Surgical Hand Tracking in Open Surgery Using a Versatile Motion Sensing System: Are We There Yet?

BRADLEY GENOVESE, M.D.,*† STEVEN YIN,‡ SOHAIL SAREH,* MICHAEL DEVIRGILIO,* LAITH MUKDAD,* JESSICA DAVIS,* VERONICA J. SANTOS, PH.D.,†§ PEYMAN BENHARASH, M.D.*†

*From the *Division of Cardiac Surgery and †Center for Advanced Surgical and Interventional Technology, University of California at Los Angeles, Los Angeles, California; ‡Electrical Engineering Department, University of California at Los Angeles, Los Angeles, California; and §Mechanical and Aerospace Engineering Department, University of California at Los Angeles, Los Angeles, California*

With changes in work hour limitations, there is an increasing need for objective determination of technical proficiency. Electromagnetic hand-motion analysis has previously shown only time to completion and number of movements to correlation with expertise. The present study was undertaken to evaluate the efficacy of hand-motion-tracking analysis in determining surgical skill proficiency. A nine-degree-of-freedom sensor was used and mounted on the superior aspect of a needle driver. A one-way analysis of variance and Welch's *t* test were performed to evaluate significance between subjects. Four Novices, four Trainees, and three Experts performed a large vessel patch anastomosis on a phantom tissue. Path length, total number of movements, absolute velocity, and total time were analyzed between groups. Compared to the Novices, Expert subjects exhibited significantly decreased total number of movements, decreased instrument path length, and decreased total time to complete tasks. There were no significant differences found in absolute velocity between groups. In this pilot study, we have identified significant differences in patterns of motion between Novice and Expert subjects. These data warrant further analysis for its predictive value in larger cohorts at different levels of training and may be a useful tool in competence-based training paradigms in the future.

SURGICAL MASTERY IS not solely based on perfection of technical skills but is an amalgamation of knowledge, decision-making, communication skills, and leadership.[1] Each of these competencies is matured throughout a surgeon's training and career. Nonetheless, development of excellent technical skills serves as the cornerstone of surgical training.[2] The apprenticeship model of training established by William Halsted in 1889, did not have objective milestones to define surgical maturity and was solely based on the judgment of educators.[3] In the current era, however, surgical training is limited to five clinical years, with each stage guided by Accreditation Council for Graduate Medical Education milestones.[4] Yet, assessment of technical skills and operative proficiency continues to remain subjective.[5]

Technologic advances in computer simulation along with the need for more efficient training paradigms have expedited the introduction of video recordings, motion analysis systems, and virtual reality simulators.[6, 7] In fact, proficiency in fundamental of laparoscopic surgery, a phantom-based platform, is now mandatory for advancement in general surgery training.[8] Laparoscopic- and robotic-based trainers rely heavily on the fixed fulcrum linked motions associated with minimally invasive surgery.[9] Freedom of motion in the unrestricted spatial environment of open surgery complicates movement analysis as a means of skill evaluation. This is the fundamental reason technical assessment is still based on expert observation.[10] With the increase in attention of the public and media for transparency on physician performance, there has been an increasing interest in objectifying surgical technical performance, as seen from ProPublica's creation of the "Surgeon Scorecard."[11]

The present study was performed to evaluate the utility of hand-tracking technology in assessment of technical skills in a simple vascular anastomosis model. The primary objective was to determine motion-derived parameters that would best correlate with subjects' experience in open surgery.

Address correspondence and reprint requests to Peyman Benharash, M.D., 10833 Le Conte Avenue, Division of Cardiac Surgery and Center for Advanced Surgical and Interventional Technology, UCLA Center for Health Sciences, Room 62-249, Los Angeles, CA 90095. E-mail: pbenharash@mednet.ucla.edu.

Methods

The study was approved by the Institutional Review Board at the University of California, Los Angeles, and informed consent for voluntary participation was obtained.

Participants, including medical students, surgical residents, and surgical attendings, were divided into Novice, Trainee, and Expert groups. Medical students who had previously completed their clerkship in surgery comprised the Novice group, surgical residents who completed one to two clinical years were labeled Trainees, and board-certified cardiothoracic surgeons comprised the Expert group. The study task involved simulation of large vessel patch anastomosis for all three groups, using a 25-mm dacron graft with an 8-cm elliptical incision. Markings were created approximately 0.5 cm apart on each side of the graft to create a standardized entry and exit point, as shown in Figure 1. A 4–0 polypropylene suture was anchored at the apex of the incision before initiating the task. The subjects performed a continuous running suture method while taking each side of the anastomosis in two bites, totaling 20 individual throws. Synthetic material rather than animal or cadaveric tissues was used to reduce variability and allow replication between users.

Motion analysis was performed using a custom-built system and an Adafruit BN0055 nine-degree-of-freedom absolute orientation sensor (Adafruit Industries, New York, NY). The system was able to record three-axis absolute orientation using Euler vectors and quaternions as well as three-axis linear and angular velocities. An Arduino microcontroller (Fig. 2) was used for data transfer via USB with Arduino 1.7.7 software (Italy). Processing 3.0 software (©Ben Fry and Casey Reas, MIT Media Laboratory) was used for data processing and three-dimensional modeling. The sensor was attached to the superior aspect of a standard needle driver (Fig. 3). The system collected data at a resolution of <1 mm and frequency of 100 Hz. The sensor allowed collection of total number of movements made (individual movement defined as a velocity that crossed zero), distance traveled (path length) in all dimensions (x, y, and z), the absolute velocity tracing of each hand in all dimensions, and total time to complete the task.

STATA 13.0 software was used for all statistical analysis (StataCorp 2013, College Station, TX) and results were considered significant if P values were <0.05. The one-way analysis of variance was performed to evaluate differences among all three groups. A Welch's t test was used to compare pairs of groups.

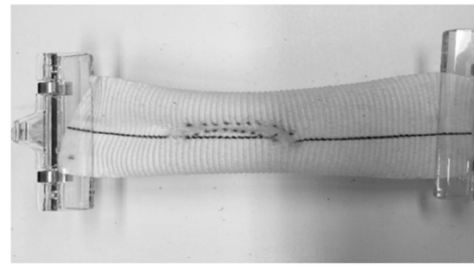


FIG. 1. Dacron graft to simulate large vessel patch anastomosis.

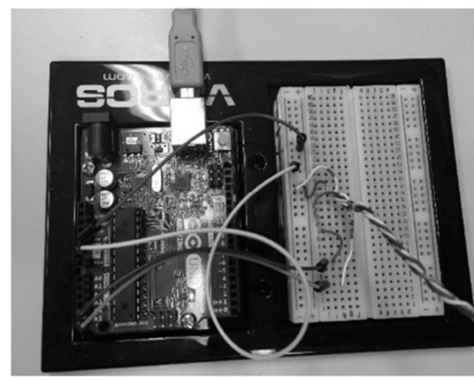


FIG. 2. Arduino microcontroller.

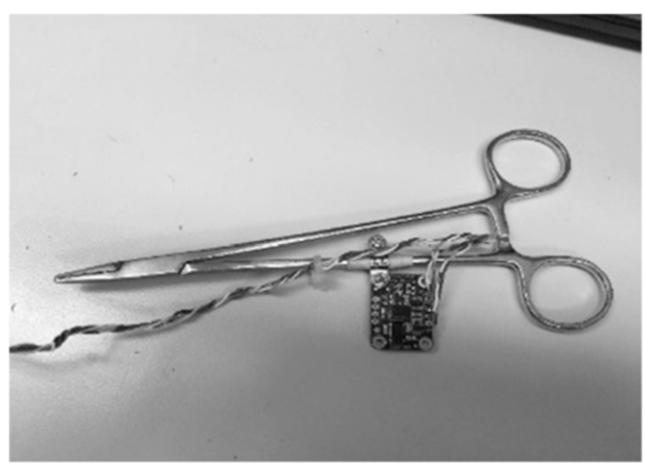


FIG. 3. Ardafruit BN0055 nine-degree-of-freedom sensor attached to needle driver.

Results

We developed a custom-tracking system with commercially available components with a total cost of less than $500. During the study period, 11 subjects were recruited, 4 Novice, 4 Trainees, and 3 Experts. All subjects successfully completed the task.

Analysis of instrument motion is shown in Table 1. Compared to the Novice, the Expert group, in general, exhibited significantly shorter instrument path length, number of movements, and time to completion of task. However, these differences did not reach statistical significance between the Trainee and Expert groups. The absolute velocity was similar among the groups in

TABLE 1. *Motion-tracking Analysis of Right Hand*

Parameters	Novice (n = 4)	Trainee (n = 4)	Expert (n = 3)	ANOVA *P* Value	Pairwise *t* Test *P* Value		
					Novice *vs* Trainee	Novice *vs* Expert	Trainee *vs* Expert
Total path length (AU)							
x	88.17 ± 6.29	70.83 ± 13.54	53.17 ± 8.86	0.006*	0.08	0.01*	0.09
y	85.42 ± 11.51	59.37 ± 15.21	40.79 ± 8.41	0.005*	0.04*	0.01*	0.10
z	76.48 ± 18.63	50.55 ± 19.25	41.55 ± 11.69	0.06	0.10	0.03*	0.48
Number of movements							
x	217.75 ± 44.58	117.00 ± 61.84	102.67 ± 29.49	0.02*	0.04*	0.01*	0.70
y	153.75 ± 46.25	104.75 ± 58.55	96.00 ± 3.56	0.24	0.24	0.09	0.78
z	252.25 ± 50.08	169.50 ± 41.49	124.67 ± 38.42	0.01*	0.045*	0.01*	0.20
Absolute velocity (AU)*							
x	0.23 ± 0.18	0.31 ± 0.25	0.34 ± 0.27	0.81	0.62	0.58	0.89
y	0.22 ± 0.18	0.26 ± 0.24	0.26 ± 0.20	0.95	0.80	0.80	1.00
z	0.20 ± 0.16	0.22 ± 0.18	0.27 ± 0.21	0.88	0.87	0.66	0.76
Time to completion (second)	381.79 ± 31.12	233.07 ± 82.46	156.64 ± 10.23	0.002*	0.03*	0.001*	0.16

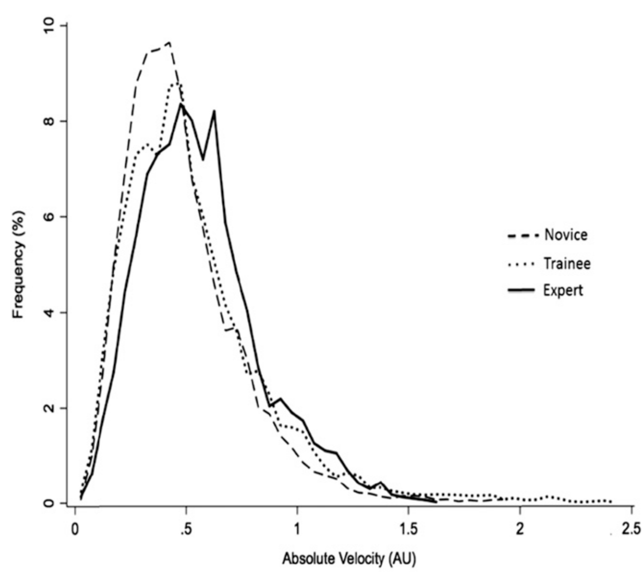
AU, arbitrary units, *significant value.

all axes. We additionally examined the vectorially added absolute velocity profiles for the groups as shown in Figure 4. The groups did not show significant differences in means, skewness, or kurtosis (P = non-significant).

Discussion

In the present study, we used tool-tracking technology to evaluate differences in hand motion during suturing among subjects of varying surgical experience. Significant difference were noted in path length, number of movements, and time to task completion. Interestingly, the absolute velocity profiles did not differ among groups. Subjects with higher expertise tended to complete the task in a shorter period with less movements and a decreased path length. Taken together, our results may be explained by the principle of economy of motion and increasing efficiency with added experience.

Path length has also previously been reported to correlate with the level of training in laparoscopic surgery.[12–14] However, studies in open surgical simulation have failed to show significant differences between levels of training.[15] We have found significant differences in path length along *x*, *y*, and *z* axes between Novice and Expert subjects. The differences in our findings might be due to the fact that our experiment focused exclusively on suturing and eliminated knot-tying, a task that has relatively long path lengths. It is important to note that the prior study by Datta obtained data from an accelerometer chip mounted on the dorsum of the second metacarpal in subjects.[16] This could lead to errors in placement between users or false movements during tasks. In contrast, we used information from the body of the instrument to reduce



	Novice	Trainee	Expert	ANOVA
Mean (SD)	0.49 (0.10)	0.55 (0.10)	0.56 (0.07)	NS
Skewness	0.77	1.09	0.75	NS
Kurtosis	3.49	4.25	3.54	NS

FIG. 4. Vectorially added absolute velocities. NS, not significant.

variability. Such a focus on tool kinematics as opposed to more variable human hand kinematics is commonly done in studies of laparoscopic surgery skills.[17]

Total number of movements to complete the task was significantly different between Novice and Expert subjects in *x* and *z* axes, with Experts using less movements. This finding again points toward the increasing economy of motion in Expert subjects. Lack of major differences in the *y* axis may be explained by video analysis, which demonstrates minimal travel in this dimension compared with Novice. This is an area where video synchronization and labeling of movements is necessary to further characterize the type of movements that are occurring across subjects at various levels.

Further analysis of instrument velocity did not reveal significant differences among study subjects with varying levels of training. However, time to task completion was significantly shorter with more surgical experience. This further highlights the importance of economy of motion and may serve as a surrogate for efficiency of movements. This could further be examined with video synchronization and labeling of specific movements.

Total time to completion of a task has been shown to be an excellent marker of level of training as reported by Datta et al. in open surgical simulation.[16] It has also been shown to be a significant marker of level of training in laparoscopic surgical tasks.[14] Our time results demonstrate significant differences in Novices compared to both Trainees and Experts, while unable to reliably distinguish Trainees from Experts. This suggests that although time to completion may be valuable in identifying major differences in skill level, it is not a sensitive measurement when comparing subjects with more developed surgical technical skills.

Our study has several limitations. Although this was a feasibility study of new technology, the small sample size may have increased the potential for Type II errors, an issue that should be addressed in future studies. Additionally, we were unable to correct for individual differences in technical skills apart from the formal level of training. Although, there was not a significant difference between Experts and Trainees in our study, there was a wide variation within the Trainee group. This could represent the fact that some trainees were performing complete or partial tasks at an expert level. We intend to further highlight this point with future studies involving video labeling of each distinct maneuver within a surgical task. And finally, we evaluated a single task and did not have access to data from the contralateral hand, which may provide additional information.

In summary, we have demonstrated the feasibility of using a simple cost-effective motion-tracking device to detect surgical performance differences in subjects with varying levels of training. Insights from this study may provide impetus for larger efforts to develop data banks for specific technical tasks. This in turn may facilitate the delivery of automated immediate feedback to trainees and enable educators to objectively assess competency in open surgical procedures.

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