fig. 6):

\[ D = |(x_1 - x_2) \cdot \cos(42°) - (Z_1 - Z_2) \cdot \sin(42°)| \]

Quality (Q): This is measured as the difference in area between the standard grid square and the area of the square after a cut is made. A lower score indicates higher quality, as this implies that the operator cut more precisely along the vertical grid lines. The scoring formula is described below as:

\[ Q = \sum_{k=1}^{n} \frac{(A_k - A) \cdot n \cdot A}{n} \]

A represents the pixels of the standard square area, \( A_k \) represents the pixels of the area being cut, and \( n \) represents the total number of grids being cut. (See Supporting Information, Appendix Figure 2, in the online version of this article for further details on how to calculate Q).

A custom program written in the programming language C was developed to implement these formulas. The parameters of analysis, including time (T), path length (P), depth perception (D), motion smoothness (S) along the x, y, and z axes, and quality (Q), comprise the magnetic-based phonomicrosurgery instrument tracking system (MPTS).

Subjects

Three experts (aged <45 years) and six novices (aged <35 years), who are all dextrorotational, received training and were familiarized with the equipment and task prior to data collection. The subjects were required to perform the task of cutting the two rows of squares with the help of elbow supports and a 10× microscope magnification. Experts performed five trials, whereas novices performed four trials. Data were imported to the MPTS custom program for analysis. The grids from the tasks were scanned and converted into JPEG files (CanoScan D1250U2F; Canon U.S.A., Melville, NY) with a resolution of 1200 dpi. The pixels of each area were calculated using a Digital Board (Cintiq 21UX; Wacom, Saitama, Japan), and Adobe Photoshop CS 4 (Adobe Inc., San Jose, CA) (see Supporting Information, Appendix Figure 1, in the online version of this article). SPSS version 16 (IBM, Armonk, NY) was used to perform t tests on individual parameters. The power of this study was verified via post hoc analysis (supplementary power analysis).

RESULTS

Differences in kinematic parameters exist between the two subject groups. For every parameter, a lower value indicates a better score. Regarding the dominant hand, experts demonstrated better motion smoothness than novices along the horizontal axis (\( P < .05 \)). No significant differences in the other dominant hand parameters were noted. Regarding the nondominant hand, experts demonstrated better motion smoothness along all three axes, reduced path length, and better depth perception in comparison to novices (\( P < .05 \)). Experts also demonstrated better quality of operation than the novices (\( P < .001 \)). No significant difference in task duration (T) was noted between experts and novices (\( P = .671 \)) (see Tables I-III, Figs. 7 and 8).

DISCUSSION

The working pattern of phonomicrosurgery involves removing lesions without damaging surrounding healthy tissue while using approximately 30-cm-long microinstruments. Additionally, the operating area is no larger than 5 cm² and is accessed via a long, narrow metal tube under a microscope.15,16 As a result, the margin of success is narrow, and this kind of surgery raises high demand of surgical skills.9 To account for these challenges, phonomicrosurgeons need to receive education and training regarding operating skills.
In the past, the evaluation of surgical skill was primarily based on surgical results and subjective criteria, as the evaluation of technical proficiency is a difficult and complex task. Novices have to learn the correct operation through observing the procedure video and by teaching themselves from real practice on patients. Even with experts providing on-site supervision, the following problems still persist. First, a supervising surgeon cannot always accurately evaluate the characteristics of hand movements. Second, the evaluation is usually made afterward by the observer’s memories. This approach cannot provide adequate details or accurate, instantaneous feedback during an operation, let alone describe the operating characteristics of a surgeon. Therefore, developing an objective and instantaneous system to quantitatively evaluate operational motion becomes necessary to both education and scientific research in phonomicrosurgery.

We developed the MPTS to evaluate phonomicrosurgical manipulation. This system could provide instructors with an effective, efficient, and economical training platform outside of the operating room. The metrics of this system have the ability to measure and evaluate the characteristics of instrument motion, to quantitatively describe successful and unsuccessful motion, and to provide an objective description of trainees’ performance. Thus, novices would know the key factors in surgical manipulation and what they need to improve. As a result, the learning efficiency would be significantly improved and the level of confidence and comfort with the phonomicrosurgery greatly increased.

Regarding the paper task, to complete this procedure, the dominant hand needs to follow up and cut the target as the nondominant hand holds the object with the forceps. This requires two-hand coordination, hand–eye coordination, and good depth perception. Based on the results, the expert group had significantly better operation results ($Q$) than the novice group. The experts’ improved motion parameters mainly lay in the nondominant hand that controlled the forceps. Only the expert’s horizontal smoothness was better in the dominant hand that controlled the microscissors. Experiences with the microflap procedure have indicated that great care should be taken not to tear or fenestrate the flap. Achieving this requires holding an object using the forceps with accurate depth perception and targeting. Once the object is held, the nondominant hand should remain stable as the dominant hand makes the cut. The motion of the dominant hand as the surgeon aligns the microscissors consists of subtle adjustment in x-axis and y-axis, which elicits horizontal tremor and unsteadiness.

An efficient metric should not only provide information about performance but also identify the key success/failure factors of performance and the size and nature of the gap between expert and novice performance. Thus, it should reveal the action that needs to be taken to resolve these gaps. In our study, this evaluation system can describe the differences between success or failure of performance by multiple metrics, but which ones are the

| TABLE I. Comparison of Dominant-Hand Parameters. |
|-----------------|-----------------|-----------------|-----------------|
| Prs              | x-axis          | y-axis          | z-axis          |
| Novices          | 0.294 ± 0.1870  | 0.366 ± 0.1918* | 0.381 ± 0.2256  |
| Experts          | 0.261 ± 0.1391  | 0.146 ± 0.0377* | 0.373 ± 0.1628  |
| $P$              | 40.080 ± 22.4007| 38.020 ± 16.2938| 15.600 ± 9.1191|
| $D$              | 13.490 ± 5.9172 |                |                |

*Statistically significant differences in a one-tailed $t$ test ($P < .05$).
$D =$ depth perception; $P =$ path length; $S =$ smoothness.

| TABLE II. Comparisons of Nondominant-Hand Parameters. |
|-----------------|-----------------|-----------------|
| Prs              | x-axis          | y-axis          | z-axis          |
| Novices          | 0.188 ± 0.0870* | 0.211 ± 0.0907* | 0.220 ± 0.0952* |
| Experts          | 0.101 ± 0.0696* | 0.116 ± 0.0596* | 0.098 ± 0.0519* |
| $D$              | 9.109 ± 3.2757* |                |                |

*Statistically significant differences in a one-tailed $t$ test ($P < .05$).
$D =$ depth perception; $P =$ path length; $S =$ smoothness.

| TABLE III. Comparison of Quality Scores and Time. |
|-----------------|-----------------|
| Q               | $T$, s          |
| Novices         | 0.099 ± 0.0794* | 32.140 ± 11.0040 |
| Experts         | 0.021 ± 0.0236* | 35.473 ± 6.0100  |

*Statistically significant differences in a one-tailed $t$ test ($P < .001$).
$Q =$ quality; $T =$ time.
key factors is not clear. More data should be collected, especially expert motion data, to find out the power of each metric.

Regarding the time of operation, there was no significant difference between experts and novices. In the microsurgery studies, speed was actually not considered a necessary factor for a successful surgery. Smith et al.\textsuperscript{20} found that in laparoscopic surgery, the improvement in time occurred much faster than the improvement in accuracy. This group argued that time alone could not be the criterion to judge the success of operation. In a study on training residents in vascular suture skills, the frequency of vascular leakage was related to the manipulation accuracy but not to the time of operation.\textsuperscript{21} With more tasks developed in the future, this MPTS could also be used to evaluate performance with

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Fig. 7. Instrument motion along x-, y-, and z-axis of experts and novices. The first row displays a novice’s motion. The second row displays an expert’s motion. The first column is for the dominant hand. The second column is for the nondominant hand. Experts had a significantly shorter path length in the nondominant hand.
different surgical instruments and equipment settings. This would provide objective criteria for phononicsurgical equipment and tools optimization.

CONCLUSION
The magnetic-based MPTS has been demonstrated to objectively and quantitatively evaluate motion characteristics with high accuracy. Experts were better than novices in vertical cutting (two-hand coordination) as evidenced by better motion smoothness, better depth perception, shorter path length associated with the non-dominant hand, as well as better motion smoothness along the horizontal axis associated with the dominant hand. No significant difference in time of operation was noted between the two groups.

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BIBLIOGRAPHY