The American Journal of Surgery (2014) 207, 226-230

The American Journal of Surgery®

Association for Surgical Education

Hand motion patterns of Fundamentals of Laparoscopic Surgery certified and noncertified surgeons

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KEYWORDS:
Surgical education;
Basic technical skills;
Motion analysis;
Computer-assisted feedback

Abstract

BACKGROUND: With the increasing use of simulation in surgical training there is an increasing need for low cost methods of objective assessment.

METHODS: Hand-motion data (3 degrees of freedom) were acquired using microelectromechanical gyroscope tracking devices worn on both hands during an intracorporeal suture/knot-tying laparoscopic task performed by FLS-certified and non-FLS-certified surgeons. Each data sample was processed into a symbolic time series, and the Lempel-Ziv complexity metric was calculated for each hand for the whole task and the first 60 seconds of the task from the dominant hand.

RESULTS: FLS-certified surgeons had more complex hand-motion patterns. This was statistically significant only for the dominant hand ($P = .02$) but was still statistically significant when calculated from the first 60 seconds of the task ($P = .04$) and therefore independent of the total time taken to complete the task.

CONCLUSIONS: Hand-motion patterns were quantified and shown to be different between FLS-certified and non-FLS-certified surgeons using low-cost microelectromechanical technology and the Lempel-Ziv complexity metric.
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The advantages of semiconductor-integrated circuit manufacturing include low cost, small size, and reliability. Devices made using integrated circuit manufacturing techniques, called microelectromechanical systems (MEMS), can measure changes in orientation and are ubiquitous in modern smart phones and tablet devices.[1] The sizes of MEMS subcomponents range from 1 to 100 μm, and the size of a MEMS device itself ranges from 20 μm to a few millimeters. There are many commercial applications for MEMS, such as the gyroscopes and accelerometers found in airbag systems, computer peripherals, car navigation devices, and consumer electronics such as game controllers, personal media players, cell phones and tablet devices. This low-cost technology provides the opportunity to obtain hand-motion data during a laparoscopic task. Previously, high-cost electromagnetic tracking devices, virtual reality simulators, or specially instrumented box trainers have been used to acquire motion data, which have been analyzed using simple economy metrics: the number of movements and path length.[2] These economy metrics are highly correlated to total task time, but neither economy metrics nor task time quantifies or describes the quality of a subject's movements.[3] Total task time, despite this limitation, is currently the most

This study was supported by an Academy of Educators award from the University of North Carolina at Chapel Hill.

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Manuscript received March 13, 2013; revised manuscript October 1, 2013

0002-9610/$ - see front matter © 2014 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.amjsurg.2013.10.007

used and most cost effective metric in common use. The metrics used in the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills, from which Fundamentals of Laparoscopic Surgery (FLS) is derived, are task time and a quality measure (error penalty) using a human evaluator.[4]

We hypothesized that the quality of hand movements could be evaluated by identifying different hand-motion patterns between 2 groups with different levels of laparoscopic proficiency. We have previously used nonlinear complexity metrics to quantify motion patterns in open surgical tasks. Using different motion sensors, we have shown that the information content and complexity of hand-motion patterns during the open surgical subtask of single-handed knot tying were reduced with increased expertise, by comparing medical students with attending surgeons. However, in a follow-up study, hand-motion patterns during the open surgical task of creating an anastomosis showed an increase in the complexity of motion patterns with greater surgical experience or surgeon grade. A explanation for these conflicting findings could relate to a hierarchy of pattern structure: experts use simpler subtask motifs in more complex and denser patterns.[5,6] The Lempel-Ziv (LZ) complexity metric quantifies the recurrence of patterns of symbols in a signal.[7] In the calculation of LZ complexity, the hand-motion signal is first turned into a sequence of symbols, after which the pattern of symbol recurrence is analyzed. LZ complexity is related to the number of distinct substrings or subsequences and the rate of their recurrence along the given sequence. It has been applied to study brain function[8] and to detect ventricular tachycardia and fibrillation.[9] In a pattern sequence without complexity, the LZ complexity metric approaches 0, and for a pattern with maximum information or complexity, the metric approaches 1.[10] In our previous studies with open surgical techniques, we assumed that experienced surgeons had more surgical skills and that residents and students had less, therefore demonstrating only surrogate construct validity whereby level of training was a surrogate marker of real surgical skill and performance. However, FLS is a validated metric that can be used as a marker of competence in basic laparoscopic tasks that is independent of a surgeon's grade or rank.[11,12]

Methods

We voluntarily recruited attending surgeons, surgical residents, and fellows from the University of North Carolina at Chapel Hill. All data were collected in 2012. To standardize the results, left-hand dominance was an exclusion criterion.

All study participants performed the simulated laparoscopic task of intracorporeal knot tying. Hand-motion data were recorded using a pair of custom-made, low-cost (<$150 each to construct) Bluetooth MEMS gyroscope tracking devices worn on both hands (Fig. 1). These tracking devices were created using a breakout board with an analog SD740 (SensorDynamics AG, Graz, Austria) integrated inertial module with a triaxial gyroscope. This was breadboard prototyped to an ATmega328-based microcontroller (Atmel Corporation, San Jose, CA) interfaced to a wireless adapter module and Bluetooth Bee acting as a serial port using the Bluetooth protocol version 2.0 (with enhanced data rate) to create a wireless transmission distance of 20 to 30 m.

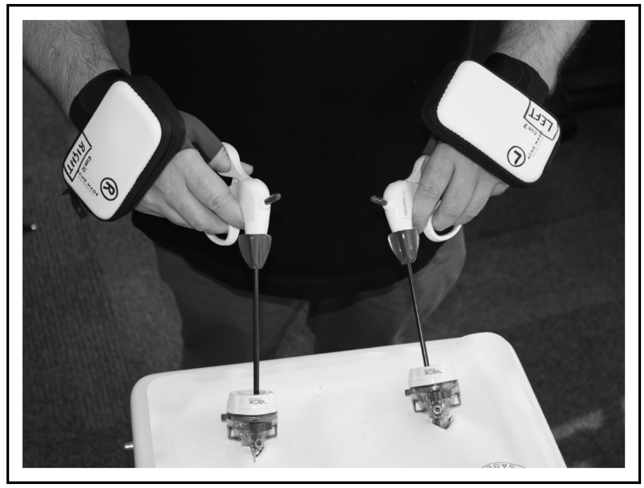

Figure 1 Hand-motion data were acquired using a pair of MEMS gyroscope tracking devices worn on both hands during the simulated laparoscopic task using Bluetooth to create a wireless transmission distance of 20 to 30 m.

We analyzed the hand-motion data sets using custom MATLAB software (The MathWorks, Natick, MA). The signal of the relative change in yaw, roll, and pitch from each hand was recorded, and then each data sample was processed into a binary symbolic time series. We used a symbolization scheme based on the first-order difference in the observed measurements, which is preferred with nonstationary data when change over time is more important than absolute values. This dynamic transform considered the difference between 2 measured values at a time interval apart.[13] The LZ complexity metric was then calculated from these binary symbolic time series for the whole task of each hand and also for the first 60 seconds of the task from the dominant hand.[10] The LZ complexity was normalized by a factor, $n/\log(\alpha n)$, where n is the sequence length and α is the number of alphabets in the symbolic sequence (therefore, in a binary symbolic time series, $\alpha = 2$). The Kolmogorov-Smirnov test was used to confirm the normality of the distributions of the LZ metric in the 2 groups, and then a 2-tailed unpaired Student's t test was used to test for the null hypothesis, with P values $<.05$ indicating statistical significance. All LZ complexity results were also pooled together and tested for linear correlation against the paired task times using Pearson's product-moment correlation coefficient. The Institutional Review Board of the University of North Carolina at Chapel Hill approved all procedures.

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