Analysis of the Instrument Vibrations and Contact Forces Caused by an Expert Robotic Surgeon Doing FRS Tasks

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INTRODUCTION

The widespread growth of robotic minimally invasive surgery has led to the need for a standardized training curriculum. Toward that end, the Institute for Surgical Excellence is conducting the Fundamentals of Robotic Surgery (FRS) validation trial. This multi-site study is testing both novice and experienced surgeons using Intuitive Surgical da Vinci robots and robot simulators. While a standardized curriculum will increase training consistency, the tasks performed on the robot itself will still rely heavily on expert observation of a trainee's performance. While common in traditional surgical skill assessment, observation-based ratings are both subjective and time consuming for the expert reviewers.

Thus, there is also a growing need for more objective and automatic approaches to surgical skill assessment during robot-based training [1]. Although several studies have assessed surgeon performance by analyzing the robot arm motions, e.g., [2], these analyses do not account for the quality of the physical interaction between the instruments and their environment. Our work on VerroTouch, a system that provides real-time haptic feedback of instrument vibrations [3], has shown that instrument vibrations are a construct-valid measure of surgical skill during robotic *in vitro* training tasks such as suturing and peg transfer [4]. While instrument vibrations can capture rough interactions between the instruments and with stiff tissue, some contacts with soft tissue do not produce measurable instrument vibrations [5]. We hypothesize that the quality of these interactions can be monitored by examining the forces that the robotic instruments exert on the tissue; we can measure such forces during *in vitro* and *ex vivo* training tasks but not during *in vivo* surgery.

To better understand how instrument vibrations and contact forces may elucidate the skill level of a surgeon during various tasks, we have recorded surgeon interactions with the *ex vivo* avian tissue model used during the robot-based portions of the FRS validation trial at our institution. This paper provides a descriptive analysis of the vibrations and forces caused by a single expert robotic surgeon in this study.

MATERIALS AND METHODS

One experienced colorectal surgeon (>50 robotic cases on human patients) performed a series of psychomotor tasks with a da Vinci Si robot as part of the FRS validation trial taking place at the University of Pennsylvania. The five tasks included knot tying, suturing, fourth-arm cutting, pattern cutting, and vessel energy dissection. The tasks were performed on an avian tissue model (a turkey leg quarter) as a post-test to the FRS training curriculum.

The da Vinci Si was augmented with our system for measuring instrument and camera vibrations, as well as the forces applied to the tissue (Fig. 1). A three-axis accelerometer (LIS344ALH) measured the vibrations of the left tool, the right tool, and the camera; each sensor was attached using a plastic bracket on the shaft. A force sensor (ATI Mini40) was mounted under the plate holding the tissue model; the three vibration axes were combined into a single magnitude, and the force measurement was separated into normal and tangential components. We also recorded the camera video feed.

We measured the vibrations and forces during three selected FRS tasks. Their instructions were as follows:

A. **Suturing:** Close the incision using a continuous horizontal mattress suture pattern, with the needle entering and exiting through the marks placed on the skin. The suture is already anchored on one side

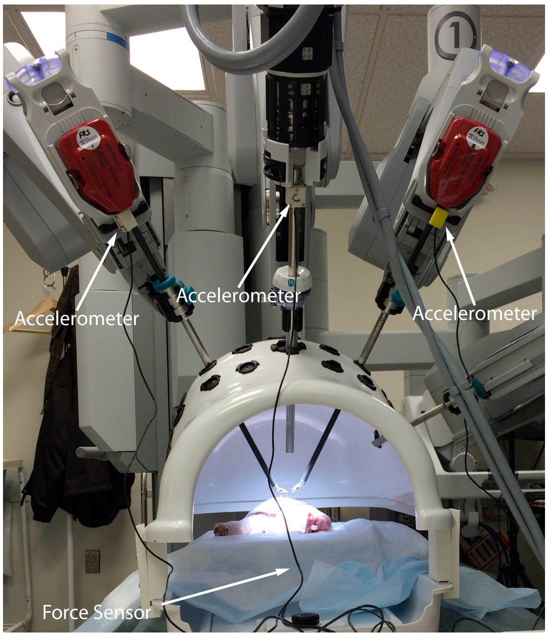

Fig. 1 A da Vinci Si robot augmented with accelerometers that measure instrument and camera vibrations. The avian tissue model is resting on top of a draped plate that is equipped with a three-axis force sensor.

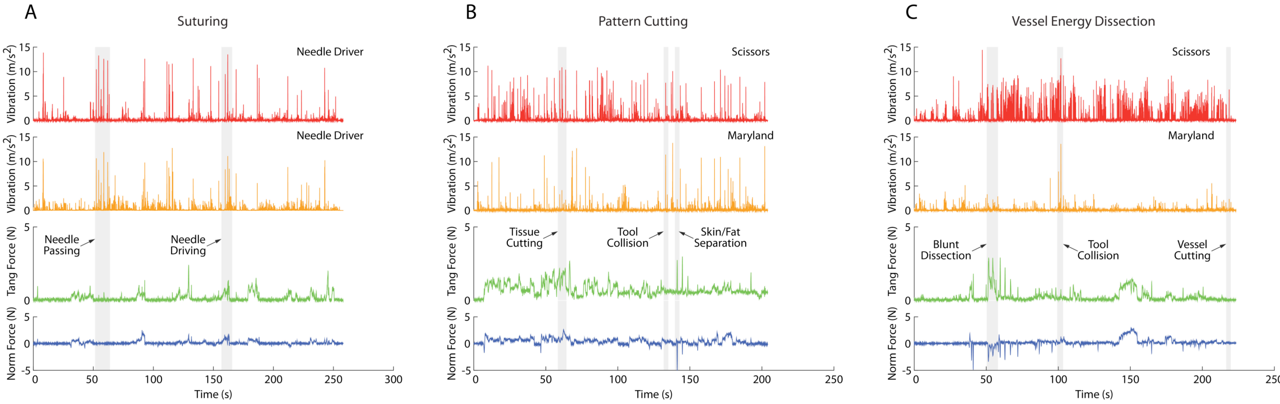

Fig. 2 Vibration and force recordings for the (A) suturing, (B) pattern cutting, and (C) vessel energy dissection tasks performed on the avian tissue model. Shaded grey regions highlight key events that are visible in the vibration and/or force data.

of the incision. At the end of the closure, tie the suture to itself using a surgeon's knot – a double throw, followed by two single throws. Tools: (2) Large Needle Drivers.

B. **Pattern Cutting:** Cut and peel the skin off exactly along the marked line, avoiding damage to the underlying muscle tissue. Tools: (1) Maryland Bipolar Forceps, (1) Curved Scissors.

C. **Vessel Energy Dissection:** Dissect down to the turkey femoral artery or vein. Liberate a (>3 cm) segment of the vessel from the surrounding tissue, cauterize at two points (>0.5 cm apart), and cut the vessel in between those points. Tools: (1) Maryland Bipolar Forceps, (1) Curved Scissors.

To provide an analysis of time-synced events in the force and vibration data, the experimenter considered the time-series signals alongside the recorded video.

RESULTS

The Suturing task data shows large vibration spikes on both tools when the needle is passed from hand to hand (see Fig. 2A). The normal and tangential force exerted on the tissue increases when the surgeon pulls up on the tissue to drive the needle or pulls tight on the suture to close the incision. A negative normal force can also occur when the surgeon pushes on the tissue with one tool while pulling on the suture with the other.

The Pattern Cutting task generates more vibrations than Suturing, especially from the scissors (see Fig. 2B). With sufficient counter-tension, the vibration caused by the cut is also transmitted to the Maryland forceps. A few large vibration spikes are caused by collisions between the instruments. Both the tangential and normal forces exhibit peaks when the surgeon pulls on the tissue to create counter-tension for the cut. The negative normal forces typically stem from the surgeon pushing on the tissue to separate the skin from the fat.

The Vessel Energy Dissection task shows the strongest vibrations of the studied tasks (see Fig. 2C); these vibrations occur when the surgeon bluntly dissects the tissue, cuts tissue during the dissection, and cuts the vessel near the end of the task. Large vibrations also result from instrument collisions. There are both positive and negative normal forces exerted on the tissue, with corresponding tangential forces; these forces are the result of the surgeon pressing and pulling on the tissue to locate and dissect out the vessel.

DISCUSSION

This paper described the instrument vibrations and contact forces generated by one expert surgeon performing three FRS tasks on an avian tissue model. These recordings are consistent with those from other surgeons in the FRS trial. However, with further analysis, we do expect to find variation between subjects in different surgical specialties, especially when novice surgeons are considered. These results will hopefully unravel the unique signatures within the vibration and force data that can be used to not only identify a given task, but also automatically evaluate how skilled a surgeon is at performing that task.

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