MITRAL VALVE SURGERY WITH THE *DA VINCI* ROBOTIC SURGICAL SYSTEM

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INTRODUCTION

The public has long been familiar with media portrayals of "robots" as machines carrying out activities with near-human characteristics. The official definition of a robot by The Robotics Institute of America is more prosaic: "a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks." Devices under direct manual control are one of the four categories specified.1

Autonomous, programmed machines have been used widely in industry for decades to perform a variety of tasks. Indeed, it is estimated that there are almost one million robots in use worldwide for these applications. Robots designed to directly assist humans in medical, military, or domestic applications are estimated at about 40,000 units. This category is anticipated to increase two-fold by 2010.[2]

HISTORY OF ROBOTICS IN SURGERY

The introduction of robots inco surgical practice has been much slower, beginning in 1985 with the use of the Puma 560 device to position a needle during a CT-guided scereocaccic brain biopsy.3 The subsequent history of robot use for surgery has been well described by Lanfranco et al.[4] The development of the current da *Vinci*® Surgical System now employed in cardiac surgery began in the 1980sat the NASA Ames Research Center. The goal was to develop a device chac would enable surgeons to perform surgery remote from a patient yet feel as if they were present in the OR with the on-sice surgical team. This was termed "telepresence." This work was expanded and continued at the Stanford Research Institute (SRI) into the early 90s. Additional support was forthcoming from the U.S. Army, which saw the potential benefit of bringing the expertise of a highly qualified surgeon away from the battle from into a MASH operating room. In 1995, Intuitive Surgical, Inc. was founded to continue developing the SRI device.[4,5]

THE *DA VINCI* SYSTEM

The da *Vinci* Surgical System was the culmination of these efforts. Introduced commercially in 1995 (Figure 1),45 the initial da *Vinci* robot was a major advancement in the field of surgical robotics. The robot was positioned on the right side of the patient in place of the surgeon, with three fully controllable arms ro carry instruments on shafts that were introduced into the chest (Figure 2). A range of instruments could be connected to these arms, each of which had fully mobile "wrist joints" (Figures 3 and 4). There were three small ports: one for the camera and two more for the right and left "hands." A small rhoracotomy or a 20 mm port (our preference) provided additional access for passing materials in and out of the field. The arms precisely followed the motion of the surgeon's fingers and wrists (Figure 4), making the robotic surgical procedure similar to normal surgery with regard to the basic movements involved in tissue manipulation, cutting, and sewing. The instruments were controlled by a pair of motion sensors into which the surgeon placed his thumbs and index fingers (Figure 5). These were mounted on a separate Consol where che surgeon sat to perform the operation. Foot pedals were provided to change instruments, move and focus the camera, and use electrocaucery (Figure 6). The other major advancement was a binocular optical system chat provided the surgeon with lOx

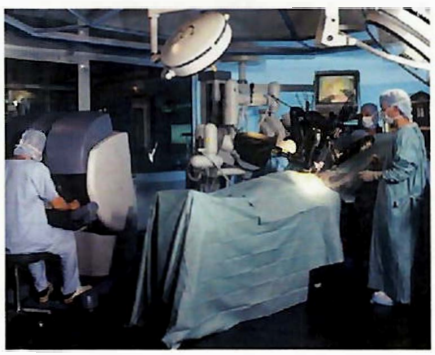

Figure 1. The original *da Vinci* Surgical System in the OR. The surgeon sits at the console. The three-arm robot is docked on the right side of the patient. preventing access for an assistant.

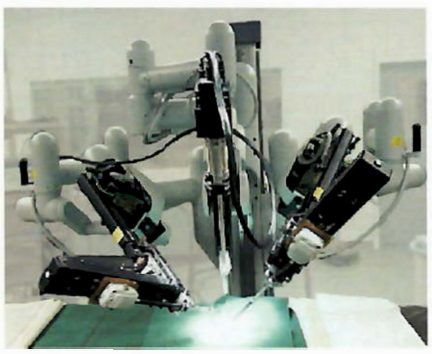

Figure 2. Original three-arm robot with the instruments and camera attached.

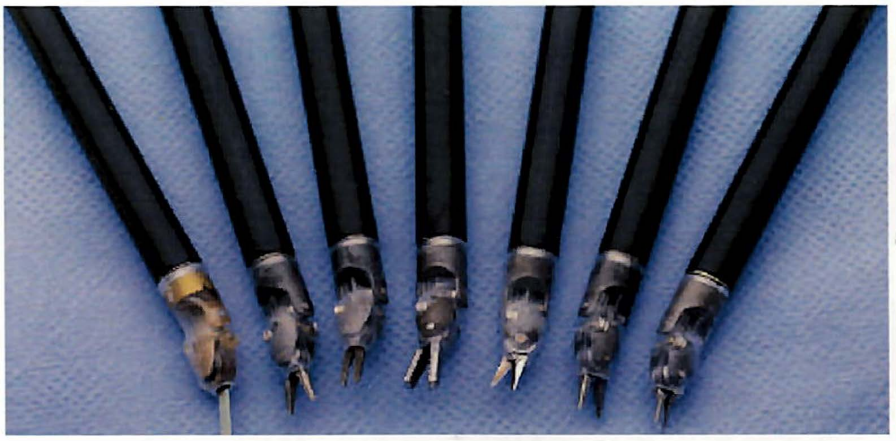

Figure 3. Types of exchangeable instruments available for attachment to the right and left arms.

Figure 4. The tips of the instruments are mounted on "wrists" that allow a full range of normal wrist motion to be duplicated.

magnification and a three-dimensional image, and thus true depth perception. However, there was no way co retract the heart during surgery.

The first successful mitral valve repair using a prototype of this machine was reported in 1998 by Or. Alain Carpentier in France.[6] Subsequently, experience accumulated rapidly with reports of a series of patients from Chitwood in 2000,[7] Mohr in 2002,[8] and Nifong and Chitwood in 2003.9

An FDA phase I clinical trial was initiated at East Carolina University under the direction of Dr. Chirwood. Following successful completion of surgery on 20 patients in this trial, a phase II multicenter trial began in 2000 and was successfully completed wich an experience of 112 mitral valve repairs.10

FURTHER DEVELOPMENT OF THE SYSTEM

These results were achieved wich the first model *da Vinci* robot with only three arms.[6,9] Considering the pioneering nature of these efforts, the results were remarkable with high reparabiliry rates and a low incidence of complications. However, this experience showed che serious limitation imposed by the inability co retract on che heart to provide good exposure. The addition of a fourth arm to the computer provided the capability to deploy a "dynamic" aerial retractor, which utilized the "wrist" technology co deploy a rwo-bladed retractor (Figure 7). This device greatly improved the surgeon's ability to visualize the intracardiac structures. le had full 360 degree motion at its wrist, and che blades could be spread or closed.

The other important breakthrough came when Dr. Douglas Murphy from Sr. Joseph's Hospital in Atlanta placed the robot on che left side of the patient with the arms reaching across to the right side of the chest. This allowed an assistant to sit on the right side of the table (Figure 8) and actively participate in the operation by passing sutures and devices in and out of the chest and providing supplemental retraction and suctioning of blood from the field. This also allowed room fur a second scrub nurse to help the assistant in addition to the first scrub nurse ac the main instrument cable. Dr. Murphy reported his initial experience with this new approach in 2006.11

THE METHODIST HEART VALVE INSTITUTE ROBOTIC CARDIAC SURGERY PROGRAM

In 2002, Intuitive Surgical invited several surgeons from The Methodist Hospital to train and become certified on the original three-arm *da Vinci* Surgical System at a training sire ac the University of Texas Medical Branch in Galveston. We all were struck by the extreme difficulty involved in using this early device and, despite completing certification, decided not to pursue its use for cardiovascular surgery at rhac rime. In 2006, I was invited to visit Dr. Murphy ac Sr. Joseph's Hospital. After observing him perform a procedure, it was apparent char robotic surgery was now feasible due to advances in che robot and Dr. Murphy's own innovations described earlier.11 A dedicated team was formed at the MDHVC consisting of a surgeon, physician's assistant, anesthesiologist, perfusionist, and three OR nurses. We all traveled together ro Spokane, Wash. for an intensive rwo-day course of instruction. Subsequently, the ream assembled rwice a week in the Methodist Institute for Technology, Innovation, and Education ac The Methodist Hospital to develop and refine our techniques on the pig-heart model. After six months, we felt we had reached a good level of proficiency, and the clinical program was initiated.

A central principle of our program was chat the patients treated robotically for micral regurgitation would receive our advanced mitral valve repair technique, che "American Correction," in an unmodified form.12,14 We believe chat we remain alone among robotic programs in having achieved chat goal. Because ofrhe unique technical demands of robotic surgery, ocher programs have attempted co simplify the procedures by using metallic clips to secure annu-

Figure 5. Using the two toggles mounted on the surgical console, the surgeon can transmit all his finger, hand and wrist movements to the instruments within the chest.

Figure 7. The dynamic left atrial retractor for cardiac retraction for use with the fourth arm of the improved *da Vinci* robot.

loplasty rings to the mirral annulus. They have resorted to doing partial ring annuloplasry instead of circumferential annuloplascy, a regressive move. The long-term consequences of these modifications to proven techniques are unknown. Many have avoided more complex mirral repairs and confined themselves to the simplest posterior leaflet resections.

RESULTS

Robotic mirral surgery using the da *Vinci* Surgical System has proven safe and effective. Ir also has some unusual features compared co conventional surgery. All reports have documented aortic cross-damp and cardiopulmonary bypass rimes rwo-to-three-rimes longer than conventional surgery using median sternocomy incisions.[15, 17] Despite che longer cardiac ischemic times, recovery of cardiac function has been excellent. This may be due to the fact that rhe heart is not manipulated, and the sustained cooling of the heart fully enclosed in the chest may also provide superior myocardial protection. After our initial experience, overall operative rimes are routinely in the range of open surgery. Patients have had experiences similar to conventional surgery in the first few days after the operation. However, from che end of the first week, rhe robotic patients experience a remarkably rapid return to unrestricted activity such as driving and physical work compared to patients with median sternotomies (Figure 9). The cosmetic results are excellent, especially for women.

This type of surgery requires institution of perfusion via the common femoral artery and vein. All patients undergo screening of their arterial tree by CT angiography. The presence of arheroscleroric disease is considered a concraindication because of the risk of cerebral embolism or retrograde aorric dissection. Ocher relative contraindications include advanced age, very shore or tall individuals, and significanc obesity.

Previous reports have documenced low morbidity and mortali$_{ty}$ in these selected series of pacients.[7-11] Of a personal experience of 1,150 mitral valve repairs, 35 have now been performed roborically. There has been no mortaliry, and a stroke in one patient has been the only serious complication. In our earliest experience, five patients required conversion to either sternoromy or right thoracotomy due to prolonged operative rimes, severe adhesions, or persistenc bleeding. All repairs have been successful and no reoperations have been required.

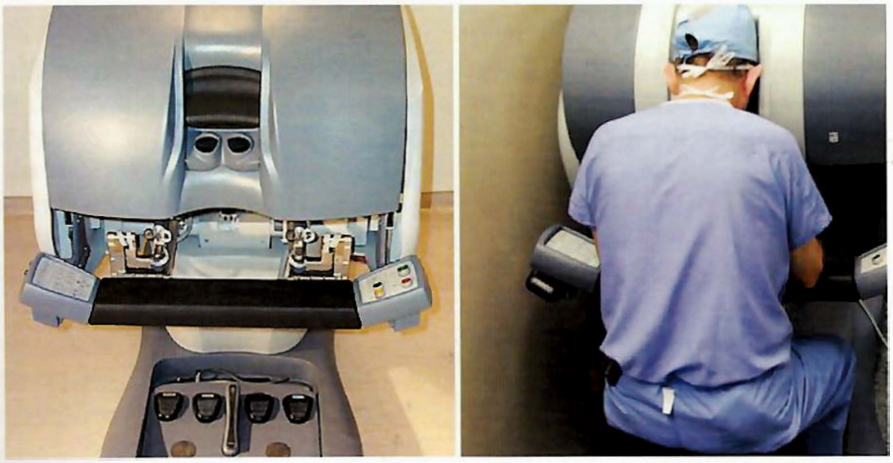

Figure 6. The surgeon's console provides the mounting for the binocular eyepieces, (top), the right and left hand toggles and machine control buttons (middle), and foot pedals (bottom).

CONCLUSION

The current da *Vinci* system provides a useful alternative to the conventional median sternotomy approach for mitral valve repair in selected patients. The main disadvantages of the current system are that it requires a significant commitment on the part of the hospital to provide a specialized team to participate in all the surgeries, and surgeons

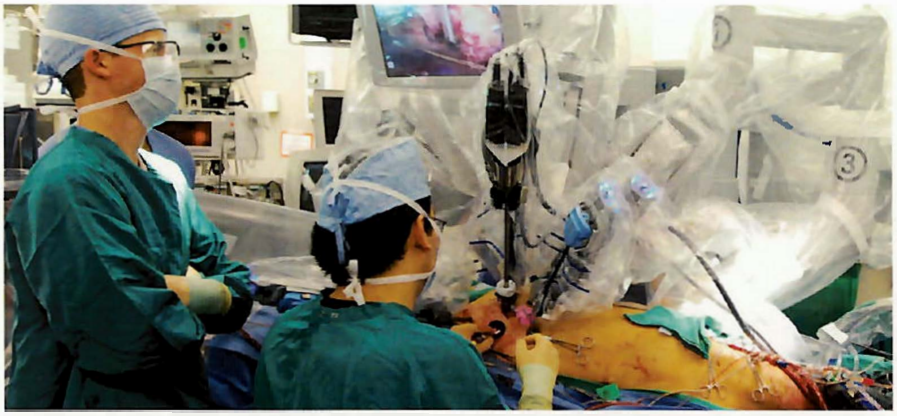

Figure 8. The four-arm robot is positioned on the left side of the patient. An assistant and nurse can work on the right side of the chest through the 20 mm working port. The assistant has his own monitor in which the same view seen by the surgeon is displayed.

Figure 9. This 52-year-old man spent his sixteenth postoperative day fishing in the Gulf of Mexico with no restrictions.

find it difficult co master. Many centers have tried it and then abandoned it. Some surgical leaders are pessimistic about the furn re o f this field.[18].[19] We feel it provides definite advantages for properly selected patients. We have also used it to resect aerial myxomas, and ochers have found it a simple way to close atrial sepcal defects.[20].[21] It has now become feasible to schedule multiple cases in the same day to follow the robotic case. We believe that it represents the future direction o f cardiac surgery. It is worth the effort, and our patiencs love it.

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