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Analysis of hand motion differentiates expert and novice surgeons

Munenori Uemura, MMedSci,[a] Morimasa Tomikawa, MD, PhD, FACS,[b] Ryuichi Kumashiro, MD,[b] Tiejun Miao, PhD,[c] Ryota Souzaki, MD, PhD,[b] Satoshi Ieiri, MD, PhD,[b] Kenoki Ohuchida, MD, PhD,[a] Alan T. Lefor, MD, MPH, FACS,[b] and Makoto Hashizume, MD, PhD, FACS[a,b,*]

[a] *Center for Advanced Medical Innovation, Kyushu University, Fukuoka, Japan*
[b] *Department of Advanced Medical Initiatives, Faculty of Medical Sciences, Kyushu University, Fukuoka, Japan*
[c] *TAOS Institute, Tokyo, Japan*

ARTICLE INFO

Article history:
Received 26 October 2013
Received in revised form 21 November 2013
Accepted 13 December 2013
Available online 19 December 2013

Keywords:
Clinical skills
Laparoscopic surgery
Surgical training
Kinematic analysis
Hand motion
Mathematical analysis

ABSTRACT

Background: The number of operations performed by a surgeon may be an indicator of surgical skill. The hand motions made by a surgeon also reflect skill and level of expertise. We hypothesized that the hand motions of expert and novice surgeons differ significantly, regardless of whether they are familiar with specific tasks during an operation.
Methods: This study compared 11 expert surgeons, each of whom had performed >100 laparoscopic procedures, and 27 young surgeons, each of whom had performed <15 laparoscopic procedures. Each examinee performed a specific skill assessment task, in which instrument motion was monitored using magnetic tracking system. We analyzed the paths of the centers of gravity of the tips of the needle holders and the relative paths of the tips using two mathematical methods of detrended fluctuation analysis and unstable periodic orbit analysis.
Results: Detrended fluctuation analysis showed that the exponent in the function describing the initial scaling exponent (α_1) differed significantly for experts and novices, being close to 1.0 and 1.5, respectively ($P < 0.01$). This indicated that the expert group had a greater long-range coherence with an intrinsic sequence and smooth continuity among a series of motions. Likewise, unstable periodic orbit analysis showed that the second period of unstable orbit was significantly longer for experts in comparison with novices ($P < 0.01$). This demonstrates mathematically that the hands of experts are more stable when performing laparoscopic procedures.
Conclusions: Objective evaluation of hand motion during a simulated laparoscopic procedure showed a significant difference between experts and novices.

* *Corresponding author*. Department of Advanced Medical Initiatives, Faculty of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan. Tel.: +81 92 642 5992; fax: +81 92 642 5199.
E-mail address: mhashi@dem.med.kyushu-u.ac.jp (M. Hashizume).

http://dx.doi.org/10.1016/j.jss.2013.12.009

1. Introduction

Although laparoscopic surgery has many advantages, such as decreased scarring, faster recovery, and cosmetic advantages, laparoscopic surgical skills may be harder to learn for some surgeons, and in some ways differ from the techniques used in conventional open surgery. Specialized training is important and necessary for surgeons to perform laparoscopic surgery safely and accurately.

The number of operations performed by a surgeon is sometimes considered an indicator of surgical skill, and surgeons who have performed many operations are considered "expert surgeons." In addition to facilitating the safe and efficient conduct of an operative procedure, experience enables surgeons to seek strategic remedies when faced with difficulties during an operation. The hand motions made by a surgeon during an operation may also reflect the skill of a surgeon. It is sometimes said that surgeons seek "economy of motion" in reference to manipulating surgical instruments, but measuring this desirable trait is a complex matter. We hypothesized that the hand motions of expert surgeons differ significantly from those of novice surgeons, regardless of whether the expert surgeons are familiar with the specific tasks during a particular operation.

Ordinarily, expert surgeons are distinguished from novice surgeons by performance scores, which are based on performance time, the speed with which instruments are manipulated, and the number of errors made during an operation. Performance scores are frequently used to assess surgeons being trained to perform laparoscopic procedures [1–4] and have been used to distinguish experts from novices in the conduct of laparoscopic procedures. Performance scores alone, however, cannot assess the skills required for laparoscopic surgery. Other measures that may distinguish expert from novice surgeons being trained in laparoscopic procedures include psychomotor skills and eye–hand coordination [5–11], although these factors alone are neither necessary nor sufficient for distinguishing the skills of expert and novice surgeons in performing laparoscopic procedures.

The goal of this study was to identify latent factors possessed by experts in the conduct of laparoscopic procedures. Kinematic analysis of the motions made by a surgeon's forceps during a skill assessment task were evaluated, and two mathematical analysis techniques used to assign numerical values to features of surgical performance such as "fluctuation" and "unstable periodic orbits," which may at least in part describe the concepts attributed to "economy of motion."

2. Materials and methods

2.1. Study participants

Participants in this study included 38 surgeons who have taken a laparoscopic surgery training course held at Kyushu University Training Center for Minimally Invasive Surgery [1,12,13]. Examinees were divided into two groups. The expert group included 11 expert surgeons, each of whom had performed >100 laparoscopic surgical procedures and completed the skill assessment task, and the novice group had 27 young surgeons, each of whom had performed <15 laparoscopic surgeries and had not completed the skill assessment. Participants were given informed consent by staff of the Kyushu University Training Center for Minimally Invasive Surgery and voluntarily agreed to participate.

2.2. Assessment task and objective data collection

Figure 1 shows the skill assessment task, which was developed at the Kyushu University Training Center for Minimally Invasive Surgery to evaluate the skills of trainees who had taken the training course [14]. Two identical needle holders were set into the box. A six-degree-of-freedom magnetic tracking sensor was mounted onto the tip of each needle holder. The box contained a stretched rubber sheet, with a printed circle and eight pairs of dots (Fig. 1A). Each examinee was required to pick up and hold the needle correctly, tie two throws after the placement of the first suture at any pair of dots (Fig. 1B), and then continuously suture each pair of dots along the printed circle (Fig. 1C). Sutures were placed from an outer dot to the corresponding inner dot. The assessment task ends with the final two throws tied to the tail of the first suture (Fig. 1D). The entry and exit points of the needle had to be placed precisely on the center of the dots. The time allotted for the task was 7 min.

During the assessment, the path of the tip of each needle holder was tracked using the magnetic tracking sensor and the data recorded. The paths of the centers of gravity of both instruments (Fig. 2A) and the relative paths of the centers of movement of both tips (Fig. 2B) were then analyzed using two mathematical methods.

2.3. Mathematical analysis methods

2.3.1. Detrended fluctuation analysis

Detrended fluctuation analysis has several advantages over conventional methods, including its ability to detect long-range correlations embedded in nonstationary time series and the avoidance of spurious measurements, and has been previously described [15]. First, the signal time series is integrated to "mimic," a random walk after subtracting the mean value of the signal. Next, the integrated time series $y(n)$ is divided into boxes of equal length n. Within each box, a least-squares linear fit of the data, representing the trend within that box, is calculated. Subsequently, the integrated time series is detrended by subtracting the local trend in each box. Finally, the previously mentioned computations are repeated over all time scales (box size n) to yield a relationship between $F(n)$ and box size n (i.e., the observation window). A power-law relationship between the average root-mean-square fluctuation function $F(n)$ and the observation window size indicate scaling. Fluctuation correlations are characterized by a scaling exponent α as

$$F(n) \alpha n^{a} \quad (1)$$

We calculated the fluctuation function by increasing the value of n. Two different scaling regimes were characterized using the scaling exponents α_1 and α_2. Of these, we only used α_1 estimated for the range within 3.2 s in evaluating scaling behavior. A lower value of α_1 indicates less fluctuation.