Surgical Instrument Vibrations are a Construct-Valid Measure of Technical Skill in Robotic Surgical Training Tasks

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Introduction

The da Vinci Surgical System is a robotic surgical platform that allows surgeons to operate their instruments remotely with improved visualization, dexterity, and ergonomics. However, physical separation from the instruments precludes the surgeon from using his or her sense of touch to interact with the operative environment. This lack of haptic (touch) feedback in existing robotic systems raises questions about the safety of robotic surgery and creates an additional challenge in training surgeons to use the robot.

Traditional surgical skill assessment relies on observation of a surgeon’s performance, a method that is both subjective and time consuming. The growing demand for robotic minimally invasive surgery has increased the need for objective methods of assessing technical skill for surgical training [1,2]. Several prior studies have analyzed the kinematic motion of the robot to calculate performance metrics such as economy of motion and instrument speed [3,4]. However, these metrics do not account for interactions between the instruments and the surgical environment.

One possible method of objectively accounting for the quality of these interactions is to measure the transient mechanical vibrations of the robotic instruments. These vibrations primarily result from instrument contact with objects in the environment, such as collisions and needle hand-offs, with larger vibrations generally generating greater reliability. Abrupt movements of the surgical instruments also cause measurable vibrations. Our work on VerroTouch, a system for providing real-time auditory and haptic feedback of instrument vibrations [5], has shown that robotic surgical tasks can be easily measured with low-cost accelerometers mounted on the patient-side robot. In this study, we aimed to determine whether this metric can be an indicator of skill level for a series of robotic surgical training tasks.

VerroTouch System Design

VerroTouch enables the surgeon to feel tool contact and other important tactile events through the use of basic modules, which can be readily attached to existing da Vinci S systems without requiring permanent modifications. Although these components were initially customized for the da Vinci S, they are now compatible with the da Vinci Standard and Si models and can be adapted for other telerobotic systems.

Methods

Thirteen surgeons (6 experienced, 7 novice) used a da Vinci S Surgical System augmented with VerroTouch to perform three in vitro manipulation tasks (shown below) using four different feedback conditions, which were presented in pseudo-random order:

- **V** Visual feedback only (i.e., unaugmented da Vinci)
- **VA** Visual with audio feedback of tool vibrations
- **VH** Visual with haptic feedback of tool vibrations
- **VAH** Visual with audio and haptic feedback of tool vibrations

The VerroTouch system (described above) measured the high-frequency accelerations of the left and right needle driver instruments, and a force-torque sensor mounted within the task board measured the forces applied to the task materials. For each trial we calculated the RMS vibrations and forces of the robots presented in pseudo-random order, as compared to novices, as seen in Table 1.

Independent-sample t-tests were conducted on the task data to compare the instrument vibrations of novice and experienced surgeons. Applied force, completion time, and rated skill were also compared to determine whether differences existed between the two groups.

Results

Experienced robotic surgeons recorded significantly lower instrument vibrations than the novice surgeons for all three tasks. Needle Pass: p = 0.049, Needle Pass: p = 0.023. Box plots of the RMS vibration data for both tasks are provided in Fig. 2. Experienced surgeons also recorded lower RMS forces and task completion times compared to novices, as seen in Table 1.

Discussion

The presented results demonstrate that instrument vibrations, as measured by VerroTouch, are a construct-valid measure of technical skill during robotic in vitro training tasks. In contrast to the kinematic measures recorded by the robotic system, instrument vibrations provide information with respect to the quality of instrument handling and interaction with the operative environment. Measurement and awareness of an instrument vibration metric should encourage more careful control of the robot and more deliberate interactions with the surgical environment.

Furthermore, previous work has shown that providing visual feedback of objective skill measures may increase a surgeon’s ability to improve their performance [4]. Therefore, it is reasonable to hypothesize that the real-time audio and haptic feedback of instrument vibrations provided by VerroTouch could enhance the training of robotic surgeons. Studies utilizing this metric and this type of feedback in resident training are currently in progress.

Translation

The translational spirit of this work lies in the interaction between surgeons and their instruments, as well as how this interaction affects surgical performance and—which eventually—clinical outcomes. Just as translational research on pharmaceutical agents involves rigorous assessment of patient selection, dosing, and mode of administration, surgical techniques are therapeutic interventions that require evaluation of their related instrumentation, educational methods, and surgeon providers. This paradigm for translational research on surgical interventions is presented in Figure 2. This study established that instrument vibrations, measured using VerroTouch, are a valid and reliable indicator of surgical skill in surgical training tasks. Current studies aim to assess the effect of haptic feedback provided by VerroTouch on the skill of surgeons during live patient operations, thereby translating the knowledge gained about haptic feedback from preclinical simulation-based data to the performance of medical practitioners.

References


Fig. 1. Box plots of the average measured RMS instrument vibrations for the peg transfer and suturing tasks. The mean value for each group is marked with *, and outliers are indicated with x. Experienced robotic surgeons caused significantly lower instrument vibrations than novices in both tasks (p values indicated on plots).

Fig. 2. A translational paradigm for the administration of surgical interventions.

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