Journal of Clinical & Experimental Cardiology

Valdis, J Clin Exp Cardiolog 2016, 7:10
DOI: 10.4172/2155-9880.1000470

Short Communication OMICS International

The Evolution of Robotic Surgical Training: A Short Communication on the Evaluation of Robotic Cardiac Surgery Simulation Training: A Randomized Controlled Trial

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Received date: August 08, 2016; **Accepted date:** October 01, 2016; **Published date:** October 20, 2016

Short Communication

Robotic cardiac surgery possesses great potential for both patient and societal benefits in regards to postoperative pain, infection rates, cosmesis, and earlier return to normal activity [1,2]. Despite these proven benefits, robotic cardiac surgery is offered at a relatively small number of institutions and has largely failed to be adopted by the majority of cardiac surgeons. There are several reasons explaining the reluctance to accept this new technology in cardiac surgery, including; aging surgeon demographics, high upfront and operating costs, scarcity of randomized trials, etc. Each of these factors plays an intricate and dynamic role in altering institution and surgeon perceptions and willingness to adapt to patient demands for minimally invasive techniques. Similar to the adoption of laparoscopic and thoracoscopic techniques in other specialties, robotics requires the acquisition of an entirely new skill set from traditional "open" operations. This learning curve unfortunately can be a difficult and anxiety provoking period for the institution, patient and surgeon, and can be fraught with higher rates of complications and adverse events. This is even more significant in robotics, as the high upfront investment of significant resources and increased operating costs, create little room for anything but exceptional clinical results and patient outcomes, as patients and institutions demand a return on their investments [3]. This fact may be, by far, the greatest barrier as to why robotics has failed to become more mainstream in cardiac surgery. Truly subspecialized centers of excellence in robotics are few and far between and consist mainly of a small number of early adopters of the technology. These centers have made the commitment to invest huge resources to get their programs off the ground, and then recruit large numbers of patients to provide a steady caseload in order to maintain and advance their surgical skills and abilities, and make a robotic surgery program financially viable at their center. At most institutions this is not possible. The reluctance of many surgeons and institutions to accept robotics is not solely due to the high upfront and operating costs (as all cardiac surgery operating rooms are expensive to initiate and keep running), but rather because of the steep learning curve that is associated with these non-traditional techniques, and the difficulty in achieving optimal patient outcomes during this process. In an age where coronary bypass and mitral valve surgery carries an operative mortality rate of ~2-3% (especially when patients are stratified for the low-risk individuals typically selected for robotic surgery), proving robotics to be a superior alternative to traditional sternotomy is a difficult task. No institution is going to invest millions of dollars up front and allow for early graft failures, high conversion rates, longer operating and cardiopulmonary bypass times and the potential for increased morbidity, mortality and inferior patient outcomes. No insurance company is going to pay for a more expensive procedure which has the potential for increased complications in unskilled hands. And lastly, no patient is going to seek out a surgeon or institution with suboptimal outcomes simply because they have the newest technology available. It is a harsh reality of the medical profession that the demand for perfection and the constant cutting of healthcare costs inhibits innovation and evolution as it does not to allow for the natural growing pains that our profession once suffered to bring us to where we are today. With obligatory outcome reporting, the ease of disseminated patient information and the constant rise of healthcare costs, the hurdles for innovation do not seem to be going away any time soon. We must therefore seek out new strategies for developing innovative training techniques in safe environments in order to allow for the specialty to evolve and to improve care, safety and costs to society.

This is where our group began when we set out to develop a standardized training program at our institution for trainees attempting to gain experience with robotic cardiac surgery [3]. Trainees coming to our center for robotic training have a limited number of cases that they will be exposed to during their training. Typically, training in robotic surgery has followed the same course as traditional surgeries which does not take advantage of the superior differences with these new technologies [4,5]. With the traditional method, the progress of trainees can be viewed as three stages of operative training. The first is an observation stage, where individuals spend a period of time observing during the surgery (whether scrubbed or not), to gain insight as to the general routine in the operating room and the procedure. This is followed by a second stage where the individual participates in assisting the surgeon during the operation. And lastly, the third stage involves the trainee being entrusted to complete small portions of the procedure which increases to a greater percentage of the surgery as the trainee's skill and comfort level increases. Theses stages may overlap or even occur simultaneously, depending on the complexity of the operation and the availability of help in the operating room. This approach, although historically successful in training, requires a long and inefficient process to develop a competent surgeon. Using technologies that are readily available to everyone today, such as Google or YouTube, trainees can easily watch edited and narrated operations from a variety of centers and world experts long before they come to our institution to train or even enter the robotic operating room, essentially removing the observation stage of training. The limited time available to trainees in the operating room should be regarded as a precious commodity and should be used to its full potential. Fellows coming to train at our institution usual are funded for 1 year duration and will only have exposure to a maximum of 30-50 robotic cases. Wasting the first few months of operating room experience with prolonged observing periods and figuring out the basics of the robot's manipulation is substantial given the limited amount of time trainees will be at our institution. With this, we recognized a problem, and felt that this process could be dramatically improved upon by incorporating simulation based exercises into our training program.

When we began this process, the largest systematic analysis of current simulation based training in robotic surgery came from the Obs/Gyn literature [6]. This publication highlighted 35 different published trials involving wet-lab, dry-lab, or virtual reality simulation based training. Of these 35 trials, only 3 actually compared the efficacy of training between two different types of simulation for a given task. Each of these 3 trials had sample sizes of only 2 people per group and all compared only a wet-lab and a dry-lab [6]. It became very obvious that the efficacy of simulation training and the advantages and drawbacks of each of the three simulation-based methods have never been properly investigated or compared. Certainly a training institution investing significant resources in the education of their trainees should have more significant evidence to rely on before they embark on initiating a program such as these. From here we set out to complete one of the largest studies of its kind and the first ever prospective RCT comparing the major simulation platforms currently used in surgical training with an untrained control [3].

For this study we enrolled 40 surgical trainees who had limited previous exposure to robotic surgery (<10 h driving the robot or simulator). All of these individuals were shown a standardized video on dissection and surgical techniques and were given a brief introduction as to the use of the robot's controls. Participants then completed two robotic cardiac surgery tasks (dissection of a 10 cm internal thoracic artery pedicle and a mitral valve annuloplasty) in porcine models. These attempts were recorded and deidentified, then scored based on time to completion as well as with a validated objective scoring tool used to evaluate intraoperative robotic performance [7]. Following this baseline assessment, individuals were randomized to one of the three major simulation platforms; wet-lab, dry-lab or virtual reality simulation. Each of these simulation platforms was carefully designed with the input from multiple expert robotic surgeons in order to focus on the most important and universal robotic skills necessary to operate the robot successfully. The actual protocols can be found published elsewhere [3,8]. Once the training in each stream was completed, and trainees were able to meet the levels of proficiency set by our expert surgeons, they were brought back to repeat the initial assessment which again was recorded, deidentified and scored to look for improvements with training and to compare performances between the different groups.

At the completion of the experiments the results were quite surprising. By far and away the individuals in the wet lab outperformed all other training methods. These individuals proved to be able to complete both tasks significantly faster than all other groups and even faster than our experts [3]. The scoring tool that was used to assess intraoperative performance was unable to detect any difference between the performance of these individuals and that of our experts indicating that they had reached the expert's level of proficiency [3]. This information created a strong argument that wet-labs offer superior simulation training compared to other modalities. Although this does appear to be true, many lessons were learned from this experiment including a better understanding as to the feasibility of instituting a wet-lab as a reliable and reproducible training platform. The first major drawback to this method of simulation based training involved the expenses and difficulties in obtaining, storing, preparing and disposing of the proper tissues for these exercises. The porcine chest walls used to simulate dissection of the internal thoracic artery were obtained directly from an abattoir, careful negotiation needed to be had with several facilities before a deal could be made to obtain these tissues. The reason for this is that the chest plate that includes the internal thoracic vessels cuts into the side-ribs of the animal which is the most lucrative portion for these establishments. Even at an elevated price most companies are unwilling to jeopardize the quotas that they have with ongoing orders from major customer accounts. Too often the chest plate that was obtained had significant damage to the internal thoracic vessels from the supplier trying to save as much side-rib as possible. This realization was only made after the tissues were purchased thawed and prepared prior to experimentation. The chest plates gave an excellent representation of the tissues and anatomy necessary for replicating the artery dissection. However, pigs have over developed intercostal muscles compared to humans and this required extensive preparation in order to remove this thick muscle layer in order to expose the vessels which are often readily accessible in humans. This process takes approximately 30 minutes per chest wall in order to prepare it correctly for the task. Lastly, the major drawback with wet-lab simulation appeared to be the need for supervision from an expert at all times to provide feedback and guidance. Due to differences in anatomy and tissue quality it is impossible to standardize these exercises when using real tissues. The presence of an expert is required much the same as in the operating room, to give subtle tips and tricks along the way. Without this, bad habits can develop that are hard to break. Due to the difficulty and cost of acquisition with these tissues, the lengthy preparation and the need for an expert to be present at all times, trainees are unable to repetitively complete these exercise indefinitely and independently. Because of this, wet-lab training may not be the best overall methods of feasible and reproducible simulation based robotic training despite its superior results compared to virtual reality and dry-lab training in our trial [3].

The virtual reality curriculum that we created for this experiment was designed in a similar fashion to previous literature [8]. For this we had our expert robotic surgeons identify the basic robotic skills that were necessary for robotic cardiac surgery. We examined the 55 different exercises that were available on the simulation unit we have at our institution, the da Vinci Surgical Skills Simulator (Intuitive Surgical, Sunnyvale, CA). An extensive amount of time was spent working with these exercises in order to determine which were the easiest to understand, focused most directly on the skill we were interested in developing and which was the most users friendly. From this we constructed a 9-exercise curriculum that began with simple robotic skills such as camera clutching and movements, and slowly progressed the user though more complex tasks such and endowrist manipulation, fourth arm control and eventually to advance needle handling and intracorporeal knot-tying [8]. Completion of this program to the level of competency set by our experts proved to be a lengthy and arduous process for our trainees. Due to operator fatigue and to accommodate surgical trainee schedules, most training sessions were limited to 1-2 h as recommended by Chitwood [1]. In some cases completion of this curriculum took over 20 sessions, a considerable amount of time to have a surgical resident commit to, given their regular work weeks of ~100 hours. Although there were more tasks involved in this training stream the significant reason the virtual reality training took so much longer than the others was due to the robust and powerful scoring system that the simulators use (MScore, Mimic Technologies, Inc. WA). These exercises track far more than time to completion and major errors in performance like the other simulation methods. Every metric such as; total distance travelled, distance travelled out of view, excessive force, needle accuracy, etc. can be monitored and tracked through a trainee's progress indicating to the individual where areas of weakness occurred upon completion of each task. This largely prevents the development of the bad habits, that were mentioned earlier, and forces the trainee to complete the tasks in the correct manner. Progression with our curriculum creates a stable foundation of basic skills that slowly build on one another to leave the individual a competent technician of the surgical robot at its completion [8].

Lastly, the dry-lab group was adapted from the Fundamentals of Laparoscopic Surgery (FLS) program, which is one of the most successful examples of simulation based training in surgery as it has been adopted into most surgical training programs [9]. However, the dry-lab proved to be inferior to the other two training modalities based on all of our scoring methods; however individuals in this training stream still showed significant improvement [3]. It became apparent when comparing these different modalities, there were deficiencies in the training received by the dry-lab group. This method of training only offered exposure to basic skills and the individual can only focus on; time to completion and major predefined errors. Trainees are not able to practice procedurally specific tasks or gain experience with handling real tissues. What we found was that this gave our trainees the ability to pilot the robot effectively but with the development of bad surgical habits (fast/jerky imprecise movements, carrying instruments off screen, traumatic manipulation of tissues, etc.).

The results of our work give a comprehensive overview of establishing a simulation based training program for robotic surgery. Although we focused specifically on cardiac surgery tasks, the individual skills we helped trainees develop (camera movements, endowrist manipulation, suturing, needle control, etc.) are in no way unique to cardiac surgery and these training strategies can easily be applied to other surgical specialties interested in training robotic surgeons. Each of the three modalities that are currently in use today have their benefits and drawbacks and their implementation should be reviewed by each institution to determine which modality they are able to offer given the availability of resources at their disposal.

For our institution, where we have access to a large robotic training facility capable of acquiring, processing, storing and disposing of the necessary animal tissues, as well as access to a virtual reality simulator, we recommend the following for new trainees coming to our institution to learn robotic cardiac surgery. First, the individual will be introduced to the robot and simulator and asked to complete our 9-task virtual reality curriculum to the level of proficiency set by our experts on their own time. Once this is completed trainees, now considered competent technicians of the robot, will be brought to the robotic training facility for a single session with an expert surgeon to go over the anatomy, dissection and procedural techniques needed to complete the cardiac surgery tasks. This limits the costs associated with running the wet-lab as the basic robotic functions have already been mastered and exercises are directed towards more advanced skills only. After this session, trainees are still proficient technicians of the robot but who now have a good understanding as to the procedures involved in robotic cardiac surgery. At this point, trainees will be ready to come to the operating room and play an active role in the procedure from their first surgery, optimizing their time in the operating room and the time that they have to learn from an expert surgeon at our center.

As technologies develop they become more reliable, readily available and cost begin to fall with market competition. This too will happen with robotic surgery, and as it becomes more mainstream across the surgical specialties, the need for a reliable robotic training program will become paramount. This work will hopefully serve to guide training programs invest resources in cost-effective, high yield simulation exercises to improve the training of new robotic surgeons.

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