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Chapter 9

Robotic Resection of Left Atrial Myxoma

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Additional information is available at the end of the chapter

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1. Introduction

1.1. General considerations

Cardiac myxoma is a benign primitive tumor of endocardial origin that occurs with an incidence of 40-50% of all detected primary cardiac neoplasms. The vast majority of them are manifest as cavitary gelatinous masses and they may have a smooth or rough surface or thrombus adherent. The tumor is constituted by primitive connective tissue cells form rings, cords and nests that are often associated with capillaries and they exist in a myxoid stroma that is composed of variable amounts of proteoglycans, elastin and collagen.

Approximately 90% are solitary and pedunculated and the most common site of attachment is at the border of the fossa ovalis in the left atrium (75-85%), although myxomas can also originate from the atrial appendage, 25% of cases are found in the right atrium and up to 7% arise in the ventricular cavities [1].

The etiology remains to be determined and most cases are sporadic. About 75% of sporadic myxomas occur in females and the mean age for these cases is 55 years. Myxomas are familial in only 5-7% of the cases, and they have atypical features such as multicentricity, atypical localization, recurrence after excision and association with Carney complex [2]. Although atrial myxomas are typically benign, local recurrence due to malignant change has also been reported [3].

The growth rate of these tumors has been cited as reaching 0.15 cm per month and the clinical presentation varies according to the size, tumor's location and mobility (depending on the extent of attachment to the interatrial septum) [4-5]. Left atrial myxomas may produce symptoms by mechanical interference of blood flow across the mitral valve or pulmonary venous drainage, symptoms associated with embolization, constitutional symptoms and arrhythmias. Embolism is a major feature of cardiac myxomas, with systemic embolism

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occurring in 30% to 40% of patients with a left atrial tumor, although in general terms, the site is dependent upon the location (left or right atrium). Signs of heart failure with pulmonary congestion or pulmonary embolism are presented in 22% and 20% of patients respectively, indicating a high-risk situation [6]. Sudden death may occur in 15% patients with atrial myxomas and it is typically caused by coronary embolization or obstruction of heart valves.

In about 20% of cases, myxoma may be asymptomatic and discovered as an incidental finding by imaging techniques, such as transthoracic or transesophageal echocardiography (TEE), cardiac magnetic resonance imaging or computed tomography (CT). Cardiac imaging along with a high index of suspicion plays an important role in the diagnosis and subsequent management of patients with cardiac myxomas who can potentially benefit from surgical treatment.

Although these tumors are histologically benign, they may be lethal because of their strategic position and, after the diagnosis has been established, surgery should be performed promptly because of the possibility of embolic complications or sudden death previously described. In the past, cardiac myxoma has been generally considered a surgical emergency. However, currently it tends to be observed in a more elderly and higher risk population, often at an early stage because of the development of cardiac imaging techniques and, because of this reason, emergency surgery is not appropriate in stable forms [6]. With the exception of real emergency situations, there is no reason why surgery for cardiac myxoma should not comply with the usual recommendations for preoperative routine assessment before any form of cardiac surgery.

Long-term follow-up is recommended and annual echocardiograms are useful for early detection of recurrent tumors after surgery.

1.2. Surgical considerations

Operative resection of atrial myxoma is the treatment of choice and it is a safe procedure, with an early postoperative mortality of 2% and an excellent long-term prognosis [7].

Surgery is usually curative and includes a complete resection with adequate margin. In most cases, cardiac myxomas can be removed easily because they are pedunculated. Simple resection is justified in the most of patients, avoiding a large resection of the atrial septum below the tumor implantation, although extensive resection appears to be mainly justified in high-risk cases of recurrence, such as familial myxomas [8]. Right atrial tumors are resected through the right atrium and left atrial tumors can be removed using a trans-septal or trans-atrial approach.

Optimal operative technique emphasizes minimal manipulation of the tumor before institution of cardiopulmonary bypass (CPB) to prevent fragmentation and embolization and the tumor must be removed intact. Recurrence is possible after surgery and it can be attributed to incomplete excision of the tumor, intracardiac implantation from the primary tumor or growth of a second focus.

Traditionally, surgery for cardiac myxomas has been performed by median sternotomy, which provides a generous exposure. However, a challenge is occurring and minimally invasive cardiac surgery has grown in last decade because of the observed benefits of minimal access surgery, such as reduced surgical trauma and decreased pain. Moreover, the advancements in three-dimensional (3D) video and robotic instrumentation have progressed to a point where a large number of cardiac procedures (including myxomas excision) are feasible by specially trained cardiac surgeons.

Currently, resection of atrial myxomas can be performed through small port sites with enhanced technological assistance rather than a traditional median sternotomy. The application of robotic telemanipulation systems enables the surgeon to provide the most effective and least invasive treatment option available for this condition, offering all the potential benefits of a minimally invasive procedure, including smaller incisions with minimal scarring, less trauma (including less pain and less bleeding), a decreased risk of infection, shorter hospital stay and recovery, and a quicker return to daily activities [9].

Removal of left atrial myxomas under robotic assistance has demonstrated to be safe and efficient with no limitations to resection of the tumor, allowing the surgeon generous access to the heart and surrounding structures. It can be done with reasonable cross clamp and perfusion times, conversions to open surgery are uncommon and excellent mid-term results can be achieved by well-trained surgical teams.

With this relatively new technology being more widespread, it is important to know about standard surgical procedure for resection of left atrial myxomas under robotic assistance, as well as acknowledge any related complications for this procedure.

2. Historical background

Prior to advances in robotic technology, a variety of smaller incisions were developed for endoscopic heart operations in the mid-1990s, such as coronary artery bypass grafting or valve surgery [10-11]. In 1998, Carpentier [12] and Mohr et al [13] performed endoscopic mitral procedures and coronary artery bypass grafting using peripheral perfusion and endoaortic cross-clamp techniques.

Minimally invasive approaches have also been applied for cardiac myxomas resection, such as right parasternal or partial sternotomy with standard cardioplegic techniques [14], right submammary port-access method with antegrade cardioplegia and ascending aortic balloon occlusion [15] or right submammary incision with femoro-femoral bypass and nonclamped ventricular fibrillation [16]. In general terms, video-assisted resection by using these approaches has been successfully described, providing satisfactory exposure for atrial and ventricular myxomas [17-19].

Nevertheless, endoscopic instrumentation (with four degrees of freedom) reduces the dexterity needed for delicate cardiac surgical procedures, along with the loss of depth perception by using two-dimensional viewing systems. Robotic technology provides a solution to these problems and it has been born to facilitate cardiac procedures, initially by

providing enhanced endoscopic camera control and in the recent decade, by allowing the manipulation of surgical instruments through thoracoscopic port incisions.

In 2001, Torracca et al [20] first reported a series of atrial septal defect closure using robotic device in Europe and, in the last decade, surgical telemanipulation systems have expanded to coronary revascularization, left ventricular lead implantation, congenital heart surgery, valvular surgery, arrhythmia procedures (Cox-Maze III) and cardiac tumors. The American Heart Association identified robotic surgery as one of the top 10 research advancements of 2002 [21].

The first group of robots consisted of assisting tools that were used for holding and positioning the endoscope during surgery, such as the robot AESOP (Automatic Endoscopic System for Optimal Positioning; Computer Motion Inc, Goleta, CA) [22], although cardiac procedures have not obtained any relevant benefit from this system.

The second group comprises surgical telemanipulation systems, which are under the control of a surgeon who works at the console. The development of telemanipulation systems was performed in the late 1980s: the da Vinci Surgical System (Intuitive Surgical Inc, Sunnyvale, CA) and the ZEUS robotic system (Computer Motion Inc, Goleta, CA) [23]. In 2003, Intuitive Surgical and Computer Motion agreed to merge and the ZEUS system was phased out in favor of the da Vinci system.

The advantages of the da Vinci system include 3D-viewing system, the robotic wrist and it can provide up four robotic arms. These characteristics seems to be more advantageous in mammary artery harvesting for coronary artery bypass grafting, but are also interesting features for a number of cardiac procedures, such as atrial myxomas excision.

The initial experience with robot-assisted excision of left atrial myxomas has been reported using the da Vinci Surgical System and it is the most widely used for cardiac procedures. It comprises three components: a surgeon's console, an instrument cart (including two robotic operating arms with a diameter of 11 mm, their articulating instruments, the camera arm and an optional fourth arm) and a 3D-visioning platform for enabling natural depth perception with high-power magnification. The surgeon is seated in front of the computer console and operates the robotic arms while viewing the surgical field in 3D-image. The finger and wrist movements are registered digitally and the dual master controls translate them to the operation being performed on the patient with the surgical robotic arms, allowing various types of movements including rotating, sliding and squeezing. "Wrist-like" instrument articulation emulates the surgeon's actions at the tissue level, and dexterity becomes enhanced through combined tremor suppression and motion scaling. It minimizes opportunities for human error when compared with traditional approaches.

3. Application area

As mentioned above, robotic-assisted cardiac surgery using the da Vinci Surgical System has allowed performing selected coronary artery bypass surgery, mitral valve repair or replacement, atrial and ventricular septal defect repairs [24-25] and most recent totally endoscopic removal of atrial myxomas. Isolated cases of removal of uncommon cardiac tumors using

robotic techniques have also been reported, such as aortic valve papillary fibroelastoma, with excellent results [26].

The first successful application of robotic technology for totally resection of left atrial myxoma with da Vinci Surgical System was reported in 2005 by Murphy and associates [27], through transeptal and left atrial approaches. In 2008, at Beijing (China), Changqing Gao et al reported a new successful resection of left atrial myxoma by using this technology [28]. To date, approximately 30 cases of cardiac myxomas excision under robotic assistance have been described [28-29] and this author have reported the largest single institution series of robotic resection of left atrial myxomas, with 19 consecutive patients undergoing this procedure with no operative deaths or strokes [30] and follow-up echocardiograms up to 18 months noted no recurrence or atrial septal defect.

To minimize patient risk in this setting, cardiac surgeons should have previous experimental training in robotic techniques (in vivo animal laboratory work and human cadavers can be used) and they must demonstrate clinical proficiency to operate the robotic equipment per FDA (Food and Drug Association) approved company testing.

4. Surgical procedure

4.1. Anesthetic considerations

Some anesthetic considerations must be done. Cardiac anesthesiologists must be trained in order to recognize potential complications and challenges posed by the use of robotic systems, such as long surgical times or problems with single-lung ventilation. Management of TEE and minimally invasive percutaneous CPB management are also desirable for the anesthesiology team.

Patient monitoring consisted of standard electrocardiography, oxygen saturation, end-tidal CO_2, bispectral index, urine output and nasopharyngeal and bladder temperatures. Arterial blood gas analysis for acid-base status, oxygen and CO_2 arterial pressures, hematocrit, haemoglobin, potassium and ionized calcium is performed during the procedure as needed.

TEE is a valuable adjunct in robotic cardiac surgery. During establishment of peripheral CPB, TEE is used to guide placement of the cannulas in the inferior and superior venae cavae and ascending aorta. When the midesophageal bicaval view (80-110º) is obtained, the venous cannula must be identified as two parallel lines surrounding the fluid-filled lumen. As example, the midesophageal aortic valve long-axis view (120-160º) can be obtained to assess the placement of the endoclamp for aortic occlusion when it is used.

After weaning from CPB, TEE is also used to evaluate the completeness of air removal. TEE identifies patients at risk for significant complications before they leave the operating room [31].

Other special anesthetic considerations required for robotic cardiac surgery, in order to maintain stable hemodynamic and oxygenation, are single-lung ventilation and carbon dioxide insufflation [32]. It may reduce cardiac output and result in hypercapnia and hypoxia. These characteristics are especially relevant for patients with chronic obstructive pulmonary

disease because of the creation of a transpulmonary shunt through the collapsed lung, worsening arterial oxygenation.

An active communication between anesthesiologist and surgeon is key to ensure the success, timely execution and safety of cardiac robotic surgery.

4.2. Surgical approach

Robotic resection of left atrial myxomas is considered a good right-sided atrial approach with excellent visibility, which includes an adequate exposure of the attachment point of the tumor, excision of tissue margins and debridement, meticulous removal without fragmentation and a careful examination of intracardiac chambers. To date, robotic enhancement has been used to perform portions of intracardiac procedures via thoracotomy incisions as well as the application of this technology for totally endoscopic open heart surgery. For removal of left atrial myxomas, both approaches have been reported.

In first place, robotic arm placement and specialized equipment must be reviewed with the operating room staff.

Then, the patient is anesthetized and intubated with a dual-lumen endotracheal tube, allowing single left-lung ventilation; the lung needs to be deflated on the side of the chest that the robot is entering so visualization of the heart is not obstructed. Arterial pressure monitoring line and central venous catheter are inserted and transesophageal echocardiographic (TEE) study is performed. If an endoclamp for aortic occlusion is used, bilateral radial arterial catheters are required to monitor correctly balloon placement.

As there is limited access to the heart for direct defibrillation, external defibrillator pads are required.

The patient is positioned with the right chest elevated 30°–45° and the right arm positioned along the right side. This position permits direct access to the thoracic cavity and decreases the risk for brachial plexophaty. Patient positioning is of fundamental importance in decreasing patient-robot conflict during surgery, defined as a limitation in the free movement of the robot's telemanipulated arms by interference with the patient's body.

Percutaneous cannula (15-17 F) is inserted through the right internal jugular vein for drainage from superior cava vein under TEE assistance *(Figure 1)*.

After sterile preparation and draping the patient, a transverse right groin incision is made and femoral artery and vein are dissected and prepared for cannulation *(Figure 2)*.

When totally robotic resection of left atrial myxoma is performed [28], the da Vinci endoscope is inserted through a 12-15 mm port in the fourth intercostal space (ICS), approximately 2-cm lateral to the midclavicular line. The camera is then introduced through the endoscope port into the pleural space and a small working port (2 cm) is created in the same ICS upward from the camera port.

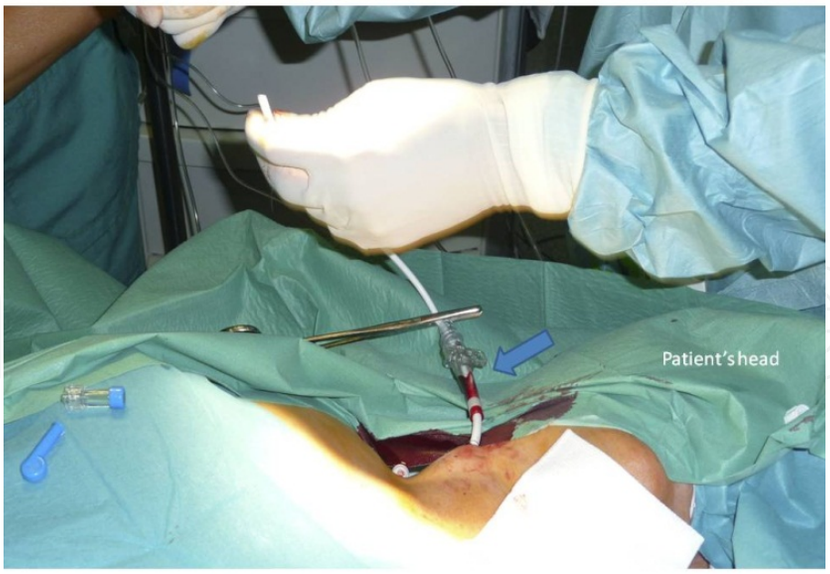


Figure 1. Percutaneous cannula through the right internal jugular vein. This venous cannula is advanced into the right atrium.

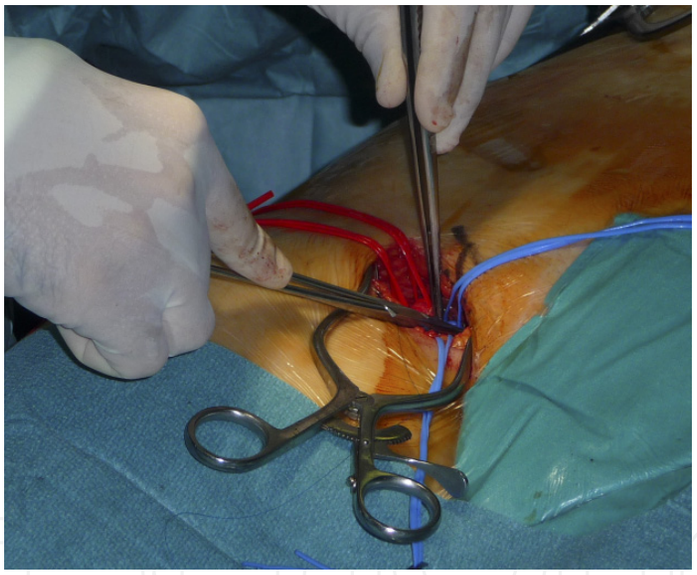


Figure 2. The common femoral artery and femoral vein are dissected free from the surrounding structures. Both are dissected circumferentially and vessel-loops are placed for bleeding control.

Then, the da Vinci instrument arms are inserted in their respective ports through three 1-cm trocar incisions in the right side (anterior axillary line): the right instrument arm is positioned 5 cm lateral to the working port in the 6th ICS; the left arm, medial and cephalad to the right arm in the 2nd or 3rd ICS; and the fourth arm trocar is placed in the midclavicular line in the 5th ICS (to achieve an optimal interatrial exposure). For this approach, no rib-spreading retractor is necessary.

In selected cases, this approach can be modified and removal of giant left atrial myxomas is performed via thoracotomy incision under robotic assistance *(Figure 3)*.

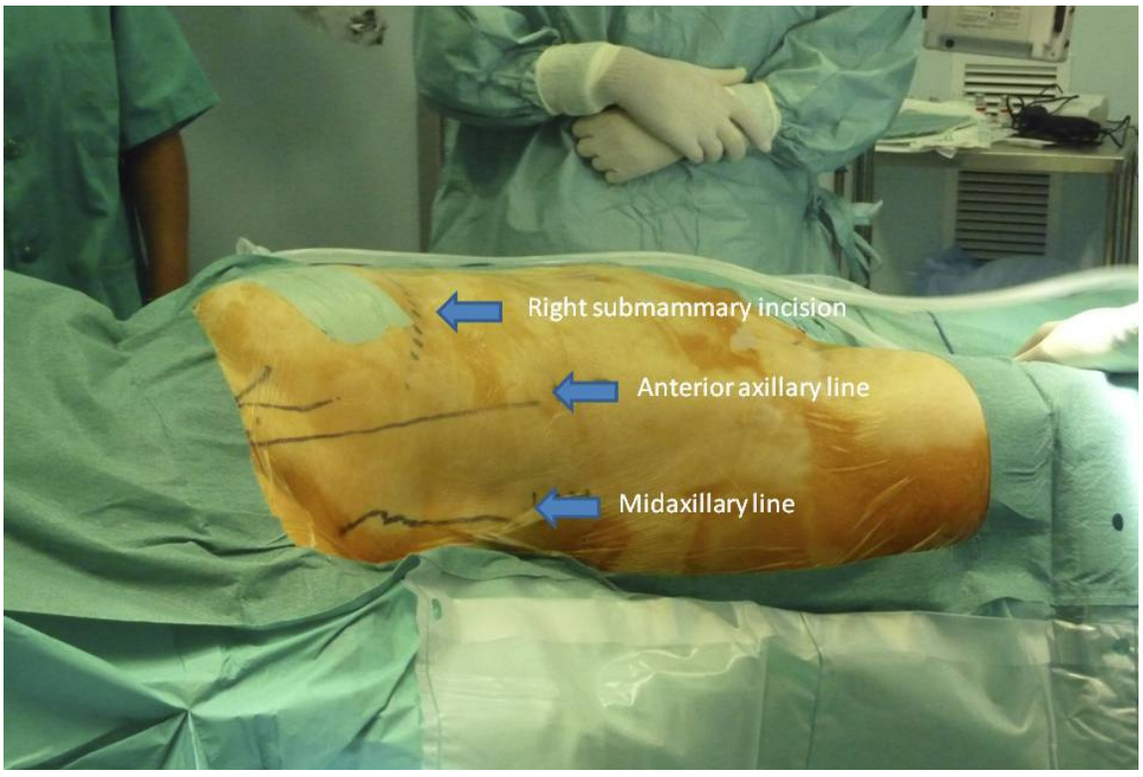


Figure 3. Positioning of the patient when anterolateral thoracotomy under robotic assistance is the selected approach.

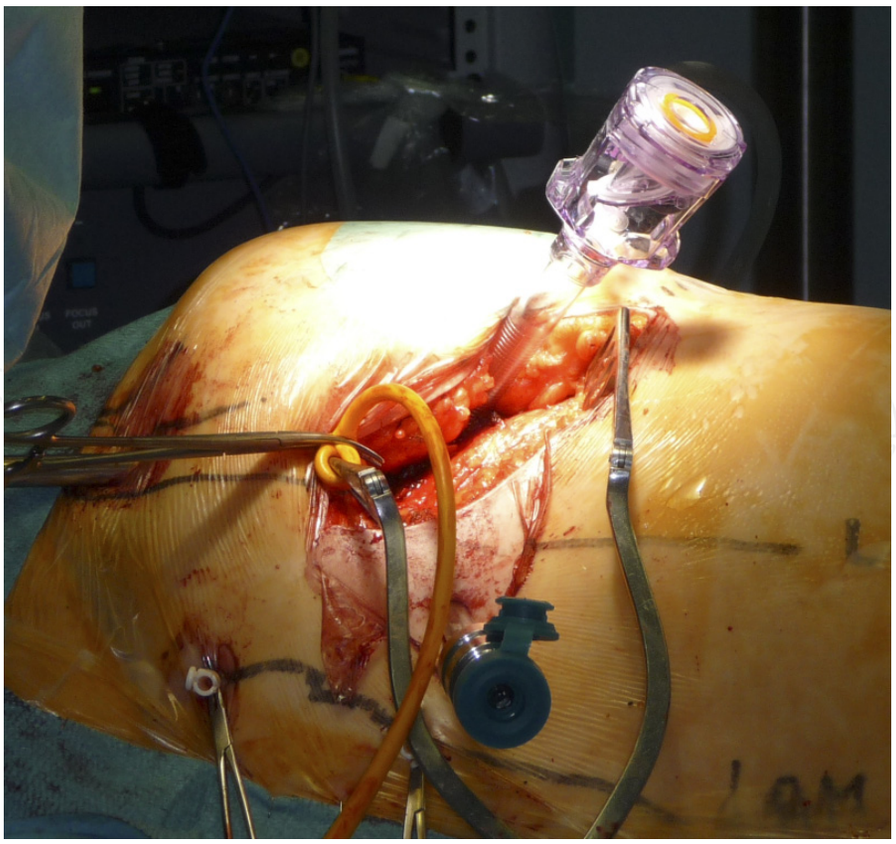


Figure 4. Anterolateral thoracotomy. The da Vinci endoscope is introduced through the incision.

For these cases, a right submammary skin incision (about 9-10 cm) is made with the aim of reaching the chest wall, retractor is used and the camera is then introduced *(Figure 4)*. This camera port and the working port can be fused together to be a new work-port for the intracardiac procedure.

For both approaches, after port insertion, the entire operation (including pericardiotomy, atriotomy and myxoma excision) are performed with robotic assistance.

After the selected approach has been initiated, the patient is heparinized and peripheral cannulation is performed as previously described for minimally invasive cardiac surgery [33] (bicaval venous drainage through the jugular and femoral cannulas along with arterial perfusion through femoral cannula placed into the ascending aorta). The sizes of the cannulas are determined by the patient's body surface area and circulatory requirements. Cannulas are inserted over the Seldinger guidewire, are confirmed to be in the correct placement by TEE and the guidewire is then removed.

After the da Vinci endoscope and instrument arms have been inserted *(Figure 5)*, pleural adhesions are rule out, the right pleural space is insufflated with carbon dioxide to create working space (intrapleural pressure of 5 to 10 mm Hg) and, via 4 port incisions and a working port, this procedure can be completed with a 30° angled endoscope facing upward with the da Vinci Surgical System.

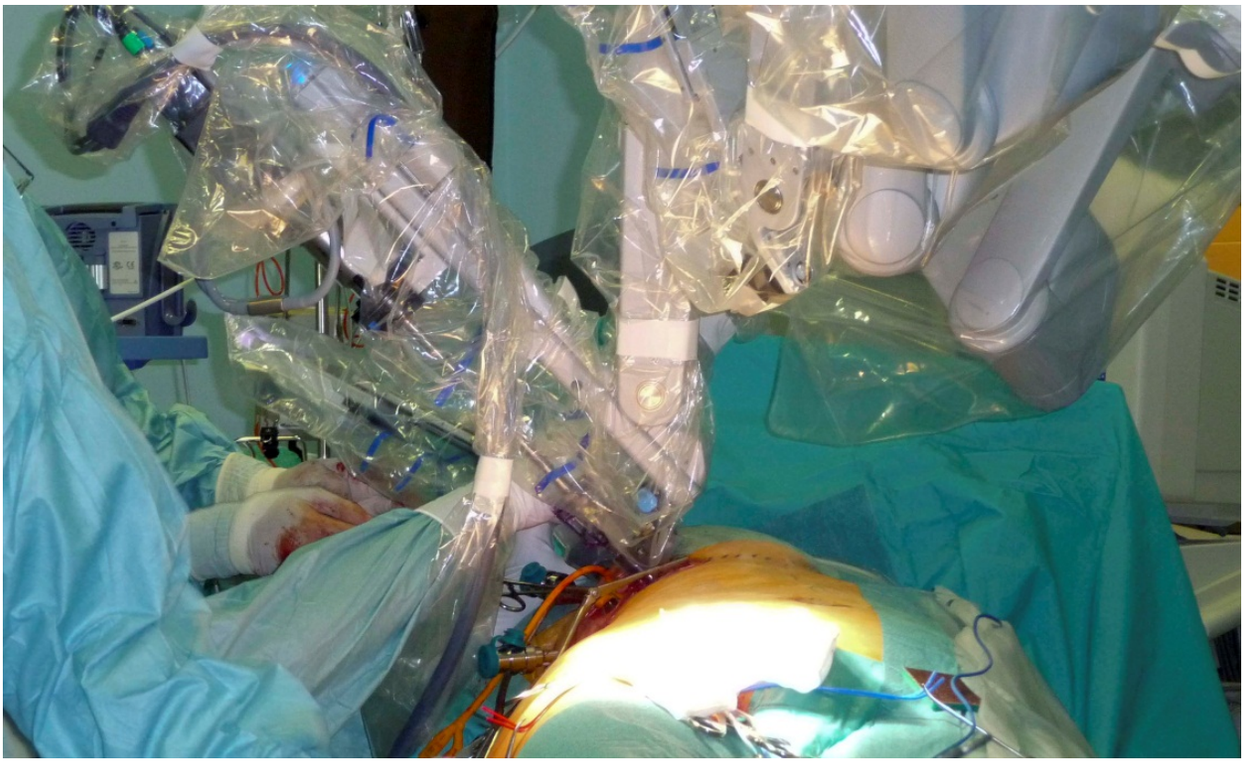


Figure 5. View of the da Vinci robotic system's arms positioned in the patient's chest, for robotic assistance when a thoracotomy incision has been made.

The operating surgeon is positioned at the operative console and begins the intrathoracic portion of the operation by controlling the robotic camera and surgical instrument arms. The patient-side assistant changes instruments, supplies and retrieves operative materials.

The pericardium is opened with direct visualization of the phrenic nerve (3-4 cm anterior to the nerve) and it is excised (for a possible atrial septal reconstruction). Traction sutures are placed low on the pericardium on the right side (usually three sutures are necessary for better visualization of the septal rim of the left atriotomy). This maneuver enables an optimal exposure of the left atrium.

The venae cavae are encircled with linen tapes and caval snares are placed using a long-tip forceps and passed out of the working port. Total CPB is started. Usually, CPB is established at 26 °C through peripheral vessels, using femoral arterial inflow and kinetic venous drainage through a femoral (21–23 Fr) and right internal jugular vein (15-17 Fr) cannula.

The management of extracorporeal circulation for robotically assisted cardiac surgery has suffered modifications from the standard procedures. As mentioned above, for most of the patients, extracorporeal circulation is established through a femoral arterial cannula, femoral venous cannula and right internal jugular venous cannula, with vacuum-assisted venous drainage and continuous blood gas monitoring. The femoral artery needs to be able to fit this cannula and provide adequate flow. A learning curve of perfusion technique is necessary for the establishment of this type of extracorporeal circulation system and adequate communication between the surgical team is essential.

There are different venous cannulas for peripheral cannulation in robotic surgery, such as 25 F Quickdraw (Edwards LifeSciences, CA, USA) or 21-23 F cannula (Medtronic, Inc, Minneapolis, Minnesota, USA). For arterial cannulation, different cannulas can be used. For endoaortic clamp, a 21-23 F EndoReturn cannula (Edwards LifeSciences, Irvine, CA, USA) is available. Any standard femoral access cannula may be used if cross-clamping is going to be achived. Finally, a remote access perfusion cannula has been developed to avoid both retrograde perfusion and cross-clamping (RAP Cannula, Estech Inc., Danville, CA, USA).

Aortic occlusion can be performed with a transthoracic cross-clamp, such as Chitwood (Scanlan International, Minneapolis, Minnesota, USA) developed by Chitwood, Elbeery and Moran [34], which enables central aortic occlusion without the use of an intra-aortic balloon. It is inserted through the 3rd or 4th ICS in the midaxillary line and is applied across the aorta. It is usually used for patients in whom use of endoaortic occlusion balloon is not indicated due to extensive calcification or tortuosity of aorto-iliac axis or aneurysmal disease.

When endoaortic clamping is going to be achieved, the aortic balloon is positioned in the ascending aorta (1 cm above the sinotubular junction) by TEE assistance. The aortic balloon is then inflated to a pressure of 250 to 300 mm Hg. The myocardium is protected with antegrade cold blood cardioplegia delivered through the distal lumen of the balloon, or directly through the second ICS working port with a 14 F angiocatheter if cross-clamping is used. Then, the heart is arrested. Repeat doses can be given when necessary during the procedure. Currently, the cardioplegia cannulas used in this setting are the dual-lumen

antegrade cardioplegia cannula (Medtronic DLP, Minneapolis, MN), allowing for the simultaneous delivery of cardioplegia and aspiration of the aorta and left heart; or the RAP cannula (Estech, Inc, Danville, CA) mentioned above.

De-airing is ensured through the same angiocatheter for cardioplegia or with a left vent across the mitral valve.

When left atrial myxomas are attached to the interatrial septum, exploration can be achieved through an oblique right atriotomy for an optimal exposure of the atrial septum [27] and, when the point of attachment has been identified, the incision can be made in the septum (medial to the fossa ovalis) and it is extended 360º around the myxoma attachment following the entering to the left atrium. For this approach, margins of normal septal tissue must be maintained.

A left atriotomy through Sondergaard's groove (anterior to the pulmonary veins) has been also described for patients with tumor attachment to the posterior left atrial wall. Traction sutures can be placed at the left atriotomy and pulled upward, or and atrial retractor (Estech, Inc., Danville, CA, USA) can be used for achieving an optimal operative field.

For selected cases, an atrial EndoWrist retractor (Intuitive Surgical, Inc, CA) is placed through the fourth robotic arm for an adequate exploration of the atrial myxoma. This dynamic robotic atrial retractor makes the right side of the heart to rotate up and the left side to rotate down and, along with the magnification provided by the robotic optical system, enhances the exposure and visualization in the left atrium.

Then, excision can be achieved by dissecting a plane at the point of attachment and atrial septum is maintained. Calcified areas and adherences must be identified. When atrial myxomas are located in the right atrium, they can be completely resected from the beating heart with the superior and inferior venae cavae snared.

Resection of full-thickness wall or only an endocardial attachment is controversial, although a partial thickness resection of the area of tumor attachment when anatomically is necessary has been reported, without an increase in recurrence rate [35]. The base of the myxomas can also be cauterized to prevent recurrence when, despite to be anatomically necessary, it has not been completely resected.

Because myxomas are generally very friable, their removal through a small working port is an important step during the robotic procedure. Endoscopic specimen baskets have been developed and are routinely used for laparoscopic procedures with good results and its use to catch and remove atrial myxomas has demonstrated to be safe and without risk for the patient when a video-assisted myxoma excision is performed [17]. For robotic procedures, the tumor is removed and grasped by the tissue margins and is extracted using an Endopouch bag (Ethicon Endo-Surgery, Cincinnati, Ohio) through the service port without fragmentation in the pleural space.

A vacuum-extractor device has also been reported for this procedure [36], allowing the extraction of giant left atrial myxomas. The components for this device are the top of a

plastic bottle of fluid serum (of 3-5 cm in diameter) connected to a flexible tube with a suction device. It is introduced and placed without aspiration through a thoracotomy incision, facilitated with the robotic magnification, and once the tumor is reached, it is removed with vacuum-traction under active aspiration *(Figure 6)*. This device allows the manipulation and a complete removal of the tumor, even if it is friable.

The interatrial septum can be removed with the tumor, but it seems to be indicated only in high-risk patients. When an atrial wall defect is created after excision (usually at the septum), it is repaired using the principles learned from endoscopic atrial septal defect repair. It can be repaired primarily by a running suture in the most of cases or by patch closure using autologous or bovine pericardium. After resection, empty left atrial and left ventricular chambers inspection is accomplished with the da Vinci endoscope.

The entire procedure can be performed with the da Vinci Surgical System, including left atrial closure with running suture, although the left atrium can be closed under direct vision to decrease operative times for selected patients.

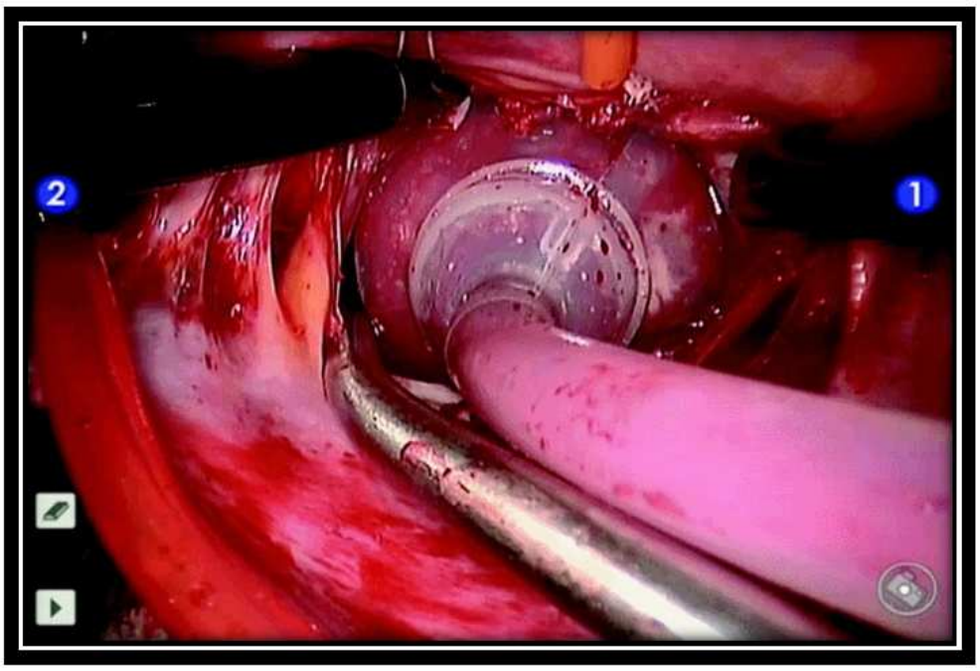


Figure 6. Resection of a giant atrial myxoma through a left atrial approach using the da Vinci Surgical System. Vacuum-extractor into the left atrium (viewing from the console's surgeon).

After de-airing, aortic cross-clamp is deflated and removed. TEE is used for proving the absence of tumor in cardiac chambers, adequate removal of air as well as residual atrial septal defect or mitral regurgitation *(Figure 7)*. Then, the patient is rewarmed and weaned from CPB.

Protamine is given and the femoral vessels are repaired once off CPB and the groin incision is closed. When cardioplegia has been infused through the second ICS, the site can be closed with extracorporeal knot tying through the working port and surgical close of the chest wall may be performed in the standard fashion.

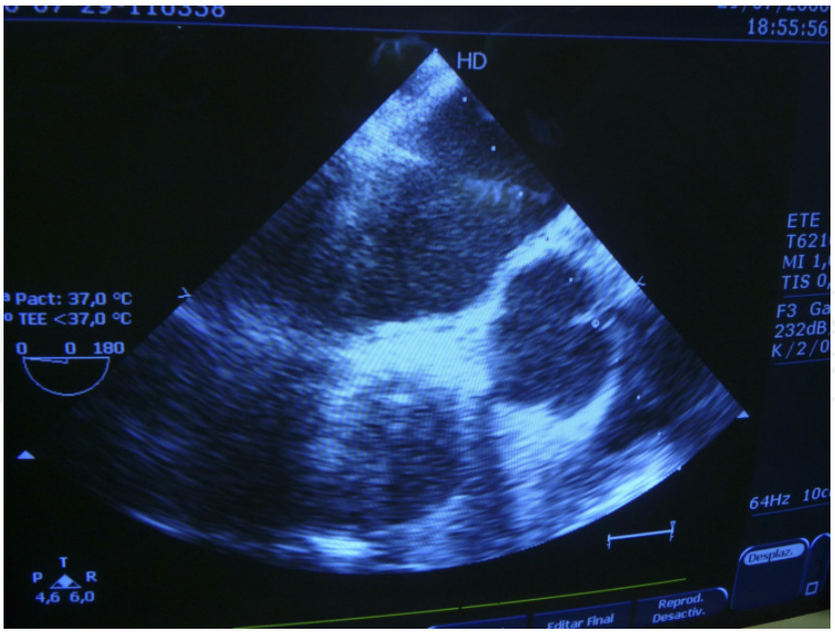


Figure 7. TEE allows for an exhaustive inspection the cardiac chambers after removal of the atrial myxoma.

In most of patients, temporary cardiac pacing wires are not routinely required. When this step is required, it must be performed previously to removal of aortic clamp. The chest tube (or Blake drain, depending on institution) is placed in an existing intercostals porthole and they are usually left in the pericardium and in the right pleural space. The double-lumen endobronchial tube can be changed to a single-lumen tube. In selected cases, the patient can be extubated in the operating room or shortly upon arrival to the intensive care unit.

5. Results

5.1. Current results

In general terms, although experience is limited, surgical results at a relatively large number of centres worldwide are optimal and this technology is of reproducible value with excellent cosmetic results. Despite successful cases reported of robotic-assisted excision of left atrial myxomas, most surgeons continue to use a median sternotomy approach.

An endoscopic approach to left atrial myxomas is appropriate only when the exposure of the attachment point of the tumor is optimal, excision of adequate tissue margins, removal with no fragmentation, reconstruction of atrial wall defects and an exhaustive inspection the cardiac chambers after removal of the atrial myxoma. These surgical tenets are achieved with the robotic technology.

Cross-clamp and perfusion times are longer under robotic assistance compared with conventional surgery [37-38], although a longer CPB time has not demonstrated any negative impact on operative and postoperative outcomes.

Increased total operative and cross-clamp times have been demonstrated for the endoaortic balloon versus the transthoracic clamp for valve surgery [39], but there are no studies for left atrial myxoma excision.

Learning curve can be long and minimally invasive surgery experience is desirable. The learning curve has demonstrated a progressive decline in cross-clamp, CPB, and overall operative times [40].

The perioperative results are similar to those obtained using traditional approaches and no serious complications during the robotic procedure have been reported in this setting. Necessity of conversion to sternotomy due to robotic system malfunction has not been described and to date, no operative mortality or neurologic complications have been observed [30].

The long incision in the midline of the chest, the risk of bleeding and infection and the relatively long recovery time after surgery seem to be avoided with robotic cardiac surgery. Usually, these patients benefit from low blood transfusion rate.

Intensive care unit stay duration is reduced in several studies [41-42]. Moreover, the patients are usually ready to be discharged on the third or fourth postoperative day and patient education regarding to sternotomy precautions is not needed for totally endoscopic cardiac surgery. Most patients can return to work in two or three weeks. Excellent quality of life has been demonstrated and, after discharge, these patients must be scheduled for a follow-up echocardiogram to rule out any recurrence of the myxoma.

Mid-term follow-up comparative studies between conventional and robotic surgery for removal of atrial myxomas are not yet available and data that include mid- and long-term follow-up are required.

5.2. Pitfalls and complications

It is important to keep in mind the potential complications for robotic extraction of left atrial myxomas. The working ports are only 2-2.5 cm in length and, during tumor resection through these small incisions, care must be taken to excise the mass entirely, given the friability of myxomas. Any fragment dropped during removal creates a high risk of systemic embolization and stroke [43]. When a left atrial approach is used, a "non-touch" technique (not possible with a conventional biatrial approach) is achieved, decreasing the risk for fragmentation of the tumor.

Vascular injuries from peripheral cannulation include arterial occlusion or aortic dissection (although extremely rare, but devastating).

In general terms, cardiac surgeons must be prepared to convert to a lateral thoracotomy or full sternotomy in case of unsuccessful result or emergency during the robotic procedure. For this reason, they must plan the alternative surgical procedure and choose the optimal access in advance.

5.3. Limitations

The early clinical experience with computer-enhanced telemanipulation systems has defined many of the limitations of this approach despite rapid procedural success. Limitations can include an incomplete and delayed motion tracking, although this limitation might negatively affect the quality of an anastomosis in beating-heart surgery, such as coronary artery bypass grafting [44], and it does not seem relevant for intra-cardiac tumor resection. Lack of tactile feedback has demonstrated to be also a limitation: the visual force feedback primarily benefits inexperienced robot-assisted surgeons, with diminishing benefits among experienced surgeons [45].

The operation is demanding, expensive and it is only suitable for a selected patient population, but elevated costs of instruments and maintenance may be justified by a speed of recovery and reduction in hospital stay [46]. It is necessary to determine the cost of these systems by virtue of their measured benefits.

Longer operative times and learning curve, above mentioned, are due to the complexity of the system and because of this reason, this technology must be concentrated in a few reference centres with a high volume and expertise cardiac surgeons.

6. Further research

To date, literature about feasibility of robotic resection of left atrial myxomas is focused on small series or isolated case reports, and the world experience is mostly retrospective and noncontrolled.

There are no randomized studies comparing robotic to either video-assisted or sternotomy or thoracotomy left atrial myxoma excision and, although it is generally believed that patient morbidity is significantly reduced with this minimally invasive approach, further studies are needed to support this hypothesis. Despite early procedural success, future refinements in these devices such as "haptic" technology, which provide tactile and resistance feedback to the surgeon, are needed to apply this new technology more widely in this era of cardiac surgery.

The results of robotic procedures should be at least equivalent to those of conventional methods and the time required should be comparable to conventional surgery. Long-term results are needed to determine whether robotic technology could become a new standard in cardiac tumors excision.

7. Conclusion

Computer-aided robotic surgical technology is a safe procedure and can be used to perform open-heart procedures such as atrial myxomas excision with a totally endoscopic approach.

Atrial myxoma resection using surgical telemanipulation systems such as the da Vinci Surgical System have achieved excellent results and provide an attractive cosmetic advantage over traditional approaches.

Adults with atrial myxomas are a small but constant and growing population of patients who can benefit of this minimally invasive approach.

Decreased postoperative pain and recovery times along with improved cosmetic results are the main benefits for this approach.

Further research is necessary to demonstrate the reproducible value for this technology in patients with cardiac tumors on a larger scale.

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8. References

[1] Larsson S, Lepore V, Kennergren C. Atrial myxomas: results of 25 years' experience and review of literature. Surgery 1989;105:695-8.
[2] Stajevic MS, Vukomanovic VA, Kuburovic VD, Djuricic SM. Early recurrent left atrial myxoma in a teenager with the novo mutation of Carney complex. Indian J Hum Genet 2011;17:108-10.
[3] Hou YC, Chang S, Lo HM, Hsiao CH, Lin FY. Recurent cardiac myxoma with multiple distant metastasis and malignant change. J Formos Med Assoc 2001;100:63-5.
[4] Rendón F, Agosti J, Llorente A, Rodrigo D, Montes K. Intramural cardiac myxoma in left ventricular wall: an unusual location. Asian Cardiovasc Thorac Ann 2002;10:170-2.
[5] Van Gelder HM, O'Brien DJ, Staples ED, Alexander JA. Familial cardiac myxoma. Ann Thorac Surg 1992;53:419–24.
[6] Selkane C, Amahzoune B, Chavanis N. Changing management of cardiac myxoma based on a series of 40 cases with long-term follow-up. Ann Thorac Surg 2003;76:1935-1938.
[7] Bjessmo S, Ivert T. Cardiac myxoma: 40 years' experience in 63 patients. Ann Thorac Surg 1997;63:697-700.
[8] Meyns B, Vancleemput J, Flameng W, Daenen W. Surgery for cardiac myxoma: a 20-year experience with long-term follow-up. Eur J Cardiothorac Surg 1993;7:437–40.
[9] Rodríguez E, Chitwood WR. Robotics in cardiac surgery. Scand J Surg 2009;98:120-4.
[10] Arom K, Emery R, Kshettry V, Janey P. Comparison between port-access and less invasive valve surgery. Ann Thorac Surg 1999;68:1525-1528.
[11] Navia J, Cosgrove D. Minimally invasive mitral valve operations. Ann Thorac Surg 1996;62:1542-1544.
[12] Carpentier A, Loulmet D. Open heart operation under videosurgery and minithoracotomy. First case (mitral valvuloplasty) operated with success. C R Acad Sci III 1996;319:219-223.

[13] Mohr FW, Falk V, Diegeler A. Minimally invasive port-access mitral valve surgery. J Thorac Cardiovasc Surg 1998;115:567-571.
[14] Ravikumar E, Pawar N, Gnanamuthu R, Sundar P, Cherian M, Thomas S. Minimal access approach for surgical management of cardiac tumors. Ann Thorac Surg 2000;70:1077-9.
[15] Gulbins h, Reichenspurner H, Wintersperger BJ. Minimally invasive extirpation of a left ventricular myxoma. J Thorac Cardiovasc Surg 1999;47:129-30.
[16] Ko PJ, Chang CH, Lin PJ, Chu JJ, Tsai FC, Hsueh C. Video-assisted minimal access in excision of left atrial myxoma. Ann Thorac Surg 1998;66:1301-5.
[17] Panos A, Myers PO. Video-assisted cardiac myxoma resection: basket technique for complete and safe removal from the heart. Ann Thorac Surg 2012;93:109-10.
[18] Greco E, Mestres CA, Castañá R. Video-assisted cardioscopy for removal of primary left ventricular myxoma. Eur J Cardiothorac Surg 1999;16:677-678.
[19] Li JY, Lin FY, Hsu RB, Chu SH. Video-assisted cardioscopic resection of recurrent left ventricular myxoma. J Thorac Cardiovasc Surg 1996;112:1673-74.
[20] Torracca L, Ismeno G, Alfieri O. Totally endoscopic computer-enhanced arterial septal defect closure in six patients. Ann Thorac Surg 2001;72:1354-1357.
[21] 2002 Heart and Stroke Statistical Update. Dallas, Tex: American Heart Association 2002.
[22] Jacobs LK, Shayani V, Sackier JM. Determination of the learning curve of the AESOP robot. Surg Endosc 1997;11:54-5.
[23] Pugin F, Bucher P, Morel P. History of robotic surgery: from AESOP and ZEUS to da Vinci. J Visc Surg 2011;148:3-8.
[24] Gao C, Yang M, Wang G, Xiao C, Wang J, Zhao Y. Totally endoscopic robotic ventricular septal defect repair in the adult. J Thorac Cardiovasc Surg 2012;[in press].
[25] Argenziano M, Oz MC, Kohmoto T, Morgan J, Dimitui J, Mongero L. Totally endoscopic atrial septal defect repair with robotic assistance. Circulation 2003;108:191-4.
[26] Woo YJ, Grand TJ, Weiss SJ. Robotic resection of an aortic valve papillary fibroelastoma. Ann Thorac Surg 2005;80:1100-1102.
[27] Murphy DA, Miller JS, Langford DA. Robot-assisted endoscopic excision of left atrial myxomas. J Thorac Cardiovasc Surg 2005;130:596-7.
[28] Gao C, Yang M, Wang G, Wang J. Totally robotic resection of myxoma and atrial septal defect repair. Interact Cardiovasc Thorac Surg 2008;7:947-950.
[29] Hassan M, Smith JM. Robotic assisted excision of a left ventricular myxoma. Interact Cardiovasc Thorac Surg 2012;14:113-114.
[30] Gao C, Yang M, Wang G et al. Excision of atrial myxoma using robotic technology. J Thorac Cardiovasc Surg 2010;139:1282-1285.
[31] Wang Yao, Gao C, Wang J, Yang M. The role of intraoperative transesophageal echocardiography in robotic mitral valve repair. Echocardiography 2011;28:85-91.
[32] Wang G, Gao C, Zhou Q, Chen T, Wang Y, Li J. Anesthesia management of totally endoscopic atrial septal defect repair with robotic surgical system. J Clin Anesth 2011;23:621-625.
[33] Grossi EA, Galloway AC, LaPietra A et al. Minimally invasive mitral valve surgery: a 6-year experience with 714 patients.

[34] Chitwood WR, Elbeery JR, Moran JM. Minimally invasive mitral valve repair; using a mini-thoracotomy and transthoracic aortic occlusion. Ann Thorac Surg 1997;62:1477-9.
[35] Actis Dato GM, De Benedictus M, Actis Dato A, Ricci A, Sommarival L, De Paulis R. Long-term follow-up of cardiac myxoma (7-31 years). J Cardiovasc Thorac Surg (Torino) 1993;34:41-3.
[36] Gutiérrez de Loma J, Valderrama Marcos J.F, Melero Tejedor J.M, González González S. Left atrial myxoma: extraction by robotic and vacuum assistance. Innovations 2009;4:351-353.
[37] Falk V, Diegeler A, Walther T. Developments in robotic cardiac surgery. Curr Opin Cardiol 2000;15:378-387.
[38] Autschbach R, Onnasch JF, Falk V. The Leipzig experience with robotic valve surgery. J Card Surg 2000;15:82-87.
[39] Reichenspurner H, Detter C, Deuse T. Video and robotic-assisted minimally invasive mitral valve surgery: a comparison of the port-access and transthoracic clamp techniques. Ann Thorac Surg 2005;79:485-490.
[40] Bonaros N, Schachner T, Oehlinger A, Ruetzler E, Kolbitsch C. Robotically assisted totally endoscopic atrial septal defect repair: insights from operative times, learning curves and clinical outcome. Ann Thorac Surg 2006;82:687-93.
[41] Chitwood WR. Video-assisted and robotic mitral valve surgery. Semin Thorac Cardiovasc Surg 1999;11:194-205.
[42] Reichenspurner H, Boehm D, Reichart B. Minimally invasive mitral valve surgery using three-dimensional video and robotic assistance. Semin Thorac Cardiovasc Surg 1999;11:235-243.
[43] Disesa VJ, Collins JJ, Cohn LH. Considerations in the surgical management of left atrial myxoma. J Card Surg 1988;3:15-22.
[44] Modi P, Rodríguez E, Chitwood R. Robot-assisted cardiac surgery. Interact Cardiovasc Thorac Surg 2009;9:500-505.
[45] Reiley CE, Akinbiyi T, Burschka D, Chang DC, Okamura AM, Yuh DD. Effects of visual force feedback on robot-assisted surgical task performance. J Thorac Cardiovasc Surg 2008;135:196-202.
[46] Morgan JA, Thornton BA, Peacock JC, Hollingsworth KW, Smith CR, Oz MC, Argenziano M. Does robotic technology make minimally invasive cardiac surgery too expensive? A hospital cost analysis of robotic and conventional techniques. J Cardiac Surg 2005;20:246-251.