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Control of laparoscopic instrument motion in an inanimate bench model: Implications for the training and the evaluation of technical skills

David Gonzalez[a], Heather Carnahan[a], Monate Praamsma[a], Adam Dubrowski[b,*]

[a]Department of Kinesiology, University of Waterloo, Canada

[b]Department of Surgery, University of Toronto, 200 Elizabeth St., Eaton South 1E 583, Toronto, Ontario, Canada M5G 2C5

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Abstract

Computer-assisted analysis of wrist movement has recently emerged as an objective laparoscopic performance evaluation method. The first purpose of this study was to assess the differences in motion characteristics between the tip of the instrument and the wrist. The second purpose was to describe the control strategies used to move laparoscopic instruments. During a bead transfer task, motions of a laparoscopic needle driver's tip, heel, and the participants' wrist were monitored. Results showed that large amplitude movements were best described by movements of the wrist, and small amplitude movements were evidenced by motions of the instrument tip. Thus, for describing expertise, and for evaluation and feedback, motion of the tip of the laparoscopic instrument should be quantified, in addition to motion of the wrist. The motions of the instrument were controlled by utilizing the flexibility of the skin of the laparoscopic trainer in addition to using the fulcrum, and sliding through the trocar. In order to increase fidelity, virtual reality trainers should simulate the flexibility of the real structures around the insertion of the instrument.

Keywords: Laparoscopy; Virtual reality design; Movement control

1. Introduction

Minimal access surgery (MAS), now a common medical procedure (Arnold et al., 2002), is a radical departure from traditional open surgery, bringing not only many benefits to patient care but also many challenges to medical educators and to the design of instruments and virtual reality (VR) trainers (Arnold and Farrell, 2002). Laparoscopic instruments with arms extending from the tissues, being manipulated to outside the patient's body, distance the surgeon from the working field. Also, this surgical environment is both novel and complex in that it lacks tactile information and restricts the surgeon's range of motion. Finally, laparoscopy is performed with a two-dimensional (2D) visual display which must be used to guide three-dimensional (3D) movements. With the increasing use of laparoscopic surgery, this unique surgical environment needs novel performance assessment methods as well as innovative training approaches.

1.1. Assessment of motor components of laparoscopic performance

Currently, technical surgical skills involved in MAS and open procedures are assessed in two ways. The first approach relies on a subjective qualification of the flow of the skills which are evaluated with standardized charts and lists (Martin et al., 1997), such as the Objective Structured Assessment of Technical Skills (OSATS). The second approach relies on the objective quantification of hand movements during the performance of these skills by monitoring movements by using electromagnetic trackers attached to a surgeon's wrist by means of the Imperial College Surgical Assessment Device (Datta et al., 2002). However, it is unclear if monitoring the motion of the wrist

*Corresponding author. Tel.: +1 416 340 4194; fax: +1 416 340 7392.
E-mail address: adam.dubrowski@gmail.com (A. Dubrowski).

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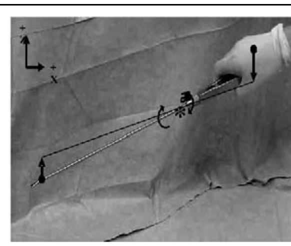
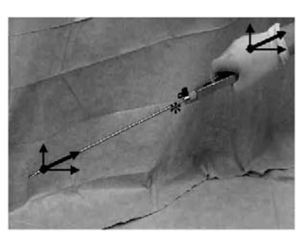
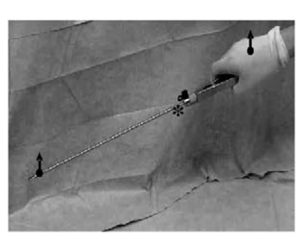
is the optimal method for quantifying laparoscopic performance. In laparoscopy, the characteristics of technical performance can be assessed in two ways: first, by measuring the characteristics of a surgeon's wrist moving a laparoscopic instrument such as a needle driver, thus indirectly inferring the motions of the instrument from the motions of the wrist (Taffinder et al., 1998; Torkington et al., 2001) or, second, by measuring directly the motions of the instrument to assess the performance, which is the case in VR simulators. Monitoring of the tip of the instrument may prove more precise, especially when making small movements, because the laparoscopic instrument can be manipulated with movements of the fingers as well as movements of the wrist (Gonzalez et al., 2005). In addition, because of the "fulcrum effect" around the insertion point where the instrument enters the body, slight movements of the wrist may cause significant movements of the tip of the needle driver (Crothers et al., 1999).

1.2. Control of laparoscopic instruments

Given the remote nature of laparoscopic performance, VR simulators have become a logical training tool. These simulators create simulated 2D operating environments in which the movements of the instruments are restricted and the tactile feedback is considerably reduced or absent. Over the past decade (Arnold et al., 2002; Arnold and Farrell, 2002), a number of such simulators have been developed, and parallel research interest has focused on the transfer of learning from VR to real-life performance (Figert et al., 2001; Fried et al., 1999; Gallagher et al., 1999) and on the development of the most effective simulations of visual and haptic representations of virtual tissues (Risucci et al., 2000; Saeian and Reddy, 1999; Schellekens et al., 1984). One important area, though, that deserves more research attention is the design of the laparoscopic instrument–simulator interface.

Most VR simulators use a joystick-like design to simulate laparoscopic instruments. This setup consists of several dimensions in which the hand movements can be controlled, which, in turn, direct the motions of the tip of the virtual laparoscopic instrument (Table 1). However, non-VR training scenarios provide additional dimensions of motion, because the skin around the trocar, where the needle driver enters the body, is elastic and allows some flexibility and stretching. This flexibility offers yet another possible strategy for the control of the needle driver's end trajectory, which, in the present study, we refer to as elevation.

Table 1
Three predominant movement control strategies responsible for movements of the laparoscopic instrument in the up–down (Z), forward–backward (X), and side-to-side (Y) dimensions

Control strategy	Definition	Pictorial representation	Hypothesis
Fulcrum	Utilizes the pivot point to move the tip of the needle driver in the direction opposite to that of the wrist movements		Significant movements of the tip of the needle driver in the Z and Y directions, but not in the forward X direction. Tip and wrist show high and negative correlations in the Y and Z directions. No correlations in the X direction are expected.
Sliding	Utilizes the ability to slide the instrument in and out through the trocar.		Significant movements of the tip of the needle driver in the Z, Y, as well as X directions. Tip and wrist show high and positive correlations in the X, Y, and Z directions.
Elevation	Utilizes the flexibility of the trainer in the vertical direction, thus allowing for elevation of the entire instrument.		Significant movements of the tip of the needle driver in the Z direction, but not in the X and Y directions. Tip and wrist show high and positive correlations in the Z direction. No correlations in the X and Y directions are expected.