Robotic-Assisted Esophagoesophagostomy

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Background/Purpose: Minimally invasive repair of esophageal atresia has been described but remains technically challenging. Robotic surgical systems address many of these technical challenges. The purpose of this study was to develop the procedure for and evaluate the technical feasibility of performing a robotic-assisted esophagoesophagostomy using the Zeus Robotic Surgical System.

Methods: Esophagoesophagostomy was performed in 10 piglets using thoracoscopic (control, n = 5) and robotic-assisted (Zeus, experimental, n = 5) approaches. An interrupted esophageal anastomosis using intracorporeal knot tying techniques was performed and evaluated for leak, narrowing, caliber, and mucosal approximation. Anesthesia, operative, anastomotic, and robotic set-up times were recorded as was the number of stitches used.

Results: All 10 anastomoses were patent with no narrowing and with excellent mucosal approximation. One anastomosis in the control group had a small leak. There was no statistically significant difference between the groups for the parameters measured. Weight (kg): control (C), 6.4 ± 0.8; experimental (E), 6.3 ± 1.0, $P = .08$. Times (min): anesthesia, C-124 ± 25, E-151 ± 20, $P = .09$; operative, C-97 ± 21, E-131 ± 27, $P = .06$; anastomotic, C-89 ± 20, E-125 ± 34, $P = .08$; robotic set-up, C-6.4 ± 9.3, E-15.6 ± 20, $P = 0.13$. Stitches (No.): C-11.8 ± 0.8, E-12.0 ± 1.2, $P = .7$. Caliber (French):C-18F-5; E-18F-4, 14F-1.

Conclusion: Robotic-assisted esophagoesophagostomy is technically feasible and offers an alternative approach to thoracoscopic repair of esophageal atresia.
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INDEX WORDS: Robotic surgery, esophageal atresia, intracorporeal knot-tying, thoracoscopy.

THE STANDARD SURGICAL approach to the repair of esophageal atresia is a posterolateral thoracotomy. Advances in minimally invasive surgery have facilitated thoracoscopic repair of esophageal atresia;[1-3] however, the anastomosis remains technically challenging because of the small mediastinal space.

Robotic surgical systems that facilitate the performance of microsurgery in a small workspace may provide an additional minimally invasive approach to the repair of esophageal atresia that may be especially important in low-birth weight infants.

The purpose of this study was to develop the procedure for and evaluate the technical feasibility of performing a robotic-assisted esophagoesophagostomy using the Zeus Robotic Surgical System (Computer Motion, Goleta, CA).

MATERIALS AND METHODS

Ten piglets weighing 5.0 to 7.8 kg were divided into 2 groups: the control group (n = 5) underwent thoracoscopic and the experimental group (n = 5) robotic-assisted esophagoesophagostomy by a single surgeon. The anesthetic management has been described previously.[4]

The patient was positioned semiprone, and 3 5-mm ports were placed in the right chest and the robotic arms positioned (Fig 1). CO_2 was insufflated to a pressure of 4 to 8 mm Hg. The scope was controlled by AESOP (Automated Endoscopic System for Optimal Positioning) in all 10 cases.

The esophagus was identified and transected high in the thorax. The anastomosis was performed in an interrupted fashion with 5-0 PDS sutures on a C-1 needle using intracorporeal knot-tying techniques. The anterior wall was approached initially, placing the first suture on the left side of the esophagus. Once the anterior wall was completed, a nasogastric tube was passed, and the posterior wall was completed, again starting on the left side of the esophagus.

Once the anastomosis was completed, the piglets were euthanized and the esophagus excised and filled with saline to look for narrowing or a leak. A nasogastric tube was then passed through the lumen to calibrate the diameter. Finally, the anastomosis was opened along one side and mucosal approximation was inspected.

The following data were compared between the 2 groups: anesthesia, operating anastomotic, and robotic set-up times; number of stitches required; anastomotic leak, caliber, and narrowing; and mucosal approximation. The robotic set-up times are not included in the operating and anesthetic times. The robotic set-up time for the control group includes only AESOP, whereas the experimental group includes both AESOP and Zeus set-up times. The mean values were calculated with standard deviation for each numerical measurement. The means were compared using the 2-tailed Student's t test, with significance at P values of less than .05. This protocol was approved by our Animal Care and Use Committee.

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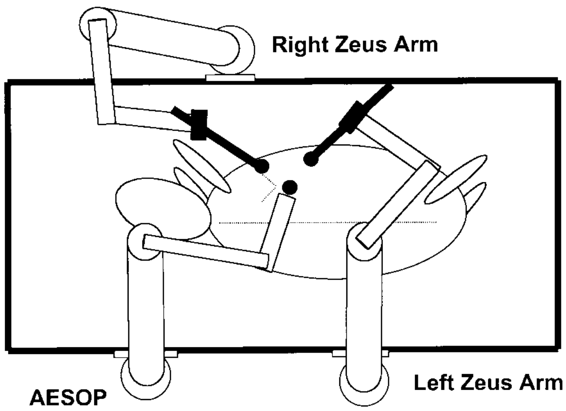

Fig 1. Robotic esophagoesophagostomy. The patient is positioned prone with the right side elevated approximately 60°. The circles represent 5-mm ports. The right and left Zeus robotic arms and the AESOP arm are positioned as shown.

RESULTS

All cases were completed successfully. All anastomoses were patent without narrowing with excellent mucosal approximation. Nine anastomoses were 18F and one (experimental group) 14F caliber. One thoracoscopic anastomosis had a small leak. There was no statistically significant difference between the 2 groups for the numerical means calculated and reported in Table 1.

DISCUSSION

Minimally invasive repair of esophageal atresia has potential advantages over standard thoracotomy including decreasing the markers of systemic inflammation,[5] avoiding the musculoskeletal sequelae of thoracotomy,[6,7] improving cosmesis of incisions, and decreasing postoperative narcotic requirements. The disadvantages to this approach include difficulty with suturing and knot tying and possibly decreased magnification and visualization. The spatial constraints of the mediastinum combined with surgeon tremor, large translated motions at the instrument tips, and a decreased view of the operative field increase not only the risk of injury to surrounding organs but also the number of collisions of the scope with the surgeon's instruments making suturing and knot-tying tasks difficult. This has been overcome by using extracorporeal knot-tying techniques. Additionally, the scope must be positioned away from the anastomosis to avoid these collisions, thus, decreasing the visualization and magnification available. This may affect the ability to precisely place sutures and ensure mucosal approximation, thereby increasing the leak rate.

The advantages of using a robotic surgical system include improved magnification and visualization, less scope manipulation, decreased risk of injury to surrounding organs, and ability to safely utilize intracorporeal suturing and knot-tying techniques. Scope collisions are decreased when tremor is filtered out and movements at the instrument tips are scaled down. This decrease allows the scope to be positioned closer to the anastomosis improving magnification and facilitating precise suture placement and mucosal approximation. Injury to surrounding organs is avoided by fixed instrument paths that guide the instruments safely back to the anastomosis. These fixed instrument paths also eliminate the need to manipulate the scope when instruments are changed. Intracorporeal knot-tying techniques minimize the manipulation of and the tension placed on the anastomosis possibly decreasing leaks and strictures.

An additional advantage to the robotic surgical systems is the ability to disseminate pediatric surgical expertise through telesurgery or telementoring. The master-slave design of the robotic systems may be important in allowing a pediatric surgeon at one institution to guide the surgical care of the patient that may be many miles away, thereby expanding the coverage area of the robotic pediatric surgeon. The robotic surgeon, working in conjunction with surgeons at the patient's institution may be able to successfully complete a complex minimally invasive operation without the patient having to travel to him or her. Although this scenario certainly is a possibility, there are logistical hurdles to overcome such as ensuring the institution has the capability of caring for the pediatric patient as well as ensuring the surgeon at the patient's institution possesses the competence to proceed with an open operation for the patient's condition should there be any robotic or communications failure.

Table 1. Results for Thoracoscopic and Robotic-Assisted Esophagoesophagostomy

	Thoracoscopic Control Group (n = 5)	Robotic Experimental Group (n = 5)	*P* Value (*t* test)
Weight (kg)	6.4 ± 0.8	6.3 ± 1.0	.8
Anesthesia time (min)	124 ± 25	151 ± 20	.09
Robotic set-up time (min)	6.4 ± 9.3	15.6 ± 20	.13
Operating time (min)	97 ± 21	131 ± 27	.06
Anastomosis time (min)	89 ± 20	125 ± 34	.08
Stitches	11.8 ± 0.8	12.0 ± 1.2	.7
Complication	1	0	

NOTE. All values are expressed as mean ± SD.

Robotic esophagoesophagostomy is feasible technically as evidenced by short-term results that are at least equivalent to those reported for the thoracoscopic approach.[3] Leak rates for the open approach are 14% to 16%. Early data showing a leak rate of 22% for the thoracoscopic approach is supported by a leak rate of 20% in this control group. Importantly, there were no leaks in the robotic group. The robotic approach offers potential advantages for the infant with esophageal atresia but the clinical significance and long-term outcome is not known. Survivor studies are needed to elucidate potential difference in outcomes between the 3 approaches to repair of esophageal atresia. Randomized, prospective trials then would be needed to determine the clinical significance of any measured differences between the groups.

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Discussion

Dr Meier (Atlanta GA): Using the system you are still using, rigid instruments without any ability to move the tip, where do you see the advantages over using the standard thoracoscopic technique using this new system?

C.M. Hollands (response): The advantage is that with the Zeus system, even though you do not have the degree of freedom of the wrist movement at the instrument tip you are given scaling control, which filters out the extra movement of the surgeon. You have a fixed instrument path so you can fix your scope in close and get higher magnification, and it scales out the surgeon tremor. So the motion actually is less and the visualization is better.

S. Rothenberg (Denver, CO): Your data suggest that there is no difference between the control when you were doing it freehand and the robot. Is that correct?

C.M. Hollands (response): That is correct.

S. Rothenberg: I think robotics are very exciting, but one of the problems I have is that I have proven with the improved instrumentation that we have and probably this anastomosis will in fact not be done freehand but will be done with a miniature EEA probably within 2 or 3 years. What is the advantage? If you are in your learning curve and you are doing this just as fast open, did you incorporate robot setup time in your operating times as you had comparable times? Did that include the time that it took to set up the robot. We need to look at this very critically, because one of the areas that we use robots is to facilitate things we can't do otherwise. Do you think using the robot would facilitate someone doing this anastomosis who might not have your level of skill using standard laparoscopic or thoracoscopic instruments?

C.M. Hollands (response): I appreciate your comments and your questions. I think that is one of the things that we struggle with is the expense of the robotics and when we show that there is no difference in time, it is hard to justify that expense.

The one thing that we did not talk about was the leak rate, which was 20% in the thoracoscopic group and 0% in the robotic. Now there are only 5 cases in each group, but the leak rate is a little bit higher in the thoracoscopic cases than in the open cases and whether, after we do more cases, that is going to become important, I don't know, and the robotic anastomosis may cause less trauma. We've taken urologic surgeons who have no laparoscopic experience, and they are doing suturing of the ureteral anastomosis in 3 to 5 minutes per suture that they cannot do laparoscopically. So I think there is a benefit for people that do not have advanced suturing and knot-tying skills.