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Clinical Comparison of Robot-Assisted and Conventional Thoracotomy with Mitral Valvuloplasty

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Abstract: Objective To compare the clinical therapeutic effects of robot-assisted and conventional thoracotomy with mitral valvuloplasty, and to further clarify the advantages and disadvantages of the Da Vinci robotic surgery system in cardiac surgery. **Method** A total of 116 patients with mitral valvuloplasty were enrolled from November 2014 to July 2018 in the Affiliated Hospital of Qingdao University, which included 38 cases of the robot-assisted mitral valvuloplasty and 78 cases of conventional thoracotomy with mitral valvuloplasty; the clinical treatment of the two patient groups was compared and analyzed. **Result** The surgical outcomes of the two groups were satisfactory and there were no deaths in the hospital. The operation time, cardiopulmonary bypass (CPB) time, and ascending aorta occlusion time were longer in the Da Vinci group than in the conventional group ($P<0.05$). Intensive care unit (ICU) time, tracheal intubation time, postoperative hospital stay, postoperative blood transfusion, postoperative drainage and incidence of postoperative complications were lower in the Da Vinci group than in the conventional group ($P<0.05$). There was no significant difference in postoperative cardiac ultrasound results between the Da Vinci group and the conventional group. ($P>0.05$). **Conclusion** Robotic technique can be safely and effectively be applied in mitral valvuloplasty, and can significantly shorten the ICU time, tracheal intubation time and postoperative hospital stay, also reduce postoperative blood transfusion, postoperative drainage, and incidence of postoperative complications. Robot-assisted surgery is a good choice for minimally invasive surgery, but its operation time, extracorporeal circulation time and ascending aorta occlusion time are longer than conventional surgery, and further improvement is needed.

Keywords: Minimally Invasive Surgery; Computer-Aided Surgery; Thoracotomy; Mitral Valve Insufficiency

Introduction

With the advancement of medical technology, many surgeons are seeking more effective surgical methods, and minimally invasive surgery is undoubtedly one of the directions pursued. Previously, minimal invasive surgery experienced small incision and laparoscopic-assistance; due to poor exposure of the surgical field and difficulty in operation, these two surgical methods gradually faded out of sight. Since Carpentier [1] completed the first robot-assisted mitral valvuloplasty with the Da Vinci robot, the minimally invasive cardiac surgery led by the Da Vinci robotic surgical system was re-developed. However, due to the small number of heart centers in the domestic Da Vinci surgery, there is little data on the comparative effect of robot-assisted and conventional thoracotomy with mitral valvuloplasty. This time, we compared the clinical data of Da Vinci robot-assisted and conventional thoracotomy with mitral valvuloplasty between November 2014 and July 2018, confirming the advantages of Da Vinci robotic mitral valvuloplasty. And, Da Vinci robot-assisted surgery still needs further improvements.

1 Data and methods

1.1 Clinical data and grouping

A total of 116 patients with mitral valvuloplasty were enrolled in the Affiliated Hospital of Qingdao University from November 2014 to July 2018, including 38 cases of robot-assisted mitral valvuloplasty, named Da Vinci group; 78 cases of conventional thoracotomy with mitral valvuloplasty, named the conventional group. Two groups of patients were selected for single mitral regurgitation disease, excluding patients with other heart diseases, secondary surgery, pleural adhesions, and pulmonary dysfunction. The general information of the two groups of patients before surgery is shown in Table 1.

1.2 Method

1.2.1 Surgical methods

Robot-assisted mitral valvuloplasty: Anesthesiologists

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used venous inhalation anesthesia, a double lumen endotracheal intubation and esophageal ultrasound was inserted. The patient took a lateral recumbent position with a right-side elevation of 30° and was attached with an external defibrillation electrode. Ventilation was only through the left lung. The surgeon lengthens incision from the fourth intercostal of midaxillary line to the upper edge of the fifth rib, about 6cm, avoiding the breast tissue. This incision was for the entrance of the lens and operation port. Surgeon punches holes in the second and the sixth intercostal space of the anterior axillary line, the intercostal hole is the entrance of the left and right instrument arm of the Da Vinci robot, and punches hole in the fifth intercostal space and the right edge of the sternum, which is the entrance of the Da Vinci robot pull hook instrument. After systemic heparinization, the surgeon establishes extracorporeal circulation through the femoral arteriovenous cannula. After paralleling CPB, the surgeon uses chain-blocking forceps to block the ascending aorta and perfuses the filling canal through the ascending aorta root with cold blood cardioplegia, and the heart stops completely. During the operation, CO_2 gas is continuously infused into the thoracic cavity, and the flow rate is 2 to 3 L/mm. The surgeon cuts the inter-atrial sulcus longitudinally and uses the robotic hook to reveal the left atrium. Exploring valvular lesions, the surgeon chooses the appropriate surgical procedure according to the situation (Table 2 for the forming method). The assistant fetches water, during which the surgeon observed that the degree of valve regurgitation was significantly better than before. The Surgeon uses the 4-0 GORE-TEX line to suture the inter-atrial sulcus continuously. After rewarming and complete exhaustion from the left heart system, the surgeon opens the blocking clamp. The perfusionist uses the esophageal ultrasound to further clarify the shaping effect. Double lung ventilation, returning oxygen debt, and gradually stopping CPB after BP, HR, and SPO_2 is stabilized. After the surgery, the anesthesiologist replaces the single lumen endotracheal intubation.

Conventional thoracotomy with mitral valvuloplasty. The patient was placed in a supine position, anesthesiologists use venous inhalation anesthesia and the single lumen endotracheal intubation. In the conventional group, the median chest incision was used, and the sternum was split longitudinally. The surgeon frees the tissue layer by layer, revealing the heart. The ascending aorta was inserted into the arterial infusion tube and the perfusion needle, and the superior and inferior vena cava were respectively inserted into the venous tube, the right upper pulmonary vein was inserted into the left heart drainage tube. Through the above operations to complete the establishment of extracorporeal circulation. The surgeon uses aortic cross-clamp to block the ascending aorta and perfuses the filling canal through the ascending aorta root with cold blood cardioplegia, and the heart stops completely. Operator obliquely cuts the right atrium, cuts the interatrial septum longitudinally, and uses the atrial hook to reveal the left atrium. The valvular lesion is explored. The forming procedure is determined according to the situation. The remaining steps are roughly the same as before.

1.2.2 Postoperative treatment and review methods

Both groups were treated in the intensive care unit after surgery, and the tracheal intubation was removed after a comprehensive evaluation of the condition. After surgery, the patients receive analgesic, cardiotonic, diuretic treatment from the clinician. In addition to warfarin, low molecular heparin was given for the anticoagulant therapy. Patients who were not placed in the formation ring were given aspirin orally to prevent deep venous thrombosis. After the operation, the patients were encouraged to exercise lung function and get out of bed early. According to the color and quantity of the drainage fluid, the drainage tube was removed, and whether the blood product is infused according to the blood vessel volume and the hemoglobin index. These are evaluated by the single center of the intensive care unit. After the patient's vital signs were stable, the echocardiography was reviewed and the results were satisfactory. Clinician allows patients to leave the hospital.

1.2.3 Statistical methods

Data analysis applied SPSS 18.0 software. The measurement data is expressed as X±s, and the categorical variables are expressed in terms of numbers or percentages. The comparison of measurement data was performed by t-test, and the comparison of count data was performed by the x^2 test. $P < 0.05$ was considered to be statistically significant.

2 Results

None of the patients died in the hospital regardless of the group. The Da Vinci group had no transposition in the operation. There were no significant differences in age, gender, body mass index (BMI), and past medical history between the two groups (P>0.05). The operation time, cardiopulmonary bypass time, and aortic occlusion time of the Da Vinci group were longer than those of the conventional group (Table 3), and the difference was statistically significant (P=0.000). The postoperative thoracic drainage, transfusion volume, ICU time, postoperative tracheal intubation time, and postoperative hospital stay time were significantly lower in the Da Vinci group than in the conventional group (Table 4). The difference was statistically significant (P = 0.000). In the Da Vinci group and the conventional group, postoperative echocardiography showed improvement in the left atrium (LA), left ventricle (LV), and pulmonary artery pressure (PASP) compared with preoperative, and the degree of reflux was significantly improved (P=0.000). There was no significant difference in the comparison between the two groups. (P>0.05). There was no significant difference in the incidence of postoperative pulmonary infection between the two groups (P>0.05). In the Da

Vinci group, 1 case complicated with deep venous thrombosis of the lower extremity was more common than the conventional group (P=0.000). The incidence of postoperative pleural effusion, malignant arrhythmia, and wound infection was higher in the conventional group than in the Da Vinci group. (P = 0.000).

Table 1. The general information of the two groups

Group	N	age（Year）	Men and women（Number）	BMI(Kg/m^2)	Hypertension (Existence/Absence)	Diabetes (Existence/Absence)
Da Vinci Group	38	51.29±13.27	19/19	25.02±3.87	18/20	2/36
Conventional Group	78	54.40±13.18	39/39	25.17±3.62	33/45	5/73

Table 2. Surgical procedure

Group	N	Simple folding valve prolapse	Implantation prosthetic ring	Simple two-hole method	Simple sutured valve junction	Simple reconstruct chordae tendineae
Da Vinci Group	38	8	18	8	3	1
Conventional Group	78	2	69	3	4	0

Table 3. Comparison of various indicators during operation

Group	N	Haemorrhage (*ml*)	Autologous blood (*ml*)	Time (t/min)			Transfusion intra-operatively(Number/Rate)			
				Operation	CPB	Aorta clamping	Erythrocyte	Plasma	Cryoprecipitate	Platelet
Da Vinci Group	38	744.74±332.13	555.21±298.07	277.61±81.36	143.21±46.92	79.00±39.72	12/31.58%	14/36.84%	19/50%	0/0%
Conventional Group	78	635.13±338.64	587.42±357.88	225.32±78.33	96.04±41.99	61.14±32.94	24/30.77%	34/43.59%	15/19.23%	1/1.28%

Note: Abbreviated cardiopulmonary bypass to CPB.

Table 4. Comparison of postoperative indicators

Group	N	ICU time (*t*/min)	Postoperative tracheal intubation time over 24h(Number)	Postoperative hospital stay time (*t*/d)	Postoperative thoracic drainage (ml)	Postoperative transfusion (Number/ Rate)	Infection (Number/ Rate)	Postoperative complications (number/ rate)			
								Pulmonary infection	Pleural effusion	Malignant arrhythmia	Incisional infection
Da Vinci Group	38	71.64±30.60	1	12.84±4.82	411.05±193.37	17/44.74%	3/7.89%	3/7.89%	0/0	0/0	0/0
Conventional Group	78	83.26±12.64	14	14.97±5.35	595.83±335.47	57/73.08%	10/12.82%	10/12.82%	2/2.56%	2/2.56%	1/1.28%

Table 5. Compared preoperative and postoperative cardiac ultrasonography in two groups

Group	N	Valve prolapse（N）			Preoperative			Postoperative			Difference			MR grading	
		AMVL	PML	AMVL+PML	LA	LV	PASP	LA	LV	PASP	LA	LV	PASP	Preoperative	Postoperative
Da Vinci Group	38	12	20	6	4.78±0.72	5.30±0.63	45.95±41.72	4.06±0.76	4.54±0.40	30.50±6.23	0.72±0.83	0.76±0.59	15.45±17.13	6.29±0.80	2.79±0.17
Conventional Group	78	11	58	9	4.88±0.92	5.34±0.77	46.37±13.61	3.98±0.74	4.65±0.56	31.42±5.73	0.91±0.66	0.69±0.57	14.95±13.69	6.32±0.80	2.74±0.10

Note: For statistical purposes, MR grading is based on echocardiographic assessment of mitral regurgitation, with 1 for no reflux, 2 for mild reflux, 3 for mild reflux, 4 for light-to-moderate reflux, 5 for Moderate reflux, 6 for moderate to severe reflux, 7 for severe reflux; compared with preoperative; Abbreviated posterior mitral leaflet to PML;Abbreviated anterior mitral valve leaflet to AMVL.Units.LA、LV：cm；PASP：mmHg.

Table 6.Compared preoperative and postoperative cardiac ultrasonography in the total of 116 patients

Group	LA	LV	PASP	MR Grading
Preoperative	4.85±0.86	5.33±0.72	46.23±14.71	6.32±0.80
postoperative	4.00±0.75	4.61±0.51	31.12±0.55	2.76±0.93

3 Discussion

Mitral valvuloplasty preserves the valve device to protect the left ventricular function [2]. Moreover, patients do not need long-term anticoagulant therapy after surgery, and the incidence of postoperative anticoagulation-related complications is lower than that after mitral valve replacement [3]. Therefore, for patients with mitral regurgitation, mitral valvuloplasty is preferred based on valvular lesions [4]. At the same time, mitral valvuloplasty has been widely accepted by the international cardiac surgery community [5]. In this study, the results of preoperative and postoperative echocardiography (Table 6) also showed that patients with mitral valvuloplasty achieved better results.

At present, a mid-sternal thoracotomy is still the standard procedure for mitral valvuloplasty [6]. In the past, it was reported that small right incision and thoracoscopic assisted mitral valvuloplasty hindered the development of both because of their self-limitations. Since the introduction of Da Vinci into cardiac surgery, it has gradually become the mainstream of minimally invasive cardiac surgery because of its own advantages. So far, some heart center studies at home and abroad have proved that Da Vinci surgery is safe and effective [7]. Da Vinci robotic surgery system has been widely used in mitral valve surgery, repair of atrial and ventricular septal defect, resection of atrial tumor, coronary artery bypass grafting and other conventional surgery [8], and has achieved good clinical results.

The Da Vinci robotic surgery system itself has four major advantages: it has a three-dimensional field of view and has a strong light source to make the field of view more clear than conventional surgery; the field of view is simultaneously magnified, making the operation more precise; the system automatically filters out the handshake. The possibility of accidental injury is reduced to a great extent, and the safety of the operation is greatly improved; the robot-specific instrument has seven degrees of freedom which is more flexible than the human wrist, enabling the surgeon to operate flexibly in a small space.

Through this study, Da Vinci robot-assisted mitral valvuloplasty can significantly improve the prognosis of patients with mitral valvuloplasty compared with conventional thoracotomy. The ICU time, tracheal intubation time, postoperative hospital stay time, drainage volume, and blood transfusion were significantly lower in the Da Vinci group than in the conventional group. Domestic studies have reported that the above factors increase the hospital mortality and infection rate [9], Da Vinci robot-assisted mitral valvuloplasty reduces the above indicators compared with the conventional group, which undoubtedly reduces the hospital mortality and infection rate. None of the patients in the Da Vinci group had a transition that the surgeon had to change the surgical procedure to thoracotomy, and the operation was safe and effective. The postoperative echocardiography showed that the Da Vinci group had satisfactory results. Da Vinci robot-assisted mitral valvuloplasty has the same reliable surgical results as conventional thoracotomy.

However, this study also confirmed that the operation time, cardiopulmonary bypass time, and aortic occlusion time were longer in the Da Vinci group than in the conventional group. The extension of the operation time considers the objective factors such as the time taken to assemble the machine and locate the place, the time of placing the patient's surgical position, the replacement time between the double-lumen endotracheal tube and the single-lumen endotracheal tube, etc. The degree of tacit understanding between surgeons, assistants, and hand-washing nurses during surgery is also crucial. It is undeniable that new technologies have certain curves in the learning process. In this study, the Da Vinci group was divided into two parts according to the start time of the operation. The difference between the two parts was statistically significant, which confirmed the viewpoint. Therefore, we need to cultivate a high-quality surgical team and strengthen the team's ability to cooperate. I believe that the above time will be shortened based on the increase in the number of operations. In addition, the application of emerging technologies such as nickel-titanium u-shaped clips and Cor-Knot™ suturing devices [10] will be reduced accordingly.

In this study, 1 case of deep venous thrombosis was found in the Da Vinci group, which was caused by the narrowing of the femoral vein after intubation. Moreover, because of the inguinal incision pain, the movement of the patient's lower extremity was reduced after the operation, and the blood flow rate also lowered. This easily leads to thrombosis. Therefore, the surgeon should strengthen the training of the suture technique, the margins should be small and the stitch length should be well-balanced to avoid needle filling. At the same time, patients with prosthetic ring need a subcutaneous injection of low molecular weight heparin, given orally. Oral warfarin, and monitor prothrombin time; patients without prosthetic ring are given oral aspirin after surgery, subcutaneous injection of low molecular weight heparin for 1 week, and patients are encouraged to move lower limbs.

Two patients with malignant arrhythmia were enrolled in the conventional group, one with sudden ventricular fibrillation and the other with cardiac arrest. Patients with postoperative malignant arrhythmia are considered to be associated with intraoperative myocardial injury, internal milieu disorder, poor cardiac function, and postoperative hyperthermia and pain [11]. In the Da Vinci group, there were no patients with malignant arrhythmia. Mihaljevic [12] and others confirmed that Da Vinci robot-assisted mitral valvuloplasty had a lower chance of postoperative arrhythmia compared with conventional thoracotomy. Through comparative analysis and intraoperative observation, it is concluded that the surgeon reduces the movement and violent pulling of the heart during operation to avoid damage to the conduction beam and reduce myocardial edema, which will reduce the incidence of postoperative malignant arrhythmia. At the same time, the placement of a temporary pacemaker during surgery is a guarantee of postoperative sudden arrhythmia. Clinicians closely monitor changes in potassium, magnesium and calcium levels and correct them in time. It is particularly important for patients to control postoperative infection and analgesia.

The surgical procedure of the conventional group is the median sternotomy, which increases not only the patient's postoperative pain and the rate of a lung infection but also the problem of sternal loosening and wound infection. Such problems may also be associated with the prolonged operation time, large postoperative activity, and poor nutritional status. In this study, one patient with incision infection appeared in the conventional group. In the Da Vinci group since there was no need to destroy the bony structure during the operation, the incision recovery problem was less likely to occur post operation.

Two patients with pleural effusion after operation in the conventional group were considered to be related to the undetected pleural rupture in the process of separating tissue and poor cardiac function, which undoubtedly increased the risk of postoperative pulmonary atelectasis and pulmonary infection. At the same time, it affects the patient's blood oxygen saturation and implicates the anoxia damage of various organs. In the Da Vinci group, chest drainage was routinely performed after surgery, and pleural effusion was fully drained. After postoperative analysis, the postoperative drainage volume of the Da Vinci group was lower than that of the conventional group.

Summarize the clinical experience of Da Vinci robot-assisted surgery in our hospital, as follows: **1**. Selection of punching position. The surgeon should select the appropriate punching position according to the patient's body shape and thoracic structure, avoid collision and limit movement between the robot arms and avoid the mechanical arm pressing the other parts of the body. The perforation position often used in our hospital is the second intercostal space, the sixth intercostal space, and the fifth intercostal space at 2 cm on the right edge of the sternum. **2**. Soft traction application. Intraoperative incision placement of soft traction can press the bleeding of urgent soft tissue; avoid lens contact with tissue and blood during the process, so that the lens is not blurred; avoid tissue debris from the incision into the heart during the operation. **3**. Single lung ventilation. Intraoperative single-lung ventilation can collapse the right lung and provide an adequate surgical field of vision. However, the application of single-lung ventilation is likely to lead to insufficient oxygen supply after the extracorporeal circulation stopped [13]. Therefore, after suturing the room ditch, the lungs should be given ventilation during the process of rewarming and exhaustedly to improve blood oxygen saturation. **4**. CO_2 perfusion. CO_2 perfusion can prevent air from entering the left heart system after the extracorporeal circulation is stopped [14]. However, the amount of CO_2 perfusion will also increase the pressure in the thoracic cavity and cause the blood flow to the vein to be blocked. In order to avoid the above situation, we should try to control the carbon dioxide flow rate at 2-3L/min, or control the chest air pressure below 1.33kPa [15]. **5**. Venous reflux. When the single vein is recirculated, the esophageal ultrasound should be used to determine the tip of the venous tube into the junction of the superior vena cava and the right atrium, or a few centimeters above the superior vena cava. When the drainage is not good, the surgeon can place the superior vena cava drainage tube into the superior vena cava through the right internal jugular vein and connect the negative pressure device [16]. Because only the right atrium collapses, the left atrium can be retracted and the mitral valve is clearly visible.

While the Da Vinci robotic surgery system has advantages, there are also limitations. The surgeon has a lack of tactile feedback on the hand, so the strength of gripping the tissue is not well controlled. Secondly, in the process of manipulating the robotic arm, the surgeon often leaves the small activity space for the assistant, and it is easy to contaminate the protective sleeve of the robot arm. If not found in time, it is easy to increase the risk of postoperative infection. However, as technology advances, we believe that both of these issues can be resolved.

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