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Validating Advanced Robot-Assisted Laparoscopic Training Task in Virtual Reality

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Abstract. The purpose of this study was to validate a complex robotic surgical task, mesh alignment, in virtual reality. Nine subjects unrolled and aligned a mesh onto an inanimate template for the mesh alignment task in both an actual (the da Vinci Robotic Surgical System) and a virtual environment. Data analysis included time to task completion, distance traveled, and speed, of the surgical instrument, as well as electromyography of the extensors and flexors of the dominant arm of the subject. Paired t-tests were used to compare the dependent variables between the actual and virtual environments. The virtual mesh alignment task was statistically similar for all variables except the flexor activity as compared to the actual task. In conclusion, virtual reality could be used as an effective environment to train the next generation of robot-assisted laparoscopic surgeons.

Keywords: da Vinci Robotic Surgical System, Virtual Reality, Laparoscopic Training

1. Background

Robot-assisted laparoscopy has grown immensely over the last decade, because robot-assisted surgery improves dexterity [1] and decreases training time for surgical residents [2, 3]. Thus, junior residents are eager to learn robot-assisted laparoscopic techniques [4]. Implementing a formal training program using virtual reality (VR) simulations can provide residents an opportunity to learn robot-assisted techniques independently and efficiently in a risk-free environment. In this effort, we had successfully validated fundamental robot-assisted surgical tasks such as bimanual carrying [5]. As a next step, we developed in the present study a more complex and advanced surgical task, mesh alignment (MA), to validate in VR.

2. Methods

The virtual MA task was compared to its corresponding actual task to determine the validity of the developed VR environment. Nine right-handed participants (24.8±5.6 yrs) with no or limited prior experience with the da Vinci Surgical System (dVSS; Intuitive Surgical, Inc.) were recruited to participate. They were instructed to complete five trials of the MA task in both the dVSS (actual environment; Figure 1) and in a VR environment (Figure 2). The order of presentation of these two conditions was randomized.

The MA task mimics a mesh-based hernia repair where the anatomical features and surgical mesh must be aligned prior to stapling or suturing. [6] The VR environment was constructed based on the dimensions and interactions recorded during the actual task. The MA task was comprised of three training steps. Participants first positioned the mesh (Step 1). During step 2, participants must stabilize the lower edge of the mesh and continue unrolling with the opposite hand. Lastly, participants must use both hands to align the mesh onto the anatomical template. The MA task requires the identification and alignment of clinically relevant landmarks.

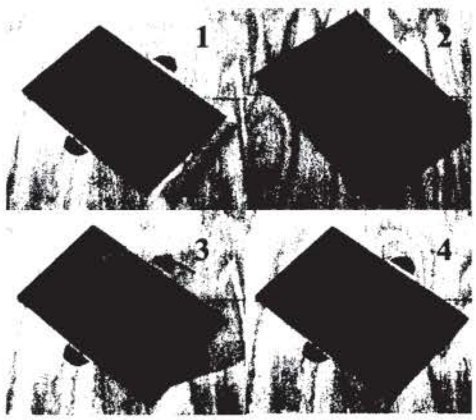

Figure 1: Actual environment for the Mesh Alignment Task; steps 1) Initial Position 2) Unrolling 3) Repositioning 4) Final Position (from left to right)

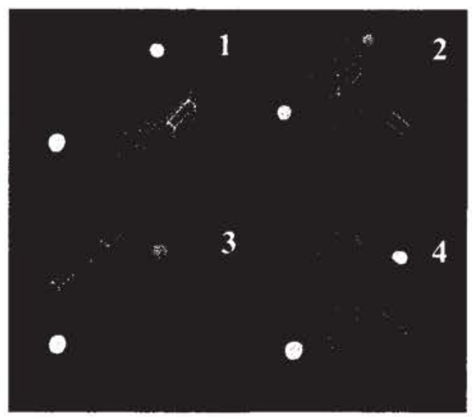

Figure 2: Virtual environment for the Mesh Alignment Task; steps 1) Initial Position 2) Unrolling 3) Repositioning 4) Final Position (from left to right)

The MA task is the first training simulation developed for mesh-based robot-assisted laparoscopic hernia repair. The VR environment was constructed using the simulation software Webots (Cyberbotics Ltd). The dVSS instruments and training platform were modeled as 3D objects using SolidWorks (SolidWorks Corp., Concord, MA, USA). This simulation was driven by kinematic data from the robotic operating console sampled at 50 Hz. The virtual images were then overlapped on the screen inside the console. Data analysis included task completion time, distance traveled, and instrument tip speed. Electrogoniometers (Biometrics, Gwent, UK) were used to obtain the participants' range of motion (ROM) for the wrist and elbow joints. Electromyography (EMG) of flexor carpi radialis (FCR) and extensor digitorum (ED) of the dominant arm were also recorded using a Delsys surface system (Delsys, Inc., Boston, MA, USA) sampling at 1,000 Hz. The mean activation (EMGm), envelope (EMGe; integrated EMG over the entire trial) and median frequency (EMGf) of both muscles were compared. Paired t-tests were used to compare the dependent variables between the actual and virtual environments. The significance level was set at a=0.05.

3. Results

There were no significant differences for task completion time, distance traveled, and instrument tip speed (Figure 3), as well as wrist and elbow ROM (Figure 4). However, the actual MA task required significantly greater overall flexor carpi radialis activity (EMGe, $p = 0.014$) as compared to the virtual MA task (Figure 5). No significant differences were found in the mean activation (EMGm) and median frequency (EMGf).

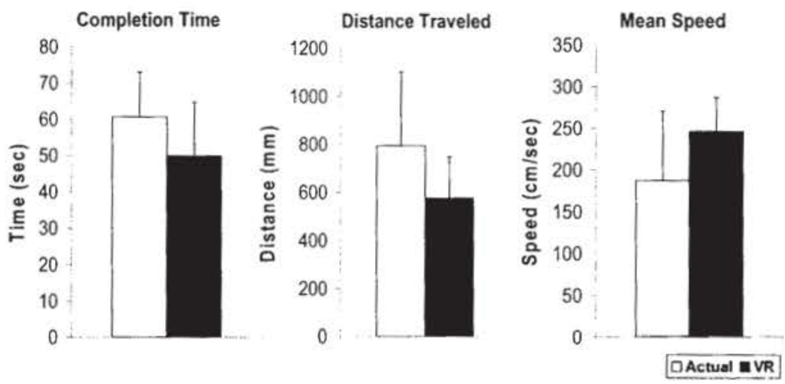

Figure 3: Comparison of kinematic parameters (completion time, distance traveled and mean speed of the instrument tip) between the actual and VR environments for MA.

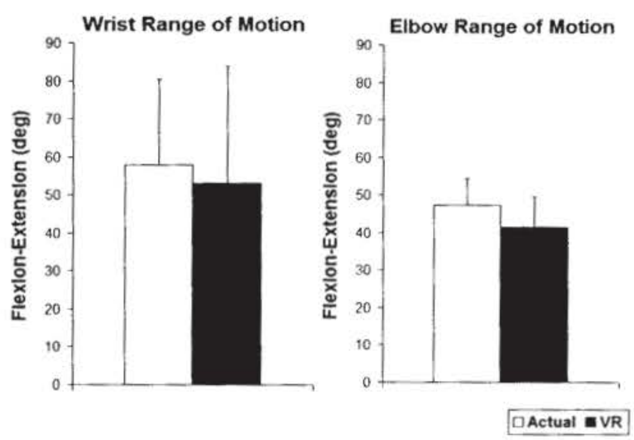

Figure 4: Comparison of range of motion (wrist and elbow) between the actual and VR environments for MA.

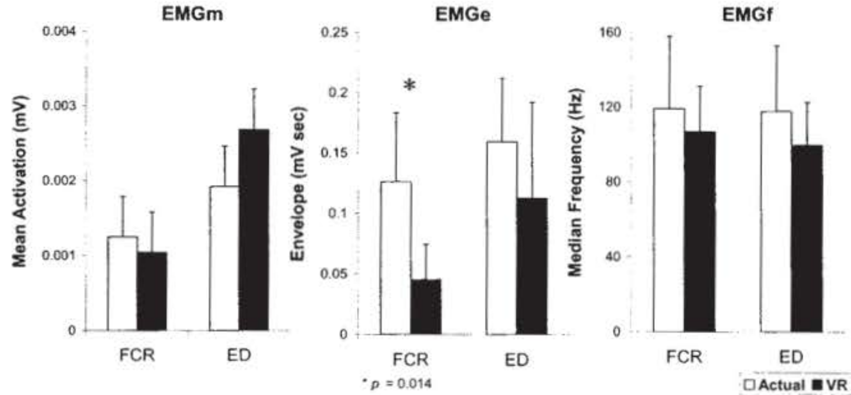

Figure 5: Comparison of EMG parameters (the mean activation (EMGm), envelope (EMGe, integrated EMG over the entire trial) and median frequency (EMGf) of muscles) between the actual and virtual MA task.

4. Discussion

The aim of this study was to validate an advanced robot-assisted training task, mesh alignment, in virtual reality. We compared performances of this task between the actual (using the dVSS robot) and the virtual reality environment using kinematic and electromyographic analyses. Linear kinematics of the da Vinci instrument tips were used to assess completion time, distance traveled and average speed. Electrogoniometry was used to assess the wrist and elbow ROM, and electromyography was used to assess two forearm muscles activity. In our previous work [5] both bimanual carrying and needle passing tasks were not significantly different between actual and virtual environments. It was concluded that fundamental robotic surgical training tasks could be successfully simulated in virtual reality. The results of the current study expand that conclusion to advanced surgical tasks, since performance during the virtual MA task is statistically similar to the actual MA task.

The fact that the actual MA task required significantly greater overall flexor muscle activity could be due to the lack of physical interaction with the mesh in the virtual environment. Thus, the virtual MA task should be given a better physical interaction, such as creating a solid boundary between objects. Overall, it is vital to continually improve both complexity and fidelity of the virtual environments for robot-assisted laparoscopic surgery. Developing an effective virtual robot-assisted surgery training environment will reduce the cost of surgical training and allow robotic surgery to grow. Our future work will include training in virtual reality with simple and advanced surgical tasks and evaluate how this knowledge transfers to the actual environment.

5. Conclusions

Since the virtual MA task was statistically similar for most parameters compared to the actual MA task in this study; we concluded that performance in the virtual environment was as effective as the actual MA task. Thus, this advanced robot-assisted laparoscopic training task, mesh alignment, was validated between the actual and virtual environments. We believe that virtual reality could be used in the future to effectively train the next generation of robot-assisted laparoscopic surgeons.

6. Acknowledgements

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