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Surgical Skill Assessment Using Motion Quality and Smoothness

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OBJECTIVES: This article presents a quantitative technique to assess motion quality and smoothness during the performance of micromanipulation tasks common to surgical maneuvers. The objective is to investigate the effectiveness of the jerk index, a derivative of acceleration with respect to time, as a kinetostatic measure for assessment of surgical performance.

DESIGN: A surgical forceps was instrumented with a position tracker and accelerometer that allowed measurement of position and acceleration relative to tool motion. Participants were asked to perform peg-in-hole tasks on a modified O'Connor Dexterity board and a Tweezer Dexterity pegboard (placed inside a skull). Normalized jerk index was calculated for each individual task to compare smoothness of each group.

SETTING: This study was conducted at Project neuroArm, Cumming School of Medicine, the University of Calgary.

PARTICIPANTS: Four groups of participants (surgeons, surgery residents, engineers, and gamers) participated in the tests.

RESULTS: Results showed that the surgeons exhibited better jerk index performance in all tasks. Moreover, the residents experienced motions closer to the surgeons compared to the engineers and gamers. One-way analysis of variance test indicated a significant difference between the mean values of normalized jerk indices among 4 groups during the performance of all tasks. Moreover, the mean value of the normalized jerk index significantly varied for each group from one task to another.

CONCLUSIONS: Normalized jerk index as an independent parameter with respect to time and amplitude is an indicator of motion smoothness and can be used to assess hand motion dexterity of surgeons. Furthermore, the method provides a quantifiable metrics for trainee assessment and proficiency, particularly relevant as surgical training shifts toward a competency-based paradigm. (J Surg Ed ■:■■■-■■■. © 2016 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: surgical skill, motion, smoothness, jerk index, acceleration, dexterity

ACGME COMPETENCIES: Medical Knowledge, Practice-Based Learning and Improvement

INTRODUCTION AND LITERATURE REVIEW

Currently, surgical trainees acquire technical skills through years of hands-on training in the operating room (OR) in an apprenticeship model, supplemented by written anatomy examinations, tutorials, and laboratory-based surgical skill courses using cadavers or models. More recently, virtual reality (VR)–based simulations have been included in this paradigm. Although knowledge of anatomy can be assessed by written or oral examination, assessment of technical skill such as dexterity and tool handling remains more subjective than objective.

Assessment of surgical skills in both open surgery and minimally invasive surgery is necessary to ensure patient safety and provides information for residents to enhance their skills before operating on patients. Surgical training is shifting to a competency-based education paradigm[1,2] and assessing surgical competence has several potential benefits, including improved safety of surgical training processes, enhanced accreditation of specialists, and maintenance of

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public confidence in the surgical profession. Currently, most of the assessment methods for dexterity of residents are based on subjective evaluation by an expert surgeon observing the residents conducting different surgical tasks. The assessment for the same task could vary depending on who evaluates the performance and could even be biased.[3,4] This article proposes a quantitative method for assessment of the motion quality and smoothness during the performance of micromanipulation tasks and explores the correlation between the level of surgical training and the proposed metrics.

Skills that are currently evaluated include respect for tissue, aggressive or smooth motion, and instrumentation handling.[3-5] The subjective assessment of trainees by their preceptors has evolved to make the assessment process more standardized. Score sheets are often used for subjective assessment; however, the scoring procedure is dependent on the assessment conducted by experts. The Objective Structured Assessment of Technical Skill rating system,[6] the Global Operative Assessment of Laparoscopic Skills,[7] and the Fundamental Laparoscopic Skills program[8] are assessment methods that incorporate checklists to calculate an overall score for dexterity. The methods include some objective performance metrics including time and number of errors, as well as some subjective measures that still require an expert to judge the performance. A complete review of assessment of technical skills is included in the publication by Grantcharov et al.[9] Accurate, quantitative evaluation, and improved training efficiency are demands imposed by new training paradigms that have reduced work hours and training resources for surgical residents.[10] Virtual simulators are one of the ways to achieve accurate and unbiased quantitative measurement of certain aspects of surgical performance.[11] Objective assessment of surgical skills reduces the need for subjective evaluation and provides information for improvement of specific surgical tasks.[12,13]

Objective feedback of technical skills is essential to the structured learning of surgical technique and provides essential feedback for trainees. This type of evaluation, while evolving, has not been widely adopted into clinical practice because of expensive instrumentation required and lack of reliable objective measures of technical performance.[12] Objective assessment methods can be categorized into procedure-specific checklists, global, rating scales, motion analysis, VR simulators, and automated video-kinematic assessment.[13] A review of objective assessment techniques has been conducted by Moorthy et al.[13] and van Hoove et al.[12] They concluded that objective feedback of technical skills is crucial to the structured learning of surgical skills. They highlighted the progress in the methods of objective assessment of technical skills to provide objective feedback and help residents to improve their skill. They also discussed the potentials of VR simulators as an objective assessment method. Additionally, it was concluded that most methods of skills assessment that are valid for measuring training progress could also be used for examination or credentialing. Moreover, different methods of skills assessment are appropriate in different assessment scenarios. However, as they mentioned, further research is required to address the limitations and determine the link between objective assessment of technical skills and measured parameters such as complication and recurrence rates and postoperative pain.

Most of the surgical tools developed for objective assessment measure kinetostatic characteristics of the surgical tool and the surgeon's hand during the performance of surgical operations. These objective measures include time, trajectory traveled by the instrument, number of movements, peak forces, and mean values of velocity and acceleration. Although the earlier measures could be considered as a set of indicators to evaluate surgical dexterity and skills without inclusion of any biased judgment, they do not provide direct feedback for motion quality or smoothness and are not sufficient to indicate a resident's surgical skill in tool handling and quality of their hand motion for the tasks involving tactical approach. To address this gap, frequency analysis and peak acceleration have recently been considered as new metrics to incorporate effect of the hand motion in both time and frequency domains.[14] The addition of data analysis in the frequency domain helps to evaluate the smooth motion that is normally violated by jerky motion, tremor, and hesitant motion.

Motion smoothness in handling a surgical tool is an essential skill that surgical residents need to acquire before operating on patients. Motion smoothness is an indicator of skilled coordinated hand motion.[15] Smoothness or gracefulness is usually quantified based on the rate of change in acceleration (third derivative of the tool/surgeon's hand position) or curvature of the path, where a low curvature shows a straight line to the target and curvature values close to 1 means abrupt changes in curvature and jerky movements.[3] Motion smoothness is also measured as a cumulative number of sudden accelerations and decelerations. Jerk index is a scalar value that quantifies the smoothness and is influenced by the duration of the task and movement amplitude. As the jerk index is measured over a time interval, the integral of the mean squared magnitude of jerk is conventionally considered. Jerk measure is a time- and amplitude-dependent factor and represents the smoothness of the motion and tool handling during the performance of a given task. The smoothest motion results in a lower jerk index. To eliminate the effects of time and amplitude, the jerk index needs to be normalized by multiplying $[(\text{duration interval})^5/(\text{3D path length})^2]$ to the jerk index.[16] It has been proved that normalized jerk cost can quantify smoothness and coordination.[16] This is because of the fact that smoothness is an indicator of movement quality that should be independent of speed and distance. A review of normalization procedure of jerk index is discussed by Hogan et al.[17]