Totally endoscopic robotic ventricular septal defect repair in the adult

Changqing Gao, MD, Ming Yang, MD, Gang Wang, MD, Cangsong Xiao, MD, Jiali Wang, BS, MD, and Yue Zhao, RN

Objective: We have previously reported total endoscopic ventricular septal defect repair in the adult using the da Vinci S Surgical System. The optimal results encouraged us to extend the use of this technology to more complicated patients with ventricular septal defect.

Methods: From January 2009 to July 2010, 20 patients underwent total endoscopic robotic ventricular septal defect repair. The average patient age was 29.0 ± 9.5 years (range, 16–45). Of the 20 patients, 9 were female and 11 were male. The echocardiogram demonstrated that the average diameter of the ventricular septal defect was 6.1 ± 2.8 mm (range, 2–15), and 4 patients had concomitant patent foramen ovale. Ventricular septal defect closure was directly secured with interrupted mattress sutures in 14 patients and patched in 6 patients. All the procedures were completed using the da Vinci robot by way of 3 port incisions and a 2.0- to 2.5-cm working port in the right side of the chest.

Results: All patients were operated on successfully. The mean cardiopulmonary bypass and mean crossclamp time was 94.3 ± 26.3 minutes (range, 70–140) and 39.1 ± 12.9 minutes (range, 22–75), respectively. The mean operation time was 225.0 ± 34.8 minutes (range, 180–300). The postoperative transesophageal echocardiogram demonstrated an intact ventricular septum. No residual left-to-right shunting and no permanently complete atrio-ventricular dissociation was found postoperatively. The mean hospital stay was 5 days. No residual shunt was found during a mean follow-up of 7 months (range, 1–22). The patients returned to normal function within 1 week without any complications.

Conclusions: Total endoscopic robotic ventricular septal defect repair in adult patients is feasible, safe, and efficacious. (*J Thorac Cardiovasc Surg* 2012;144:1404-7)

Recent advances in robotic instrumentation and clinical research on minimally invasive surgery have facilitated total endoscopic intracardiac procedures.¹⁻⁴ However, to our knowledge, endoscopic robotic ventricular septal defect (VSD) repair has not been reported in published studies since we reported our first 4 cases of closed-chest VSD repair using the da Vinci S Surgical System (Intuitive Surgical, Sunnyvale, Calif).³ We have performed more than 450 cases of various types of robotic cardiac operations in a single center since 2007.³⁻⁸ In the present study, we determined the feasibility, safety, and efficacy of total endoscopic perimembranous VSD in adults using the da Vinci S or Si Surgical System.

METHODS

From January 2009 to July 2010, 20 patients underwent total endoscopic robotic VSD repair at our institution. The institutional review board

approved the study, and all patients provided informed consent. The average age was 29.0 ± 9.5 years (range, 16–45). Of the 20 patients, 9 were female and 11 were male. The echocardiogram demonstrated that the average diameter of perimembranous VSD was 6.1 ± 2.8 mm (range, 2–15), and 4 patients had concomitant patent foramen ovale. Pulmonary function, red blood cell quantity, and hemoglobin content were within the normal range, and cardiac function was normal, although the left ventricular dimension was large in some patients. VSD closure was directly secured with interrupted mattress sutures in 14 patients and patched in 6 patients (Table 1). The surgical approach was through 4 right-sided chest ports with femoral perfusion. Aortic occlusion was performed with a Chitwood crossclamp (Scanlan International, Minneapolis, Minn), and antegrade cardioplegia was administered directly by way of the anterior chest. All the procedures were completed with the da Vinci robot using 3 port incisions and a 2.0- to 2.5-cm working port in the right side of the chest.

Surgical Technique

The patients were intubated for single-lung ventilation and cannulation, and the da Vinci S setup was established, as previously described.³⁻⁵

After cardiopulmonary bypass was initiated with kinetically assisted bivalve venous drainage, the pericardium was opened. The venae cavae were encircled with linen tapes. Aortic occlusion was performed with the Chitwood crossclamp (Scanlan International) by way of the fourth intercostal space in the midaxillary line. Antegrade cold blood cardioplegia was administered directly through anterior chest (second intercostal space) with a 14F angiocatheter, by which de-airing was done and repeat doses could be given when necessary. Carbon dioxide was insufflated continuously into the right pleural space for air displacement. The right atriotomy was performed obliquely. A suction device was placed across the naturally present or surgically created foramen ovale. Before the repair was started, the defect was carefully examined to establish that all margins could be seen and reached. The VSD was exposed with an atrial retractor (Intuitive

From the Department of Cardiovascular Surgery, People's Liberation Army General Hospital, Beijing, China.

Disclosures: Authors have nothing to disclose with regard to commercial support. Received for publication Aug 1, 2011; revisions received Dec 23, 2011; accepted for publication Jan 4, 2012; available ahead of print Feb 1, 2012.

Address for reprints: Changqing Gao, MD, Department of Cardiovascular Surgery, People's Liberation Army General Hospital, 28 Fuxing Road, Beijing 100853, China (E-mail: gaochq301@yahoo.com).

0022-5223/\$36.00

Copyright © 2012 by The American Association for Thoracic Surgery

doi:10.1016/j.jtcvs.2012.01.027

Abbreviation and Acronym
VSD = ventricular septal defect

Surgical, Sunnyvale, Calif) using the fourth arm, and excellent visualization of the perimembranous VSD was obtained (Figure 1). VSD closure was secured with interrupted mattress sutures with small pledgets using 4-0 polytetrafluoroethylene (Gore-Tex; W. L. Gore & Associates, Flagstaff, Ariz) for the patients with a small VSD. For the patients with a large VSD that abutted the tricuspid valve in the region of the commissure between the septal and anterior leaflets, our practice was that an incision was made to disconnect a portion of the tricuspid valve from the annulus, and the VSD was exposed through the resulting aperture (Figure 2). Next, the VSD was repaired with a polyester patch sewn in place using interrupted mattress sutures reinforced with small pledgets, placing all the sutures in the heart before passing them through the patch (Figure 3, A). Next, the incision of the portion of the tricuspid valve from the annulus was closed (Figure 3, B). The tricuspid valve was examined (Figure 4). The patent foramen ovale was closed with polytetrafluoroethylene running suture (Gore-Tex) when no evidence of retained air was found in the left atrium. Temporary pacing wires on the right ventricle were placed. Finally, cardiopulmonary bypass was weaned, and chest tubes were inserted.

RESULTS

All the VSD repairs and right atrial closures were completed with the da Vinci robot. The mean cardiopulmonary bypass and mean crossclamp time was 94.3 ± 26.3 minutes (range, 70–140) and 39.1 ± 12.9 minutes (range, 22–75), respectively, and the mean operation time was 225.0 ± 34.8 minutes (range, 180–300). The mean drainage volume of the study group was less than that with conventional VSD repair surgery (91.8 ± 60.8 mL vs 310 ± 90.5 mL). The trend line for the operating time for perimembranous VSD repair is shown in Figure 5. The intraoperative and postoperative transesophageal echocardiograms demonstrated an intact ventricular septum. No residual left-to-right shunting or permanently complete atrioventricular dissociation was found postoperatively. The mean hospital stay was 5 days (Table 2). Tricuspid valve regurgitation, atrioventricular conduction block, and residual shunt were not found during a mean follow-up period of 7 months

TABLE 1. Clinical patient data

Variable	Value
Total patients (n)	20
Gender (n)	
Male	11 (55)
Female	9 (45)
Age (y)	29.0 ± 9.5
Weight (kg)	56.3 ± 8.2
Height (cm)	160.7 ± 7.3
Diameter of defect (mm)	6.1 ± 2.8
Left ventricular ejection fraction (%)	66.9 ± 8.3

Data in parentheses are percentages.

FIGURE 1. Excellent visualization of the perimembranous ventricular septal defect (VSD) was obtained.

(range, 1–22). The patients returned to normal function within 1 week without any complications.

DISCUSSION

Currently, surgeons and their patients have become energized by the benefits and possibilities of minimally invasive cardiac surgery. However, cardiac surgery has lagged far behind other specialties in the development of minimally invasive surgery. In 1996, Cohn and colleagues⁹ and Cosgrove and associates,^{10,11} along with other European colleagues, first started performing minimally invasive mitral valve surgery. Recently, significant advances have been made, and encouraging reports from clinical series began to emerge.^{1,2} Concurrent advances in cardiopulmonary perfusion, intracardiac visualization, instrumentation, and robotic telemanipulation have hastened a technological

FIGURE 2. The ventricular septal defect was exposed through the resulting aperture.

FIGURE 3. A, The ventricular septal defect was repaired with a polyester patch sewn in place using interrupted mattress sutures. B, The incision of a portion of the tricuspid valve from the annulus was closed.

shift toward efficient, safe, and minimally invasive cardiac surgery. Today, robotic mitral valve repair and robotic myxoma excision have become standard practice for many surgeons, and patients are becoming more aware of their increasing availability.^{1,5}

VSD closure can be completed through a conventional median sternotomy with low morbidity, relatively low cost, and an excellent long-term results. However, patients are reluctant to undergo the operation because of the long incision in the midline of the chest, the risk of bleeding and infection, and the long recovery time after surgery. The incision leaves an unsightly scar that can be a source of persistent psychological problems and permanent dissatisfaction. Although the transcatheter closure of VSD has been used in some centers, the drawbacks of transcatheter closure of VSDs are known and include large delivery sheaths, an inability to recapture and reposition, and a high rate of residual shunt.¹²

With the advent of computer-assisted robotic surgery, another option is available for VSD closure without opening the chest. With our experience in robotic cardiac surgery,⁴⁻⁸ we have previously reported total endoscopic VSD repair in adult patients, and the surgical results were excellent.³ We believe that the possibility of closing every type of VSD, regardless of the size and location, could be

realistic and would reduce surgical trauma and minimize hospitalization while achieving optimal clinical outcomes.

The excellent exposure of whole VSD in the surgical field is paramount for successful VSD repair. In our study, excellent visualization for repair of the VSD was achieved using a dynamic atrial retractor (Intuitive Surgical) to elevate the anterior leaflet of the tricuspid valve (Figure 1). Before the repair is started, the defect should be carefully examined to establish that all margins can be seen and reached. We believe that closure of the VSD can be done with a patch for a large defect or direct suture for a small one without difficulties after the learning curve has been overcome. In some cases, because of the chordal arrangement, an incision will need to be made to disconnect a portion of the tricuspid valve from the annulus, with the VSD exposed through the resulting aperture (Figure 2). Particular attention should be directed toward determining whether the VSD is juxtatri-cuspid, in which case it will abut the tricuspid valve in the region of the commissure between the septal and anterior leaflets. The VSD is repaired with a polyester patch sewn in place using interrupted mattress sutures reinforced with

FIGURE 4. The tricuspid valve was examined after repair.

FIGURE 5. The trend line of operating time for ventricular septal defect repair.

TABLE 2. Results of robotic ventricular septal defect repair

Variable	Value
Procedure (n)	20
Direct closure	14 (70)
Patch closure	6 (30)
Operation time (min)	225.0 ± 34.8
Cardiopulmonary bypass time (min)	94.3 ± 26.3
Crossclamp time (min)	39.1 ± 12.9
Mechanical ventilation time (h)	4.6 ± 3.3
Drainage volume (mL)	91.8 ± 60.8
Length of stay (d)	5.0 ± 2.1

Data in parentheses are percentages.

small pledgets, placing all the sutures in the heart before passing them through the patch. The de-airing procedures are mandatory.

After completing more and more cases of robotic surgery, we have found that the da Vinci Surgical System and Endowrist instruments (Intuitive Surgical) allow for more precise placement of the bites of the sutures, and the three-dimensional 10× magnified view allows for easier recognition of the anatomy of the pathologic features and smaller possibility of residual left-to-right shunting and more complete atrioventricular dissociation during surgery than the conventional approach. Nevertheless, in our study, we operated only on adult patients with perimembranous VSD. We have not operated on patients with other types of VSD because of the difficulty of exposure of the whole VSD in the surgical field. For the present study, total endoscopic robotic VSD repair surgery was limited to adults because of the need for robotic instruments, femoral cannulation, and drainage suitable for the pediatric population. These issues are to be resolved in our future study.

Any new surgical approach requires a learning curve, and robotic VSD repair is no exception. In the present study, the learning curve was significant (Figure 5). Our learning curve was truncated because the senior surgeon (C.G.), as console surgeon, simultaneously performed a large volume of various types of robotic surgeries with the same team within a relative short period.³⁻⁸ We believe that with a well-trained robotic team and after overcoming a substantial learning curve, we have achieved optimal results for robotic surgical procedures. We have also found that the types of robotically surgical procedures a surgeon can perform are dependent on the surgeon's surgical experience in

the open technique, not on the robot, which is only a surgical tool. As we all know, the lack of thoracotomy or sternotomy should allow for faster recovery and quicken the return to a normal lifestyle. In addition, the benefits of robotic cardiac surgery include less trauma, lower risks of bleeding and infection, and fewer postoperative complications compared with conventional open-chest surgery. In our study, the mean drainage volume of the robotic group was 91.8 ± 60.8 mL. In contrast, in the 2004 to 2006 study, the mean drainage volume of the 56 adult patients undergoing VSD sternotomy was 310 ± 90.5 mL ($P < .01$).

Study Limitations

The results we have presented are encouraging; however, the indications for other types of VSD repair need to be extended by additional studies.

In conclusion, we believe that total endoscopic robotic VSD repair in adult patients is feasible, safe, and efficacious and that the possibility of closure of every type of VSD, regardless of the size and location, could be realistic and would reduce surgical trauma and minimizes hospitalization while achieving optimal clinical outcomes.

References

1. Lehr EJ, Rodriguez E, Chitwood WR. Robotic cardiac surgery. *Curr Opin Anaesthesiol*. 2011;24:77-85.
2. Modi P, Rodriguez E, Chitwood WR Jr. Robot-assisted cardiac surgery. *Interactive Cardiovasc Thorac Surg*. 2009;9:500-5.
3. Gao C, Yang M, Wang G. Totally endoscopic robotic ventricular septal defect repair. *Innovations*. 2010;5:278-80.
4. Gao C, Yang M, Wang G, Wang J. Totally robotic resection of myxoma and atrial septal defect repair. *Interactive Cardiovasc Thorac Surg*. 2008;7:947-50.
5. Gao C, Yang M, Wang G, Wang J, Xiao X, Wu Y, et al. Excision of atrial myxoma using robotic technology. *J Thorac Cardiovasc Surg*. 2010;139:1282-5.
6. Gao C, Yang M, Wu Y, Wang G, Xiao CS, Liu H, et al. Hybrid coronary revascularization by endoscopic robotic coronary artery bypass grafting on beating heart and stent placement. *Ann Thorac Surg*. 2009;87:737-41.
7. Gao C, Yang M, Xiao C, Wang G, Wang J, Wu Y, et al. Clinical analysis of robotic mitral valve repair. *Chin J Surg*. 2011;7:641-4.
8. Gao C, Yang M, Wu Y, Wang G, Xiao CS, Zhao Y, et al. Early and midterm results of totally endoscopic coronary artery bypass grafting on the beating heart. *J Thorac Cardiovasc Surg*. 2011;142:843-9.
9. Cohn LH, Adams DH, Couper GS, Bichell DP. Minimally invasive aortic valve replacement. *Semin Thorac Cardiovasc Surg*. 1997;9:331-6.
10. Cosgrove DM, Sabik JF. Minimally invasive approach for aortic valve operations. *Ann Thorac Surg*. 1996;62:596-7.
11. Cosgrove DM, Sabik JF, Navia J. Minimally invasive valve surgery. *Ann Thorac Surg*. 1998;65:1535-8.
12. Carminati I M, Butera I G, Chessa I M, De Giovanni J, Fisher G, Gewillig M, et al. Transcatheter closure of congenital ventricular septal defects: results of the European Registry. *Eur Heart J*. 2007;28:2361-8.