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Working volume: validity evidence for a motion-based metric of surgical efficiency

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Abstract

BACKGROUND: The aim of this study was to evaluate working volume as a potential assessment metric for open surgical tasks.

METHODS: Surgical attendings ($n = 6$), residents ($n = 4$), and medical students ($n = 5$) performed a suturing task on simulated connective tissue (foam), artery (rubber balloon), and friable tissue (tissue paper). Using a motion tracking system, effective working volume was calculated for each hand. Repeated measures analysis of variance assessed differences in working volume by experience level, dominant and/or nondominant hand, and tissue type.

RESULTS: Analysis revealed a linear relationship between experience and working volume. Attendings had the smallest working volume, and students had the largest ($P = .01$). The 3-way interaction of experience level, hand, and material type showed attendings and residents maintained a similar working volume for dominant and nondominant hands for all tasks. In contrast, medical students' nondominant hand covered larger working volumes for the balloon and tissue paper materials ($P < .05$).

CONCLUSIONS: This study provides validity evidence for the use of working volume as a metric for open surgical skills. Working volume may provide a means for assessing surgical efficiency and the operative learning curve.

Duty hour restrictions combined with increasing complexity of surgical cases require that surgical residents develop more specialized skills in a shorter amount of time.[1] To improve training of surgical residents, principles of deliberate practice must be integrated into the curricula.[2–4] Deliberate practice requires immediate and reliable feedback and an environment for exploration and error management.[2] Motion-based feedback measures have been incorporated into the training of athletes[5–7] and improving motor recovery from stroke.[5,8] The integration of motion-based performance measures into the surgical

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simulation environment may allow for improved performance evaluation and skills development through feedback. However, before integrating motion-based measures into feedback systems, we must first understand how these measures relate to performance in surgery.

Prior work using motion-based measures of performance in open surgical skills have differentiated performance based on procedure time,[9–11] path length (distance traveled by surgeon's hands),[12–14] idle time (amount of time surgeon's hands were not moving),[13] and number of hand movements.[9–11,15] These measures help describe efficiency of performance during a surgical task.[16–18] Efficiency in this situation relates to the conservation of time and motion when operating. However, the previously mentioned measures of efficiency (procedure time, path length, idle time, and number of hand movements) may not fully capture the complexity of movement displayed in the operating room.

Working volume is a measure of efficiency that has been preliminarily evaluated in laparoscopic skills performance[19,20] but has been relatively unexplored in open surgical skills. This metric describes the area of space occupied by the surgeon's hands while completing a task. In laparoscopy, measures of working volume have demonstrated evidence of construct validity to differentiate performance by experience level.[19] In addition, working volume has been used in composite measures of surgical efficiency comprised of multiple motion metrics including procedure time[21,22], path length,[21,22] control effort,[21] motion smoothness,[22] and depth perception.[22] These composite measures have differentiated performance according to experience.[21,22] Based on these findings from motion studies in laparoscopy, we were interested in evaluating this metric in an open surgical skills task. The aim of this study was to evaluate working volume as a potential assessment metric for open surgical tasks. Our hypothesis was that more experienced surgeons would have smaller working volumes than less experienced surgeons.

Methods

Setting and participants

Third- and 4th-year medical students, residents, and attending surgeons at an academic hospital were recruited through email listserv to participate in the study. Participation was voluntary and based on availability. This study was granted institutional review board approval by the University of Wisconsin Health Sciences Institutional Review Board.

Research protocol

Participants performed a suturing task on the variable tissue simulator. See D'Angelo et al,[13,14] 2015, for a detailed description and images of the simulator. Participants were instructed to place 3 interrupted sutures on 3 different simulated materials: foam (dense connective tissue), balloon (artery), and tissue paper (friable tissue). Participants were told to use the instrument tie technique while tying sutures. Needle driver, forceps, suture scissors, and 3-0 Prolene (Ethicon, Somerville, NJ) suture were provided to complete the suturing task. Prolene suture was selected to increase task complexity given the suture's memory property. The tissue paper task is considered to be a more difficult task than the foam or balloon task.

While participants performed the suturing task, data were collected with video recordings and optical motion tracking technology (Visualeyez 3000; Phoenix Technologies, Inc., Burnaby, BC, Canada). Before starting the suturing task, each of the participant's hands were instrumented with 4 light-emitting diodes (LEDs) affixed to surgical gloves with tape.[13] While participants sutured, 3-dimensional position data were recorded at 180 Hz by the optical tracking capture sensor and stored for future analysis.

Video recording and analysis

Participants' hand movements were video recorded using 2 video cameras (Q3HD; Zoom Corporation, Tokyo, Japan) with a resolution of 1920×1080 pixels and frame rate of 30 Hz. These cameras were positioned on the left and the right side of the participant at a 45° angle from their working location. Videos were stored and further analyzed using Adobe Premiere Pro video editing software (Adobe Systems Inc., San Jose, CA) to select specific time points of the start and the end of the procedure. The start of the procedure was defined as the hand leaving the starting position, and the end of the procedure was defined as cutting the final suture tails.

Working volume

After data collection, the position data were analyzed, and the effective working volume measure was calculated. For each hand, the 3-dimensional center point of the 4 LED trajectories was calculated. Effective working volume was defined as a sphere with the average distance of all the LED paths from each hand's center point serving as the radius of the sphere.

Path length and procedure time

Path length is the 3-dimensional distance the hands traveled from the starting position until the completion of the suturing task. Procedure time is the total time from when the participant's hands left the starting position until the completion of the suturing task. Analysis of path length and procedure time for this data set has been previously published.[13,14] This analysis demonstrated that attending surgeons had significantly shorter path lengths and procedure times than residents and medical students during the suturing task.[13]