A Porcine Beating Heart Model for Robotic Coronary Artery Surgery

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ABSTRACT

Background: The application of robotically assisted coronary artery surgery continues to be investigated clinically. Consequently, there is a need for a simple method to train surgeons in performing these operations. The aim of the present study was to assess a model using an excised porcine heart for the training of surgeons in creating a robotically assisted arterial anastomosis.

Methods: An ex vivo beating heart model was constructed with a porcine heart and was evaluated by 3 cardiac surgeons previously trained in robotic surgery. All anastomoses from the first half of the study were reviewed to measure anastomotic time, the number of sutures placed, and the rate of suture placement per minute and were compared to those completed in the second half of the study by means of a unpaired Student *t* test.

Results: Fifty-seven anastomoses were completed with the beating heart model, 28 in the first half of the study and 29 in the second half. The mean time to create an anastomosis in the first half of the study was 19.3 minutes (range, 10-28 minutes), compared with 15.0 minutes (range, 7-20 minutes) in the second half; the difference did not meet statistical significance. However, the number of sutures placed per minute did increase in the second half of the study with a mean of 0.77 sutures per minute (range, 0.55-1.25), compared with 0.56 sutures per minute (range, 0.40-0.80) in the first half of the study ($P < .0001$). The number of sutures per anastomosis also decreased in the second half of the study with a mean of 9.0 sutures (range, 8-11), compared with 10.6 sutures (range, 8-16) in the first half of the study ($P = .0049$).

Conclusions: This preliminary experience demonstrated technical improvements in the second half of the study. Fewer sutures were placed per anastomosis with better precision, implying a learning curve that could be accelerated with our model. This porcine beating heart model represents an inexpensive training method that mimics the beating heart, complete with coronary blood flow, and may be used multiple times to train and assess a surgeon's skill in robotically assisted coronary surgery.

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INTRODUCTION

Off-pump coronary artery bypass (OPCAB) grafting has been popularized as an alternative to conventional myocardial revascularization in the treatment of coronary artery disease and in 1999 represented 18% to 20% of all coronary artery bypass procedures performed in the United States [Mack 2001]. Furthermore, there is an increasing interest in performing these procedures even less invasively with robotic applications [Damiano 2000, Mack 2001, Donias 2002]. However, using the robotic system requires a great deal of training to acquire the skills necessary for performing a coronary anastomosis and intracorporeal knot tying. There is a growing need for a simple training method with an ex vivo simulator that will allow both the senior surgeon and the surgeon in training to develop the skills needed for consistent results when performing coronary bypass on the nonarrested heart [Stanbridge 1999]. The aim of the present study was to assess a model using an excised porcine heart for the training of surgeons in creating a robotically assisted arterial anastomosis to the left anterior descending coronary artery (LAD) on the beating heart.

MATERIALS AND METHODS

An ex vivo beating heart model was constructed with a porcine heart and was evaluated by 3 cardiac surgeons previously trained in robotic surgery. The simulated operations were carried out in a dedicated operating room with the

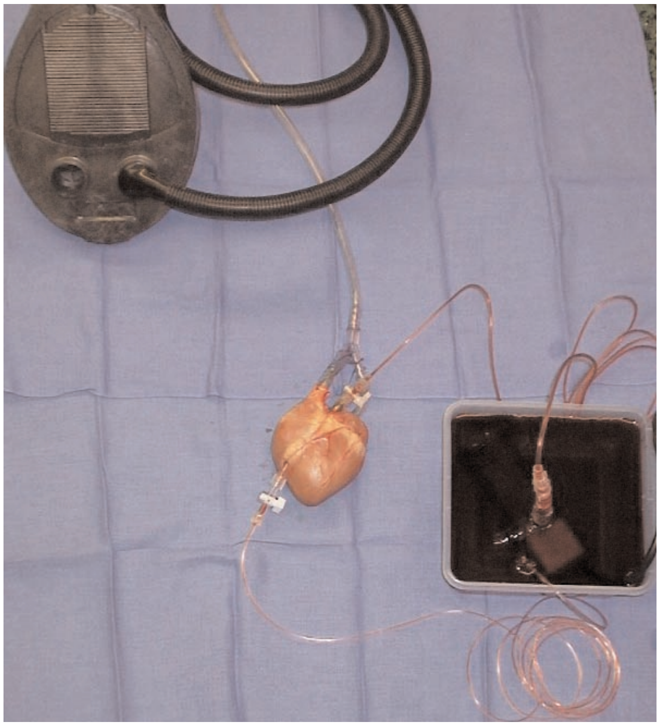

Figure 1. A view of the complete beating heart model setup, including the foot pump, the heart with a cannulated left anterior descending coronary artery, and the bath of saline with the aquarium pump.

Zeus robotic system (Computer Motion, Goleta, CA, USA). Fifty-seven anastomoses of a free arterial graft to the LAD were created with the Octopus stabilizer (Medtronic, Minneapolis, MN, USA) and intracoronary shunts (CardioThoracic Systems, Cupertino, CA, USA). Suture material used was either 7-0 polypropylene (Ethicon, Cincinnati, OH, USA) or 7-0 Gore-Tex (W. L. Gore and Associates, Flagstaff, AZ, USA) sutures or S20-ST U-Clips (Coalescent Surgical, Sunnyvale, CA, USA). All anastomoses were reviewed to measure the anastomotic time and the number of sutures placed. The rate of suture placement per minute was calculated for all anastomoses completed in the first half of the study and compared with the rate for anastomoses completed in the second half of the study by means of an unpaired Student *t* test. In addition, the patency was evaluated by passing a 2.0-mm probe across the completed anastomosis, and each anastomosis was flushed with colored saline to search for anastomotic leaks.

Model Setup

The setup of the simulator consisted of securing one end of a 0.25-in Y connector into the pulmonary artery and the other end of the Y connector into the aorta. Purse-string 2-0 silk sutures were placed in the pulmonary artery and aorta around the tubing to prevent air from escaping, and another 2-0 silk anchor stitch was used to secure the Y connector to the heart. The Y connector was attached to a commercially available raft foot pump with 1⁄16-in tubing. Any lacerations on the heart from procurement were closed with running 2-0 silk suture (Figure 1).

The left coronary artery was dissected where it branches from the aorta, and the LAD was cannulated proximally with a 14- or 16-gauge intravenous catheter (Angiocath), depending on the size of the artery. The LAD was then cannulated distally with another Angiocath. The Angiocaths were anchored in place with 2-0 silk suture, and 3-way stopcocks were attached to the Angiocaths (Figure 2). Next, an aquarium water pump (60 gallons per hour) was placed in a bath of saline. Red dye was added to the saline to simulate blood. Intravenous tubing was used to connect the aquarium pump to the proximal stopcock with appropriate connectors, and the circuit was completed by running more intravenous tubing from the distal stopcock to rest in the saline bath (Figure 3).

The graft used for each anastomosis was the right coronary artery (dissected from the heart prior to the setup of the model), the porcine inferior mammary artery, or a vein. To simulate the beating heart, an assistant operated the foot pump, and the aquarium pump was turned on to allow the lines to fill with colored saline (video). Training could then begin. The entire setup of the model requires approximately 20 minutes. Once each anastomosis was completed, a 10-mL syringe filled with colored saline was attached to the stopcock, and air or colored saline was instilled under pressure. Leaks were then assessed by noting any leaking fluid or air bubbles coming from the anastomotic line.

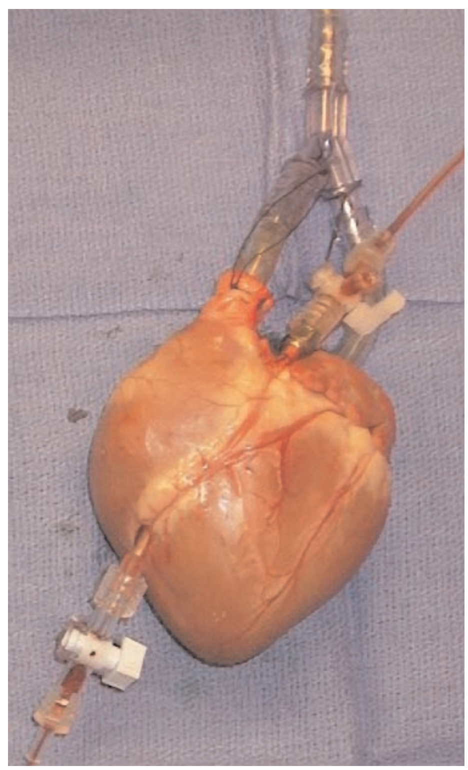

Figure 2. A close up view of the beating heart model showing the Y connector in the pulmonary artery and aorta and the cannulation of the left anterior descending coronary artery.

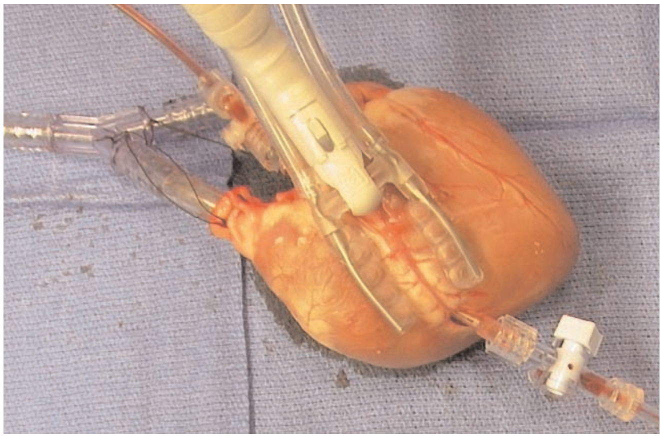

Figure 3. Another close-up view of the beating heart model with the stabilizer in place.

RESULTS

Assessment of the Model

The evaluation of the training model was very favorable with regard to the movement of the heart, the handling of tissue, and the ability to use stabilizers and intracoronary shunts. The ability to practice on excised tissue was felt to be the most profound advantage of this model. In addition, the simulation of blood flowing through the coronary artery greatly added to the experience. The 3 participating surgeons were very impressed by the level of realism achieved.

Assessment of Training

Fifty-seven anastomoses were completed with robotic assistance with the porcine beating heart model over a 2-month period by the 3 surgeons experienced in robotic surgery. Twenty-eight anastomoses were completed in the first half of the study, and 29 were completed in the second half. The mean time to create an anastomosis in the first half of the study was 19.3 minutes (range, 10-28 minutes), compared with 15.0 minutes (range, 7-20 minutes) in the second half of the study; this difference did not reach statistical significance. However, a dramatic increase in the rate of suture placement was seen in the second half of the study with a mean of 0.77 sutures per minute (range, 0.55-1.25 sutures per minute), compared with a rate of 0.56 sutures per minute (range, 0.40-0.80 sutures per minute) in the first half of the study ($P < .0001$). The number of sutures per anastomosis also decreased in the second half of the study with a mean of 9.0 sutures (range, 8-11), compared with 10.6 sutures (range, 8-16) in the first half of the study ($P = .0049$). The trend toward a faster time to completion of the anastomosis and the increased rate of suture placement suggests that as more experience with robotically assisted coronary artery surgery is gained, the surgeon will become technically more proficient and capable of performing these operations in the clinical setting. Furthermore, the decrease in the number of stitches per anastomosis suggests a gain in the level of precision in creating an anastomosis that does not leak.

DISCUSSION

The time-tested tradition of training surgeons to perform coronary anastomoses through graduated steps in living patients is not appropriate for robotic coronary surgery. The steep learning curve associated with a technology that many cardiac surgeons have never been trained to use represents a formidable obstacle to the transition from robotic applications in the laboratory to their clinical use in the operating room. Previously, the cardiac surgeon was limited to learning these procedures on cadaveric torsos [Tabaie 1999] or on excised animal hearts [Stephenson 1998]. Although both of these methods have helped the surgeon become familiar with the procedures, neither has offered the opportunity to practice on a beating heart with coronary blood flow. On the other hand, training on live animals has also proved to be useful and allows the chronic follow-up of graft patency [Stephenson 1999]; however, such training is expensive, time consuming, and limited in the number of anastomoses that can be completed per animal. Other beating heart models composed of synthetic material are available commercially, and although these models are quite realistic with regard to the feel of the tissue, handling, and the ability to use stabilizers, they lack continuous perfusion through the LAD, thereby giving the trainee the false impression of hemostasis [Stanbridge 1999]. Our model offers the advantages of operating on a beating heart consisting of excised tissue with simulated coronary blood flow. Furthermore, it is an inexpensive model that can be used repeatedly with a minimal setup and breakdown time.

Although we assessed the utility of this model with 3 cardiothoracic surgeons who have extensive experience in robotic heart surgery, the data suggest that the model has further utility for training cardiothoracic residents in the art of robotic coronary anastomoses. This preliminary experience has demonstrated technical improvements in the second half of the study. Fewer sutures were placed per anastomosis with better precision, implying a learning curve that can be accelerated with our model.

Because OPCAB grafting is becoming more popular, there is a growing need for a simple training method for surgeons in training to better familiarize them with the procedure. A survey of resident training in beating heart surgery revealed that although 88% of cardiothoracic residents at accredited programs expressed an interest in OPCAB and expected to perform off-pump surgery in their practice, only 22% had performed surgery in more than 20 off-pump cases during their training. Even fewer residents (12%) had performed more than 20 complete revascularizations off-pump [Ricci 2000]. However, another report on cardiothoracic resident training in OPCAB has proposed that operations should be performed on at least 50 patients under the supervision of a trained surgeon for the resident to obtain adequate credentials in minimally invasive coronary revascularization [Karamanoukian 2000]. Operations on the beating heart are more technically demanding, and this reality contributes to the hesitation of senior cardiac surgeons to allow surgeons in training to perform the anastomoses. Although our model was developed for training surgeons in robotic surgery, it also may serve as an important tool for allowing surgeons in training to practice their OPCAB technique multiple times so that they are more prepared and confident in their skills when they enter the operating room.

In our model, cardiac movement and coronary blood flow were very realistic, and the heart rate could be controlled by compressing the foot pump at the desired rate. However, some modifications were made during the course of this study to facilitate the use of the model. The first was the use of a second assistant dedicated to operating the foot pump. Another modification to the beating heart apparatus was to replace this second assistant with a pediatric ventilator when it was available. This substitution provided a respiratory rate sufficiently high to simulate the beating heart without the need for a second assistant. Some of the synthetic beating heart models use an air compressor to cause the heart to beat. We are currently looking into this possibility as a further modification to our model.

The red dye added to the saline bath was found to be quite messy. It stained everything it came in contact with, including the vessel walls if they were used for extended periods. To avoid this complication, we currently add some of the pig blood found in the packaging materials to the saline bath. We find this substitution to provide adequate color to simulate the blood without leaving stains throughout the work area. We have investigated other methods of coloring the saline, including the use of red-colored sports drinks, but have found the blood remaining from the pig hearts to be the best option.

Another point worth mentioning is the length of the Angiocaths. We now cut them in half or even smaller, depending on the length of the LAD. If we do not cut them to this size, the tips of the proximal and distal Angiocaths are separated by only a few centimeters in the LAD. This configuration allows space to perform only 1 or 2 arteriotomies. Cutting the Angiocaths shorter allows the performance of 3 or 4 arteriotomies on the LAD, which can be used multiple times without having to prepare another model. It is also important to remember that if multiple arteriotomies are to be performed on the same LAD, then any previous arteriotomy needs to be occluded to eliminate leakage while performing any subsequent anastomoses. Such occlusion can easily be accomplished with a running 7-0 suture.

CONCLUSION

This porcine beating heart model represents an inexpensive training method that mimics the beating heart, complete with coronary blood flow, and may be used multiple times to train and assess a surgeon's skill in robotically assisted coronary artery surgery. Furthermore, the model is easy to construct and allows surgeons in training to simulate OPCAB grafting to prepare them for their time in the operating room. We hope that its use will aid in the training of future surgeons in robotic and cardiac surgery.

REFERENCES

Damiano RJ, Ehrman WJ, Ducko CT, et al. 2000. Initial United States clinical trial of robotically assisted endoscopic coronary artery bypass grafting. J Thorac Cardiovasc Surg 119:77-82.

Donias HW, Karamanoukian RL, Glick PL, Bergsland J, Karamanoukian HL. 2002. Survey of resident training in robotic surgery. Am Surg 68:177-81.

Karamanoukian HL, Panos AL, Bergsland J, Salerno TA. 2000. Perspectives of a cardiac surgery resident in training on off-pump coronary bypass operations. Ann Thorac Surg 69:42-5.

Mack MJ. 2001. Minimally invasive and robotic surgery. JAMA 285:568-72.

Ricci M, Karamanoukian HL, D'Ancona G, et al. 2000. Survey of resident training in beating heart operations. Ann Thorac Surg 70:479-82.

Stanbridge RDL, O'Regan D, Cherian A, Ramanan R. 1999. Use of a beating heart model for training surgeons in beating heart surgery. Heart Surg Forum 2:300-4.

Stephenson ER Jr, Ducko CT, Sankholkar S, Hoenicke EM, Prophet GA, Damiano RJ. 1999. Computer-assisted endoscopic coronary artery bypass anastomoses: a chronic animal study. Ann Thorac Surg 68:838-43.

Stephenson ER Jr, Sankholkar S, Ducko CT, Damiano RJ. 1998. Robotically assisted microsurgery for endoscopic coronary artery bypass grafting. Ann Thorac Surg 66:1064-7.

Tabaie HA, Reinbolt JA, Graper WP, Kelly TF, Connor MA. 1999. Endoscopic coronary artery bypass graft (ECABG) procedure with robotic assistance. Heart Surg Forum 2:310-7.

REVIEW AND COMMENTARY

1. Editorial Board Member GX21 writes:

It is an interesting paper. I could not understand why the authors place an Angiocath into the LAD. The authors mentioned the usefulness of the Angiocath on the LAD. They stated the Angiocath could be placed with a shorter length. I could not get the idea of it. Probably, they want to show that the model can be used several times for repeating the procedure. Please describe how they can use repeat experiments.

The statistical methods they used should be mentioned also.

Authors' Response by Harry W. Donias, MD:

By cannulating the LAD with a short Angiocath, we were able to simulate blood flow through the native coronary artery, making the model more realistic in addition to adding a further assessment of anastomotic leaks. Your assumption as to the reason for using Angiocaths with a shorter length is correct. By using a shorter Angiocath, we were able to use the same model setup for multiple anastomoses simply by closing any previous arteriotomy in the LAD and creating a new one. If longer Angiocaths are used, they decrease the available length of the LAD for additional anastomoses.

An unpaired Student *t* test was used to compare the anastomotic times and the suture rate per minute from the first half of the study to the results of second half of the study. The purpose was to demonstrate a trend toward a faster anastomotic time as the surgeon gained more operative experience with the model, as well as a trend toward a faster suture rate, and thus demonstrate an increase in technical proficiency.

2. Editorial Board Member PB44 writes:

This takes Dr. Stanbridge's beating heart model to a next stage. It will provide another stimulus for developing ex vivo teaching models for cardiac surgeons.

How is the "stiffness" often seen in explanted porcine hearts overcome? Could you perfuse the aortic root to get coronary flow?

Authors' Response by Harry W. Donias, MD:

We did not run into any problem with stiffness. I feel this is because we used the hearts immediately once they were thawed and allowed them to soak in their own blood while we waited to use them. Furthermore, the foot pump provided enough force to provide an adequate simulation of the contracting heart.

As for perfusing the aortic root, I suppose it is possible; however, we did not try this technique. By directly cannulating the LAD, we were able to achieve adequate flow to simulate the blood flow in the native vessel. One problem with cannulating the aortic root would be interference from the tube, which is secured in the aorta, in insufflating air from the foot pump.