Journal of Pediatric Surgery (2007) **42**, 1757–1760

Journal of Pediatric Surgery

www.elsevier.com/locate/jpedsurg

Robotic repair of a bochdalek congenital diaphragmatic hernia in a small neonate: robotic advantages and limitations

John J. Meehan[a,*], Anthony Sandler[b]

[a]*Division of Pediatric Surgery, Children's Hospital of Iowa, University of Iowa Hospitals and Clinics, Iowa City, IA 52242, USA*
[b]*Children's National Medical Center, Washington, D.C.*

Index words:
Laparoscopy;
Congenital diaphragmatic hernia;
Robotic surgery

Abstract Minimally invasive repair for a Bochdalek congenital diaphragmatic hernia has been performed over the last few years with mixed results. Although the anomaly has been approached from both the abdomen and the chest, the defect can be difficult to close as the posterolateral region may be difficult to reach with precise suturing using standard rigid laparoscopic instruments. The articulating instruments of robotic surgery offer a substantial improvement in degrees of freedom and may help over come these obstacles. However, other limitations including instrument length in relation to patient size need to be accounted for when planning a robotic procedure in small children. We present a robotic repair of a foramen of Bochdalek congenital diaphragmatic in a 2.2 kg neonate using and abdominal approach with the Da Vinci Surgical Robot (Intuitive Surgical, Sunnyvale, CA).

The foramen of Bochdalek CDH is an anomaly which has been corrected with traditional minimally invasive instruments from both the abdomen and the chest [1-3]. However, early recurrence rates have been high in some series [4]. This may be partly due to the difficulty constructing an adequate repair with non-articulating rigid instruments. Because the posterolateral aspect of the Bochdalek CDH is usually devoid of any strong tissue to anchor a closure, sutures near this location need to be placed precisely and securely. Articulating instruments, such as those found in robotic surgery, may help a surgeon place these sutures more accurately in this difficult to reach area. We present a robotic repair of a foramen of Bochdalek CDH with the Da Vinci Surgical Robot.

1. Case report

In March of 2005, a term 2.2 kg baby girl with a prenatally diagnosed left sided foramen of Bochdalek CDH was born at 37 weeks gestation. Her pulmonary status deteriorated initially and she briefly required high-frequency ventilation. By the second day of life, she had been weaned back to conventional ventilation. After waiting a few days to be sure her mild pulmonary hypertension was stable, she was

* Corresponding author. Tel.: +1 319 356 1884.
E-mail address: john-j-meehan@uiowa.edu (J.J. Meehan).

0022-3468/$ – see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.jpedsurg.2007.06.013

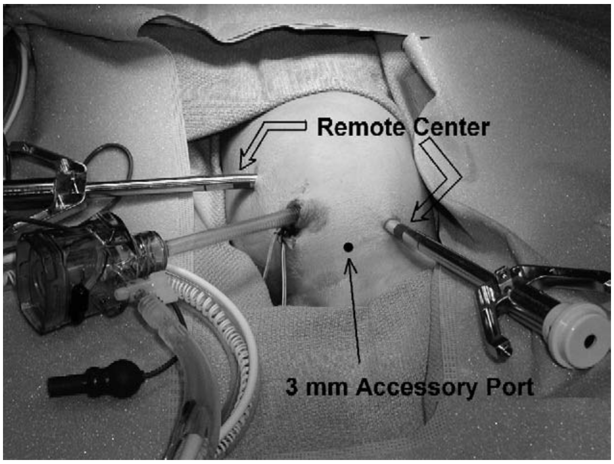

Fig. 1 Trocar placement for repair of Bochdalek congenital diaphragmatic hernia. Notice the trocar for the right arm of the robot is recessed below the umbilicus and the trocar for the left arm is recessed lateral to the midline (open arrows). A 3 mm nonrobotic accessory port for bowel retraction was added after this photo was taken (solid arrow).

taken to the operating room for robotic closure at 6 days of life. Options for closure were either through the chest or through the abdomen. Due to the constraints of the size of this small patient, we felt there would not be enough room for the robotic instruments in the hemithorax and elected to proceed with an abdominal approach. Four trocars were used including a 5 mm camera at the umbilicus, two 5 mm instrument arms, and a 3 mm accessory port (Fig. 1). The remote center of each robotic instrument trocar was retracted just outside the abdominal cavity to allow for another centimeter of intraabdominal instrument length. The intraabdominal insufflation pressure was kept at 7 mmHg throughout the case. The small bowel and colon were reduced with the robotic instruments. The bedside assistant helped keep

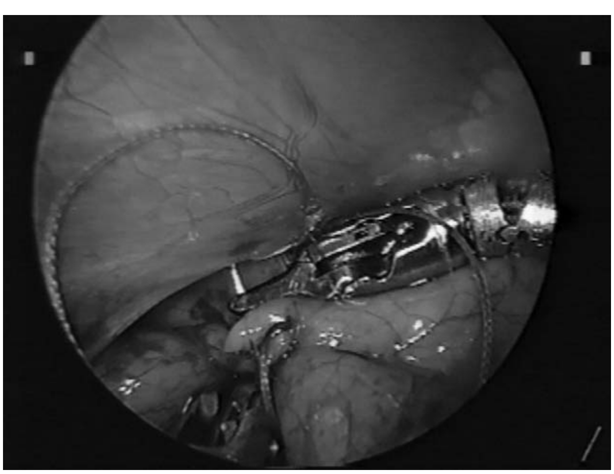

Fig. 2 Intraoperative photograph; closure of the left sided Bochdalek CDH using horizontal mattress sutures. The articulating robotic instruments allow for precise suturing.

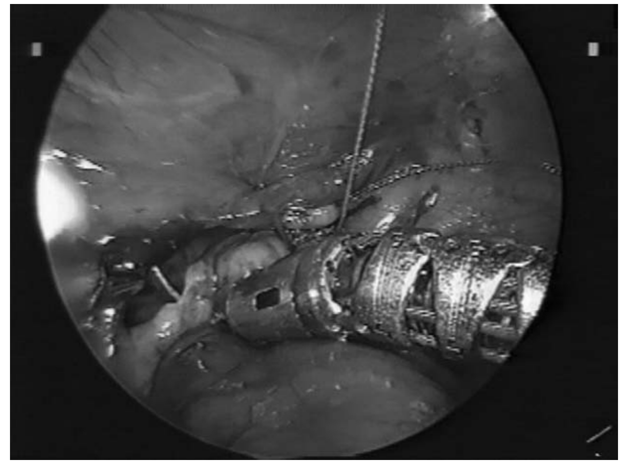

Fig. 3 Intraoperative photograph; Placement of final horizontal mattress suture.

the viscera inferiorly with the use of a 3 mm standard laparoscopic grasper. The reduction portion of the procedure took about 40 minutes. After reduction of the viscera, the defect was closed with interrupted 3-0 Ethibond (Ethicon, Inc, Piscataway, NJ) horizontal mattress sutures (Figs. 2 and 3). Total operative time was 2 hours and 59 minutes. The patient had an unremarkable post-operative course. She remained on conventional ventilation post-operatively and was extubated on post-op day 7. Feeds were slowly advanced and she was discharged on post-op day 19 on room air. She is now 2 years old, has no O_2 requirements, and doing well with no evidence of recurrence.

2. Discussion and critique

The CDH comes in several forms; the posterolateral Bochdalek CDH, the central Morgagni CDH, and a hiatal CDH. Hiatal hernias tend to present with reflux symptoms. Morgagni hernias are usually discovered in older patients because they usually do not cause pulmonary hypoplasia. Morgagni CDH patients have been repaired with excellent results both laparoscopically [5] and robotically [6]. Bochdalek hernias often present much younger, often shortly after at birth if they haven't already been detected by prenatal ultrasound. However, minimally invasive closure of a Bochdalek hernia has demonstrated a high recurrence rate in newborns [4].

There is significant debate over a laparoscopic or thoracoscopic approach as well. Both methods have their advantages and disadvantages with no clear preferred method. We attempted a thoracoscopic robotic CDH closure in December of 2003 in a 2.5 kg neonate. There was no 5 mm camera commercially available for the robot back then. However, we used a 5 mm mock-up camera which was an early potential design for the robot. Although there were some technical difficulties with this test camera, we had more of an issue with the amount of space in the hemithorax of the 2.5 kg neonate. We successfully reduced the viscera with standard MIS equipment and then we docked the robot for closure. But the viscera kept returning to the chest every time we removed instruments and attempted to dock the robot. Meanwhile, the robotic instruments inserted to the required length in order for them to function could not turn sufficiently in this small child's hemithorax in order to be useful. This problem, coupled with the technical issues related to the test camera, led us to abandon the use of the robot that day for the thoracic approach.

However, our initial experience gave us ideas for our next attempt. Several months later, a redesigned Da Vinci 5 mm 2-dimensional scope was released for general use. When our next CDH patient presented, she was only 2.2 kg in size. We felt an abdominal approach may be better suited for a child of this size. The abdominal cavity has significantly more room than a hemithorax and can be distended to increase the volume with CO2 whereas the chest cavity is rigid and non-distensible. For these reasons, we elected to approach this patient from the abdomen.

Going to the abdomen would gave us a little more room simply because the abdominal cavity is bigger than the hemithorax. But we were concerned that it may still not be enough room. Consider the design of the 5 mm robotic instruments. These instruments articulate on a series of mechanical links that bend in succession, in a sort of snake-like chain of articulations (Fig. 4). The robot software is designed to allow instrument movement only after the instrument has been moved out of the trocar a specified minimum length. This minimum length allows all of the articulations to be clear of the trocar. For the purpose of this paper, we will call that length ARTIC. This minimum length is dependant on the length of the instrument tip plus the articulations. For example, the Da Vinci 5 mm needle driver is the shortest robotic 5 mm instrument with a length of 2.71 cm from tip to last articulation. Thus, the robotic software will not allow the needle driver instrument to function until it has been moved a minimum of 2.71 cm out of the end of the trocar.

Next, we have to consider the robot trocar and the remote center. The remote center is a stationary point in three dimensional space. The robot arm pivots around this point in space. This point has been marked on the trocar and is denoted by a thick black line. The manufacturer recommends that the surgeon set the robot trocar to the depth where the remote center is just inside the patient. Unfortunately, the remote center is 2.90 cm from the end of the trocar (call this length TROCAR). Therefore, the minimum effective length that the manufacturer recommends to be inside the patient is:

$$\textit{Minimum internal instrument length} = \textit{ARTIC} + \textit{TROCAR}$$

Using our example of the shortest 5 mm robotic instrument - the needle driver - our effective length becomes

Fig. 4 The selection of 5 mm Da Vinci robotic instruments.

2.71 cm + 2.90 cm, or 5.61 cm. That is a considerable length of space that is lost, particularly in very small children. After talking with the manufacturer, the recommendation for setting the remote center just inside the body cavity, seemed arbitrary. They could have adjusted the software and had the remote center just inside the body cavity, just outside the body cavity, or 1/2 way between. Therefore, we used this to our advantage and have found a way to garner a few more centimeters of instrument length. Instead of placing the remote center just internal to the patient, we recess the trocar so that the remote center is just external to the patient. While irrelevant for large patients, this little trick reclaims another 1 to 2 cm of length which can be strategically valuable in very small patients.

We felt the operative time of 3 hours was reasonable for our first abdominal CDH closure attempt presented here. Subjectively, we felt the suturing of the defect went reasonably well. The articulations helped considerably in placing our horizontal mattress sutures and there was ample room to tie the knots. From our prior laparoscopic experience, we felt that the robotic instruments were far superior to laparoscopic instruments for closing the Bochdalek defect.

However, we also felt it took excessively long to reduce the viscera because we could not articulate the instruments far enough to make the required movements to keep the viscera effectively reduced. We believed this occurred for two reasons. First, the size of the small abdominal domain in this small patient was approaching the limit of what can be accomplished with the current 5 mm robotic instruments even with our recessed trocars. Second, the original Da Vinci Standard robot was designed to work in only one or two quadrants of any given body cavity. It is not well suited to work in the opposite quadrants once it has been oriented in a specific direction. The new Da Vinci-S has a better range of motion than the Da Vinci -Standard and this may be less of an issue in the future.

3. Summary

A foramen of Bochdalek CDH can be closed effectively using robotic surgery, even in small neonates. This patient's size pushed the limit of the available domain in the abdomen for a robotic procedure with the current Da Vinci Standard. In larger children, we expect that robotic instruments could be used for the entire procedure including reduction of the viscera. But in children less than 3.0 kg, reducing the viscera with traditional laparoscopic instruments may be preferable followed by closure of the defect using robotic instruments. The debate between a thoracoscopic and a laparoscopic approach will not be solved anytime soon. Although we predict that closure of a CDH through the chest will soon be accomplished with the robot, patient size should be a consideration when choosing between an abdominal or thoracic approach. Eventually, we may see enough robotic experience where patch closures can be accomplished as well.

References

[1] Willemse P, Schutte PR, Plaisier PW. Thoracoscopic repair of a Bochdalek hernia in an adult. Surg Endosc 2003;17(1):162.

[2] Silen ML, Canvasser DA, Kurkchubasche AG, et al. Video-assisted thoracic surgical repair of a foramen of Bochdalek hernia. Ann Thorac Surg 1995;60(2):448-50.

[3] Shah AV, Shah AA. Laparoscopic approach to surgical management of congenital diaphragmatic hernia in the newborn. J Pediatr Surg 2002;37 (3):548-50.

[4] Arca MJ, Barnhart DC, Lelli Jr JL, et al. Early experience with minimally invasive repair of congenital diaphragmatic hernias: results and lessons learned. J Pediatr Surg 2003;38(11):1563-8.

[5] Kuster GG, Kline LE, Garzo G. Diaphragmatic hernia through the foramen of Morgagni: laparoscopic repair case report. J Laparoendosc Surg 1992;2(2):93-100.

[6] Knight CG, Gidell KM, Lanning D, et al. Laparoscopic Morgagni hernia repair in children using robotic instruments. J Laparoendosc Adv Surg Tech A 2005;15(5):482-6.