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TRAINING PREDICTIVE SKILLS FOR MITRAL VALVE REPAIR

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INTRODUCTION

Mitral valve repair is a highly challenging procedure. Surgeons must modify native valve tissue through a series of tissue resections and approximations. Restoring proper valve function is difficult because the heart is arrested during the procedure, so closed valve shape must be predicted rather than directly observed. It is this prediction, not the act of cutting and suturing, that presents the greater challenge to surgeons as they must rely on analysis of the flaccid valve and past experience. This skill is developed through traditional pedagogy, namely text- and image-based references, followed by a costly and time-consuming apprenticeship model.

When analyzing the valve, the surgeon aims to identify regions of abnormal leaflet mobility by pulling upward on chordal insertion sites. Regions of excessive or restricted leaflet motion are recorded (1). Using this information, the surgeon predicts the shape of the loaded valve and develops a repair plan to achieve a more desirable geometry.

We have shown it is feasible to assess a user's ability to predict closed valve shape using an interactive, computer-based simulation (2). In this work, we demonstrate that such a system can also be used to efficiently and inexpensively supplement traditional instruction, improving subjects' prediction abilities prior to apprenticeship.

METHODS

Training Platform: Previously, we have designed and validated a computer-based interactive surgical simulator for mitral valve repair (3). First, a subject-specific valve image is input to the system. Users can then interact with the derived valve model with a haptic input device (PHANTOM Omni), allowing for both visual and haptic rendering. While improving realism and usability, a haptic device requires a 1 kHz update rate to ensure stability and haptic transparency. Therefore, we implemented a mass-spring approximation of a finite element model as the gains in computational efficiency permit such rates to be achieved. In the context of valve modeling, mass-spring models have been shown to produce little change in accuracy making them suitable for fast simulations (4). Model parameters detailing tissue properties such as leaflet stiffness are taken from ex-vivo mechanical testing found in literature.

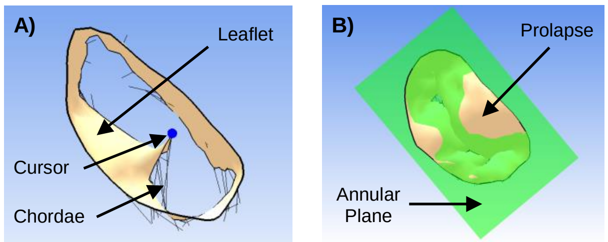

Figure 1. SIMULATOR-BASED ANALYSIS AND TRAINING

The haptic stylus also enables the user to pull on chordal-leaflet insertions, thereby mimicking the surgical valve analysis process (Fig 1a). To do so, a stiff spring-damper is engaged between the cursor and insertion point allowing for the stable bilateral application of forces to the user and the mesh. These forces are scaled and rotated to align with the user's viewpoint.

Study Protocol: This system was used to assess the subjects' ability to predict closed valve shape as well as provide instruction. Since previous work has shown that medical students perform no better than random chance when predicting closed valve shape (2), graduate students familiar with the mitral valve were studied due to their increased availability.

Subjects were presented with visual, but not haptic, renderings of four valves simulated to closure. To isolate the valve analysis process, differences in closed valve shape were the result of changes to chord length and displacement of the papillary muscles while annular and leaflet geometry remained constant. After thoroughly inspecting the closed valves from all angles, subjects were presented with an atrial view, the perspective seen intraoperatively, of an unpressurized valve. A maximum of three minutes was then provided to perform a virtual valve analysis using the simulation platform. Afterwards, subjects were again presented with the four closed valve choices and asked to select the one corresponding to the unpressurized valve analyzed.

Prior to trials, subjects were given unlimited time to familiarize themselves with the system. Five trials were then conducted. Next, instruction was provided by one of two means: either traditional instruction from *Carpentier's Reconstructive Valve Surgery* (1) or simulator-based training in which an annular plane and force feedback was used to highlight tethering or prolapse (Fig 1b). This was followed by five additional trials. The remaining form of instruction was then provided and followed by five more trials. To control for learning of the system rather than the task, the order of the instruction was randomized as was the order in which the valves were presented to the user.

RESULTS

A total of 12 subjects were tested with 7 receiving traditional instruction first and 5 receiving computer-based instruction first. While receiving traditional instruction first increased valve analysis time, the rate of successful prediction remained unchanged. However, subsequent simulation-based training increased the success rate without increasing the time required for valve analysis (Fig 2). Conversely, when the order of training was reversed, simulation-based instruction provided an immediate increase in success rates and valve analysis time. Further traditional instruction affected neither success rates nor valve analysis time (Fig 3).

DISCUSSION

Among all subjects, the average rate of successful prediction prior to training was 30%. This rate, similar to that seen in untrained 3rd-year medical students, is statistically identical to random chance, indicating both the challenging nature of the task and the need for instruction. Without training, valve analysis was performed in an ad-hoc manner with the order of areas examined varying from trial to trial, which likely contributed to the low success rate. However, formal instruction, either traditional or simulated-based, led to repeatable and systematic, albeit more time-consuming, valve analysis. Further instruction did not affect the manner in which analysis was performed nor the time required, suggesting that a single method of instruction was sufficient to teach proper analysis technique.

Nevertheless, proper technique did not always result in improved predictive abilities. Subjects first receiving traditional instruction demonstrated minimal increase in predictive success rates. Subsequent simulation-based training did increase success rates highlighting the value of this instruction methodology. By simultaneously feeling and observing pathologies during valve analysis, users were able to make a fundamental connection between valve analysis and predicting closed valve shape that text and images alone could not provide. Additionally, with similar improvements occurring when simulation-based training was provided first, we have shown that users are not merely learning the simulation platform through repetition, but instead are learning predictive skills as a result of the training itself.

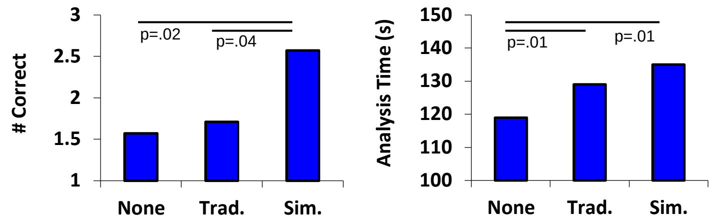

Figure 2. EFFECT OF BOOK-FIRST INSTRUCTION

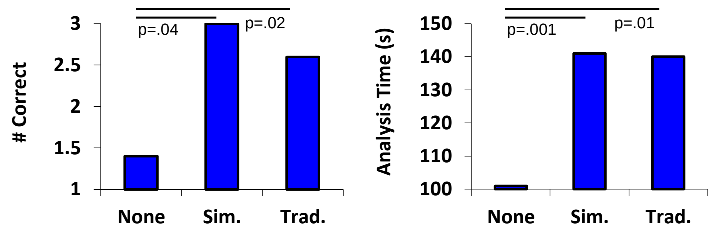

Figure 3. EFFECT OF SIMULATION-FIRST INSTRUCTION

An upper bound exists on subject performance in this study. Even after instruction, while users demonstrated an increase in predictive abilities, their success rates still fall below that observed in surgeons. Therefore, while simulation-based training improves subject performance, these results suggest it should be used to augment, rather than replace, existing pedagogy. By supplementing or supplanting traditional instruction prior to apprenticeship, surgeons in training would be better prepared and require less time under supervision, thereby reducing the cost of training.

Currently, simulation is a common tool for training the motor skills used in surgery. In this work, we have shown that simulation can also be used for training cognitive skills as well.

ACKNOWLEDGMENTS

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