Gerard R. Manecke, Jr, MD
Marco Ranucci, MD
Section Editors

Robot-Assisted Mitral Valve Repair

Kent H. Rehfeldt, MD,* William J. Mauermann, MD,* Harold M. Burkhart, MD,† and Rakesh M. Suri, MD, DPhil†

BASED LARGELY ON THE success of laparoscopic surgery in the 1990s, minimally invasive surgical approaches have gained widespread acceptance among many surgical specialties; cardiac surgery is no exception. In addition, the lay press and Internet are replete with reports of cardiac valve repair or replacement through small incisions with reportedly improved recovery times and cosmesis. Perhaps the most dramatic change to the surgical approach of valvular repair is with the use of robotic assistance (Fig 1). Many surgeons find that robotic assistance provides superior dexterity compared with thoracoscopic instruments. In addition, the dramatic and futuristic sounding nature of this approach leads many patients to seek out centers that offer robotic approaches to mitral surgery. Currently, a minority of mitral valve (MV) operations in the United States are conducted with robotic assistance and randomized trials comparing this minimally invasive approach with standard, open techniques are lacking. However, hospital stays and recovery times appear to be shorter with robotic assistance, and cosmesis undoubtedly is improved compared with an open approach via median sternotomy. These observations combined with the growing awareness of the availability of this operation among patients continue to fuel growth in this practice.

HISTORIC BACKGROUND

The era of robot-assisted MV surgery began in the 1990s when the Food and Drug Administration approved a voice-controlled system for positioning an endoscopic camera (AESOP; Computer Motion, Goleta, CA). This "automated endoscopic system for optimal positioning" was embraced by some cardiac surgeons in the late 1990s and used to facilitate a variety of operations including thoracoscopic harvest of the internal mammary artery during minimally invasive, off-pump coronary bypass surgery as well as minimally invasive MV repair.[1] MV repair using a prototype of a new robotic system (da Vinci; Intuitive Surgical, Sunnyvale, CA) was performed first in France by Carpentier et al in May 1997.[2] In 2000, the Food and Drug Administration approved the da Vinci for use in laparoscopic surgery. The following year a surgical robot known as the ZEUS (Computer Motion, Goleta, CA) received Food and Drug Administration clearance. Although the da Vinci instruments offered greater degrees of freedom within the body, the ZEUS held the edge in miniaturization.[3] The ZEUS also used a voice-activated control system similar to the AESOP. However, shortly after Food and Drug Administration approval of the ZEUS, a lawsuit was brought against Computer Motion because of an alleged infringement on an IBM patent, which had been licensed exclusively by Intuitive Surgical.[3] The legal wrangling ended in 2003 with the announcement of a merger between Intuitive Surgical and Computer Motion that effectively left the da Vinci as the sole surgical robot on the market.[3] In 2002, the Food and Drug Administration approved the da Vinci for intracardiac use.

The first robot-assisted mitral repair in the United States was performed in 2000 by Chitwood et al[4] at East Carolina University. Subsequently, Nifong et al[5] published the results of a phase II multicenter trial of robot-assisted mitral repair that involved 112 patients and 10 institutions. Although reporting no deaths or strokes, these investigators noted that 8% of study patients had grade 2+ residual mitral regurgitation (MR) as shown by 1-month follow-up echocardiography and 5.4% ultimately required reoperation. In 2005, Chitwood et al[6] reported the first 100 robotic mitral repairs performed at East Carolina University, the largest single-center series of such cases in the United States at that time. One death occurred within 30 days of surgery, and 2 patients required reoperation for failed valve repair. Two patients required surgical exploration for postoperative bleeding although only 15% received transfusion of allogeneic blood products. The average hospital length of stay (LOS) was 4.8 days. Interestingly, significantly shorter bypass times were noted in the last 50 patients when compared with the first 50 patients, suggesting a demonstrable learning curve. In fact, the bypass time for the first 50 patients was 174 minutes compared with 150 minutes for the last 50 patients ($P < 0.004$). A similarly significant trend was noted with aortic cross-clamp times. Three years later, the East Carolina group reported their first 300 robot-assisted MV repairs.[7] Nine of the original cohort of 309 patients converted to a nonrobotic, minimally invasive approach for technical reasons such as poor exposure or robot

*From the *Department of Anesthesiology and †Division of Cardiovascular Surgery, Mayo Clinic College of Medicine, Rochester, MN.*
Address reprint requests to Kent H. Rehfeldt, MD, Department of Anesthesiology, Mayo Clinic, 200 First Street SW, Rochester, MN 55905. E-mail: rehfeldt.kent@mayo.edu

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Fig 1. Robot-assisted MV repair. The operating surgeon is seated at the control console (lower left corner), whereas the surgical robot is located at the left side of the patient (upper right corner). (Color version of figure is available online.)

failure. Analysis of patient characteristics in the study group revealed that although 81% had congestive heart failure, 90% had a preoperative ejection fraction >45%. Furthermore, atrial fibrillation or flutter was noted in 18%, whereas 6% were diabetic and <1% had renal insufficiency. Moderate or mild pulmonary hypertension was present in 16% of this group. Of the 300 cases completed with robotic assistance, 2 patients died within 30 days of surgery, and 2 patients suffered strokes. Although immediate postrepair echocardiography showed mild or lesser residual MR in 99% of patients, after a mean follow up period of 815 ± 459 days, echocardiography revealed moderate or severe MR in 7.6% of patients and 5.3% required reoperation.

Other groups soon reported series and cases of robot-assisted mitral repair.[8,9] As is often typical after the introduction of new medical technology, numerous publications related to robotic cardiac surgery quickly appeared in the medical literature. Indeed, more than 200 articles related to robotic cardiac surgery were published within a 6-year period, including 60 from a single author.[10]

SURGICAL CONSIDERATIONS

Minimally Invasive Approach

Robot-assisted mitral repair usually is accomplished through a 2- to 3-cm right inframammary incision in either the 4th or 5th intercostal space. Additional trocars are inserted around this primary incision to facilitate placement of robotic arms, allow carbon dioxide insufflation, and possible placement of a trans-thoracic aortic cross-clamp (Fig 2). Because the mitral annulus lies in a near-sagittal plane within the chest, approaching the valve via a right thoracotomy offers the surgeon an excellent en face view of the leaflets and annulus from the left atrium.[11]

Mitral repair may be accomplished through a small right anterolateral thoracotomy with or without robotic assistance. Using long-shafted thoracoscopic instruments, the surgeon may operate on the mitral valve while viewing a 2-dimensional video image on a monitor. Alternatively, robotic assistance may be used. The term "telemanipulator" probably is more appropriate than "robot" when discussing machines such as the da Vinci because these devices translate scaled movements of the surgeon seated at a remote console into the surgical field. Proponents of robot-assisted surgery cite several advantages of the da Vinci system.[12] Because the robotic thoracoscope contains 2 side-by-side cameras, the surgeon is afforded a 3-dimensional, magnified view of the surgical field. Additionally, unlike standard thoracoscopic surgery in which the camera is controlled by an assistant or held motionless by a clamping system, the da Vinci allows the operating surgeon to directly control the orientation of the image from the robotic control console. The operator ends of the robotic arms are equipped with mechanical "wrists" that allow multidirectional movement within the body, thus providing 6 degrees of freedom at the site of repair. A 7th degree of freedom is afforded by the opening and closing of the robotic instrument itself. Despite greater degrees of freedom at the surgical site, knot tying using the robotic arms remains time-consuming. Therefore, 2 primary

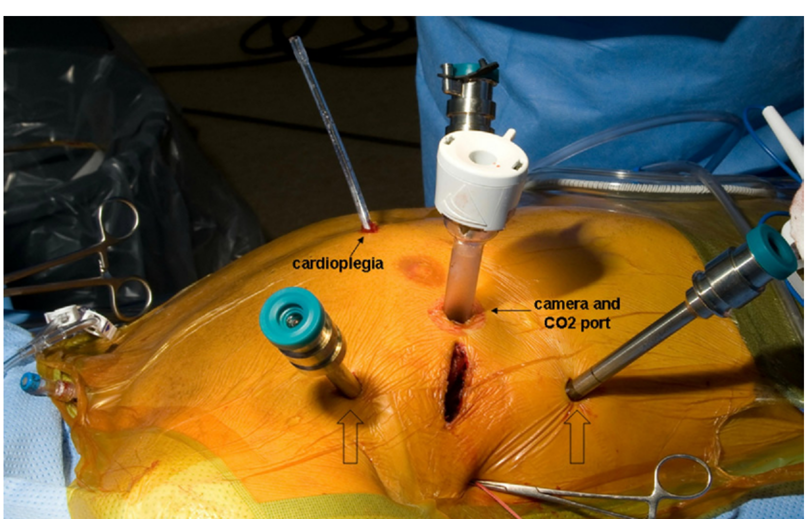

Fig 2. The operative site for robot-assisted mitral repair at the right anterior chest. The primary incision is located between ports for robotic instruments (open arrows). An additional port for the thoracoscopic camera and CO_2 insufflation is indicated. The percutaneous cannula for cardioplegia administration also is labeled. (Color version of figure is available online.)