Robotic arrhythmia surgery and resynchronization

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Abstract

Over the last decade, significant technological advancements have occurred in cardiac surgery. One such breakthrough has been the use of robotic telemanipulation systems, which allow the surgeon to perform cardiac surgery through a minimally invasive approach. As a result, surgery for atrial fibrillation and resynchronization therapy for congestive heart failure have been increasingly incorporated into the surgeon’s armamentarium. © 2004 Excerpta Medica, Inc. All rights reserved.

With the advent of laparoscopic procedures in the late 1980s, there has been a dramatic increase in the number of minimally invasive surgical procedures performed. More recently, this paradigm shift has also affected cardiac surgery, as technological advancements have continued to occur. One of the most significant tools that has been developed and applied to cardiac surgery is the computer telemanipulation system known as da Vinci (Intuitive Surgical, Inc., Sunnyvale, CA).

The da Vinci system comprises a surgeon console, an instrument cart, and a visioning platform. The console is removed physically from the patient and allows the surgeon to sit comfortably, resting his or her arms ergonomically with head positioning in a 3-dimensional vision array. Digital images are translated to analog natural depth perception with high-power magnification (×10). Analog surgeon hand motions are registered through sensors in digital memory banks. Concurrently, these data are transferred to an instrument cart, which converts them into synchronous surgical executions in the “end-effector” instruments. Every analog finger movement, along with inherent human tremor at 8 to 10 Hz/sec, is converted to binary digital data, which are smoothed and filtered to increase microinstrument precision. A clutching mechanism allows constant readjustment of surgeon hand positions to maintain an optimal ergonomic attitude with respect to the visual field. Robotic arms are placed through 1-cm trocars in the chest wall, allowing the surgeon to manipulate tissue in a highly constrained environment.

In the field of cardiac surgery, the enabling technology of robotics has resulted in 2 separate advantages: (1) it has made previously existing minimally invasive cardiac procedures (ie, mitral valve surgery, atrial septal defect closure, and coronary artery bypass grafting [CABG]) more accurate and more easily learned, and (2) it has allowed for the creation of new minimally invasive procedures that did not exist before the advent of robotics.

Minimally invasive arrhythmia surgery has had both its roots and its growth intertwined with the development of robotics. This review summarizes the impact of robotics on the development of new surgical procedures associated with atrial fibrillation (AF) surgery and cardiac resynchronization.

Minimally invasive atrial fibrillation surgery

AF is the most common cardiac arrhythmia, with a prevalence of nearly 0.5%. On average, 10% to 12% of octogenarians have this arrhythmia, and a total of >2 million Americans are affected [1]. Moreover, these numbers are expected to rise as the population ages. One of the most effective therapies developed for the treatment of AF is the Cox-Maze procedure, which was initially described by Cox and colleagues [2]. In this surgical procedure, right and left atriotomies are combined with cryoablation to interrupt reentry circuits and reestablish normal sinus rhythm. Unfortunately, this procedure is invasive, requiring a median
sternotomy with cardiopulmonary bypass and cardioplegic arrest. Although outcomes are excellent, the complexity of this operation, increased time on cardiopulmonary bypass, and risk of bleeding have tended to dissuade surgeons from its application, particularly in patients who require concomitant valve surgery. As a result, alternative, less invasive methods have been sought to perform surgery for AF. As our understanding of AF evolves, we have come to realize that a certain population of patients with AF can be successfully treated with more limited procedures aimed at the electrical isolation of discrete atrial regions, including the pulmonary veins [3]. Over the past few years, surgeons have performed AF ablation procedures during concomitant cardiac surgical procedures, most commonly with mitral valve surgery [4,5]. Furthermore, reports have been published on various lesion sets using a variety of energy sources during minimally invasive cardiac surgery.

Numerous groups have demonstrated the safety and efficacy of minimally invasive mitral valve surgery [6,7]. As technologies such as radiofrequency (RF), cryotherapy, and microwave have evolved and become legitimate energy sources, new handheld and flexible devices have also been created that enable them to be used in a minimally invasive setting (Fig. 1). As a result, the surgical treatment of AF has increased, particularly when combined with mitral valve surgery. However, a continued concern with performing AF surgery through a small incision is the inability to properly create all the necessary lesions using current technology. Nevertheless, Akpinar and associates [8] have described 33 patients who underwent mitral valve surgery and RF ablation (Medtronic, Inc., Minneapolis, MN) through a 4- to 6-cm right minithoracotomy using video assistance and a handheld unipolar pen device. This device is pliable enough to allow sufficient endothoracic movement to perform precise ablation lines through a limited incision. Left-side lesions and, if necessary, right-side ones were created as well. Typically, left-side lesions involved isolating the left atrial appendage with an ablation line toward the left pulmonary vein box lesion. Furthermore, a connecting lesion between the 2 box lesions around both sets of pulmonary veins with an ablation line toward P2,3 of the mitral valve (and an ablation line toward the reflection of the coronary sinus) was also created. There was 1 death at 27 days (3% mortality), and 1 patient required a pacemaker. At discharge, freedom from AF was 81% and 90% at 1 year. Another study from Mohr and coworkers [4] reviewed a total of 133 patients who underwent mitral valve surgery and AF ablation (Osypka, GmbH, Grenzhach-Wyhlen, Germany) involving the mitral annulus and the orifices of the pulmonary veins. At discharge, 92% (68 of 74 at follow-up) of patients who underwent minimally invasive surgery for AF alone were in normal sinus rhythm. At 1 year, 15 of 16 patients (93%) were in normal sinus rhythm. There were no deaths in the group that underwent surgery for AF alone.
Furthermore, the authors concluded that “the avoidance of a sternotomy has largely increased patient acceptance of surgical treatment for isolated AF and is the major reason for increased patient referral for antiarrhythmic surgical treatment” [4].

Moving a step further, there have been reports of completely endoscopic approaches to treat AF alone. Saltman and colleagues [9] published a case report that described complete pulmonary vein isolation performed entirely through a thoracoscopic approach on a beating heart in a patient with a history of paroxysmal AF. Using 2 5-mm ports and 1 10-mm port on both the right and left chest, they were able to place a Flex 10 microwave probe (AFx Inc., Fremont, CA) around the pulmonary veins and create a “box” lesion around all the veins (Fig. 2). In addition, the left atrial appendage was amputated with a stapler. No other lesions were created; however, at the 1-month follow-up, the patient was in normal sinus rhythm. Besides this, the group from Columbia University in New York City has applied robotic technology to minimally invasive AF surgery. Using the da Vinci system, cardiac dissection was accomplished, as was exposure and resection of the left atrial appendage. These procedures have been performed in animal models and have begun to be applied clinically as well [10]. Currently, 62 patients have undergone combined AF and mitral valve surgery, half with da Vinci and half with robotic, voice-activated video-assistance (Automated Endoscopy System for Optimal Placement [AESOP]; formerly Computer Motion, Inc., Goleta, CA, now operated by Intuitive Surgical). A variety of energy sources has been used, including RF, microwave, and cryoablation. Most commonly, we perform an endovascular box lesion around the pulmonary veins with a lesion directed at the P3 segment of the mitral valve. Operative mortality was 4.8%, with 65% of patients in normal sinus rhythm at the time of discharge. A total of 27% of patients remained in AF, and 8% required pacemaker implantation at the time of discharge. Robotic video assistance with AESOP has also been used to perform AF surgery on 10 patients. These patients underwent a 4-cm right thoracotomy and were placed on cardiopulmonary bypass with cardiac arrest (Fig. 3). Typically, left-side endovascular lesions were created using cryotherapy. At the time of discharge, 70% of these patients were in normal sinus rhythm.

Ventricular dysynchrony and biventricular pacing

Approximately 30% of patients with heart failure exhibit significant ventricular dysynchrony secondary to alterations in intraventricular conduction, as manifested by a widened QRS complex on a 12-lead electrocardiogram [11]. This ventricular dysynchrony further impairs the already depressed cardiac contractility of patients with both idiopathic and ischemic cardiomyopathies. The altered contraction pattern may worsen mitral regurgitation and is associated with an increased risk of death [12–14]. Regional abnormalities in the timing of left ventricular (LV) contraction are the primary causative factor for dysynchrony (intraventricular dysynchrony). However, alterations in the timing between LV and right ventricular (RV) contraction also may partially exacerbate heart failure symptoms (interventricular dysynchrony). Prospective randomized trials have demonstrated improvements in ventricular function, exercise capacity, and quality of life among patients undergoing ventricular resyn-
chronization therapy via LV and RV pacing [15–18]. Transvenous biventricular pacing is performed by placing standard endocardial right atrial and RV leads. The LV lead can be inserted percutaneously by taking advantage of the fact that the coronary sinus is the major venous drainage site for the coronary arteries that supply the left ventricle. By cannulating the orifice of the coronary sinus in the right atrium, an epicardial pacing lead can be fed into the coronary sinus venous tributaries and onto the surface of the left ventricle. However, technical limitations due to individual variations in coronary sinus and coronary venous anatomy result in a 10% to 15% failure rate of LV lead placement [17,18] when performed in this manner. Lead dislodgement contributes to an additional 5% to 10% late failure rate of LV lead capture [19].

Although response can be dramatic from percutaneous biventricular pacing, the overall response rate in all previous prospective randomized trials ranges from 69% to 72%. The
reason for this incomplete response is likely multifactorial and remains incompletely defined. Nonetheless, it does appear that appropriate LV site stimulation remains critical for complete LV resynchronization [20,21]. Optimal resynchronization is most likely to be achieved by pacing posterolateral sites on the left ventricle, and more anterior sites may actually worsen resynchronization [21]. LV leads placed by percutaneous coronary sinus cannulation are inserted in anterior sites (33%), lateral sites (33%), and posterolateral sites (33%) in fairly equal distribution and are primarily determined by the presence or absence of appropriate coronary sinus venous tributaries.

When percutaneous lead placement is unsuccessful, rescue therapy for these frail patients has typically involved LV epicardial lead placement through a limited anterior thoracotomy. This approach is limited both by its morbidity and its access to the posterolateral surface of the left ventricle. Our group and others developed the robotic, totally endoscopic approach initially as a minimally invasive option for posterolateral lead placement in patients with a failure of coronary sinus cannulation [22,23]. However, access to the entire LV surface also provides a unique opportunity for detailed LV mapping and precise site-directed resynchronization.

**Robotically assisted left ventricular lead placement: the posterior approach**

Whereas most robotic cardiac surgery is performed in either a right anterolateral thoracotomy position (atrial septal defect closure, mitral valve repair, AF surgery) or a left anterolateral thoracotomy position (robotically assisted CABG), robotic approaches to resynchronization are typically best performed in the full posterolateral thoracotomy position [24]. The reason for this is 3-fold: (1) the most common optimal position for LV lead placement is along the posterolateral surface; (2) massive cardiomegaly in the majority of these cases leaves the posterior working space as the only reliable entry into the chest; and (3) the posterior space allows the easiest entry into both the pleural space and the pericardial space in the setting of cardiac reoperation.

All operations are performed under general anesthesia with selective right-lung ventilation. Transesophageal echocardiography is performed routinely. The patient is placed in the full posterolateral thoracotomy position, and a camera port is placed in the seventh intercostal space in the posterior axillary line. The left and right arms are positioned in the ninth and fifth intercostal spaces, respectively (Fig. 4). The left chest is insufflated at a pressure of 8 to 10 mm Hg. A 10-mm working port is inserted posterior to the camera port and is used for the introduction of the lead and sutures as necessary. The pericardium is then opened posterior to the phrenic nerve, and the first and second obtuse marginal vessels are identified (Fig. 5). The pericardium is then retracted posteriorly with sutures that are brought out of the working port.

A pacing lead is then introduced into the chest through the working port. The LV surface can be mapped for threshold, resistance, and lateness within the native QRS complex. Typically the most advantageous position for insertion is midway between the base and the apex, between the first and second obtuse marginal vessels. The robotic arms are used to fix the lead to the LV surface either by screw-in fixation or suture technique, depending on the lead used. To maximize working space, ventilation is held during lead implantation and knot-tying. This lead is capped and delivered into the chest. A second lead is then delivered through the working port and is again fixed to the LV surface near the second obtuse marginal. The second lead can also be placed by the table surgeon as a screw-in lead if a convenient angle to the working port exists. The pericardium is then closed over the leads in all cases to aid in permanent lead fixation.

The first lead is then retrieved from the chest through the right arm port. Both leads are then tunneled to a counter incision in the axilla. A chest tube is placed through the left arm port for evacuation of air and is removed before leaving the operating room. The port sites are closed, and the patient is repositioned in the supine position. Both LV leads are retrieved into the pocket and retested for threshold. The LV lead with the best threshold is used as the pacing lead and is connected to the device. The second lead is secured to the fascia and is left-capped in the pocket as a backup lead for future use if necessary. If a right-side pacing or defibrillat-
ing lead is required, it is inserted at this time and the leads are connected to either a biventricular pacing generator or to an implantable cardioverter defibrillator/biventricular pacing device.

Using this technique, our group has had no conversions to thoracotomy in 35 patients undergoing this procedure. This included 15 patients who had undergone prior heart surgery and 4 patients who had undergone multiple prior cardiac operations [25]. Furthermore, average LV end-diastolic diameter in these patients was 6.8 ± 1.4 cm, indicating significant cardiomegaly in most patients. In Jansens and colleagues’ [26] report of 50 patients, the modified anterolateral thoracotomy position employed was comparable to that used for robotically assisted CABG. This group reported a 15% conversion rate using this approach owing to cardiomegaly or adhesions [26].

In summary, the posterolateral approach initially may be foreign to most robotic cardiac surgeons. However, this approach provides the most reliable entry into the chest while simultaneously allowing for complete cardiac access for mapping.

Can left ventricular mapping improve responder rate in biventricular pacing?

Initial success with the posterior approach for patients with failure of coronary sinus lead insertion led to the development of this technique as a primary modality for biventricular pacing. The potential advantage of the robotic approach over the transvenous approach is the ability to access, and therefore map, the entire epicardial surface. During our first 20 implants, our group used a technique of electrophysiologic mapping [27]. By identifying the area of latest electrical activation and pacing the left ventricle in this area, full LV resynchronization can be obtained.

Over the next 15 implants we have employed a technique of echocardiographic mapping that uses tissue Doppler imaging. This technique is able to identify the latest point of mechanical contraction along the left ventricle (Fig. 6). This allows for preoperative site localization to guide LV lead implantation. The technique can also be used to perform intraoperative stimulation-based mapping in order to more precisely define the region of optimal pacing along the posterolateral wall (Fig. 7). After lead placement, all patients have had documentation of resynchronization via tissue Doppler imaging.

Other mapping techniques have also been reported using a thoracoscopic approach. Most recently Dekker and co-workers [28] have used a conductance catheter to generate pressure-volume loops during site-based stimulation mapping in 11 patients undergoing LV lead placement via thoracotomy or thoracoscopy. These investigators concluded that to optimize cardiac resynchronization via epicardial pacing, mapping to determine the best pacing site is a prerequisite.

Our group has implanted 70 LV leads in 35 patients over a 30-month period. Statistically significant improvements in heart failure class and ejection fraction have been documented in these patients over 6 months. However, by using mapping techniques, we have been able to demonstrate an
early clinical response rate (improvement in ≥1 heart failure class) in 85% of patients [27]. In a 2-year follow-up, there have been 4 deaths (2 responders and 2 nonresponders). Of note, all patients had evidence of resynchronization after lead insertion, yet there remained a 15% nonresponder rate. In this small series, severe preoperative mitral regurgitation and LV end-diastolic diameter >8.0 cm were predictors of poor clinical response.
Summary

The use of robotics and minimally invasive technology in cardiac surgery has garnered the introduction of operations previously not thought possible. Surgery for AF has initially been combined with other cardiac procedures, specifically minimally invasive mitral valve surgery. As techniques and endoscopic technology have advanced, surgery for AF alone has increased. Initial results indicate that this is both feasible and efficacious. As long-term results are determined, AF surgery using robotics will find a niche in the surgeon’s armamentarium of treatment for arrhythmias.

In addition, robotic biventricular pacing has provided an excellent minimally invasive option for patients with a failure of coronary sinus lead insertion. The mapping techniques afforded by the robotic approach promise to improve the responder rate to resynchronization therapy. Ongoing randomized studies comparing percutaneous with robotic biventricular pacing will not only delineate the role of robotics in primary implantations but will continue to expand our knowledge regarding the evolving resynchronization therapies for heart failure.

References