Minimally invasive approach for double and triple valve surgery

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Contributions: (I) Conception and design: A Lio, M Glauber; (II) Provision of study materials or patients: A Lio, M Ferrarini, M Glauber; (III) Collection and assembly data: A Lio, A Miceli, M Glauber; (IV) Data analysis and interpretation: A Lio, A Miceli; M Glauber; (V) Manuscript writing: All authors; (VI) Final approval of manuscript: All authors.

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Background: Although benefits of minimally invasive cardiac surgery have been described when compared with a standard approach through a median sternotomy, few experience and data exist in the setting of double and triple valve surgery, whose annual incidence is 3% to 25% of all valve surgery. We describe our experience with minimally invasive multiple valve surgery through a right minithoracotomy.

Methods: All patients scheduled for a minithoracotomy approach underwent a preoperative evaluation, including computed tomography scan and epiaortic and femoral vessels ultrasound. Mitral and tricuspid valve disease is treated through a right minithoracotomy performed through a 4–5 cm lateral skin incision at the level of the fourth intercostal space. In case of mitro-aortic or triple valve disease, the procedure is carried out through a 5–7 cm incision in the 3rd intercostal space at 2–4 cm from the sternal edge. A femoral platform is generally used for cardiopulmonary bypass establishment, but, in selected patients, a central aortic cannulation could be also performed to allow an antegrade perfusion.

Results: We have started our minimally invasive program in 2003. Gaining experience with the minithoracotomy, all patients with a concomitant mitral and tricuspid valve disease were treated with this kind of approach. In 1,604 patients undergoing minimally invasive mitral valve surgery over a 10-year period, concomitant tricuspid valve repair was performed in 234 patients (14.6 %), with good early and long-term outcomes. The next step, especially after the introduction of sutureless aortic prostheses, was represented by the minimally invasive treatment of mitro-aortic and triple valve disease. Sixty-nine patients underwent concomitant mitral and aortic valve surgery through a right minithoracotomy, and a triple valve surgery was performed 12 (17.4%) of them. Good results were obtained in terms of postoperative mortality and morbidity.

Conclusions: Double and triple valve surgery through a right minithoracotomy is a feasible approach in this subgroup of high-risk patients.

Keywords: Minimally invasive; minithoracotomy; double valve; triple valve

Introduction

Multiple valve surgery and particularly triple valve surgery (TVS) are still challenging for surgeons, due to prolonged cardiopulmonary bypass (CPB) and cross-clamp times, with a reported operative mortality ranging from 2.5% to 25% (1). Although benefits of minimally invasive cardiac surgery (MICS) have been well described when compared with a standard approach through a median sternotomy (2-7), most reports have analyzed outcomes of single valve surgery; for double and TVS, which has an annual incidence of 3% to 25% of all valve surgery, little experience and few data exist in the setting of minimally invasive treatment (3). We have started our minimally invasive program in 2003. The first step consisted in a right anterolateral minithoracotomy in the 4th intercostal space

(ICS) for isolated mitral surgery (8); gaining experience with the technique, concomitant tricuspid disease was generally treated through the same surgical approach. The next step was represented by the treatment of aortic valve disease through an anterior right minithoracotomy (RmT) in the 2nd ICS (9). Finally, especially after the introduction of sutureless aortic prostheses, we have also expanded the minimally invasive approach to mitro-aortic and triple valve disease, performing an antero-lateral RmT into the 3rd ICS (10,11). In this report, we describe our experience with minimally invasive multiple valve surgery.

Methods

Patient selection and workup

The study was approved by the local ethical committee and individual consent was waived.

Preoperatively, all patients scheduled for a RmT procedure underwent:

- ❖ Routine blood tests;
- ❖ Chest X-ray;
- ❖ Transthoracic echocardiography;
- ❖ Coronary angiography;
- ❖ Computed tomography (CT) scan without contrast enhancement (redo-procedures or in presence of aortic valve disease);
- ❖ Epiaortic and femoral vessels ultrasound.

Mitral and tricuspid valve disease

There are few specific contraindications for a minimally invasive approach, and patients group may be even extended as experience grows and surgeon become more confident with a minithoracotomy procedure.

Presence of ascending aortic or aortic arch aneurysm, indication for the aortic root reconstruction, or surgical myocardial revascularization are considered as contraindications for this approach.

A very deep chest may be considered as a contraindication only during initial experience, because a central aortic cannulation could be difficult. These patients can be managed more easily when experience grows; this regards also patients with previous right chest surgery or trauma and low chest profile, that could be considered as relative contraindications. A short ascending aorta may be considered a contraindication for central aortic cannulation, due to the limited space for direct aortic cross-clamping: in these patients a peripheral aortic cannulation may be preferred.

Mitro-aortic and triple valve disease

All patients planned for mitro-aortic or triple valve minimally invasive surgery must undergo imaging with a 64-slice CT scanner without contrast enhancement. It is important that, during the CT scanning, patient' arms are adducted, recreating the normal patient position on operative table. Images are elaborated in the coronal and sagittal planes and then reconstructed in a 3D format to evaluate the relationship among the ICSs, ribs, sternum, ascending aorta, aortic and mitral valves.

Patients are considered suitable for RmT if the following CT scan criteria were met: (I) ascending aorta rightward at the level of the main pulmonary artery (more than one-half located on the right in respect to the right sternal border); (II) distance from ascending aorta to the sternum not exceeding 10 cm; (III) an angle between the ascending aorta and the patient's midline greater than 45°.

With experience and especially in case of aortic sutureless prosthesis use, these CT scan criteria have only relative importance. In our experience, relative contraindications for a RmT approach are: history of right pleurisy or previous right-side pleural effusion with adhesion formation; severe chest wall deformities; severe pulmonary bullous disease; and the presence of an ascending aorta aneurysm or the technical impossibility of obtaining peripheral percutaneous venous cannulation.

Preoperative preparation

Anesthesia is provided according to the standard protocol and the operation is performed under general intravenous anesthesia. The peripheral arterial and venous accesses are obtained for patient monitoring. In case of planned use of an endoaortic balloon occlusion, it is mandatory to obtain both right and left radial artery lines to control an eventual balloon migration. Two percutaneous sheath introducers are placed in the jugular vein: one (standard 4-lumen-7.0 or 8.5 Fr) is used for drug administration and central venous pressure monitoring, and the other one (8.5 Fr) for eventual placement of endocavitary pacemaker leads. Generally, a single lumen tube for intubation is used. The use of a double-lumen endotracheal tube could be helpful when a long surgical preparation (difficult cannulation, pleural adhesions) is expected and in redo-thoracotomy procedures. Two defibrillator pads are placed across the chest wall and a transesophageal echocardiography (TEE) probe is always

Figure 1 Mitral and tricuspid (12).
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placed. Patient is placed in supine position with an air sac under the right scapula, to allow elevation of the right chest slightly in order to achieve optimal exposure of the working field. Patient's right arm should be a little deviated from the body to have enough space for working port placement. Afterward, the patient's skin is prepared with antiseptic solutions and the patient is draped exposing the anterior and right lateral chest wall and both groin areas.

Results

Procedure

Mitral and tricuspid valve disease (*Figure 1*)

Prior to chest incision a 5-Fr venous introducer sheath is placed percutaneously in the right femoral vein. This is done before systemic heparinization to avoid bleeding from possible femoral artery punctures. The RmT is performed through a 4–5 cm lateral skin incision at the level of the fourth ICS. Generally, in men, the incision could be made either above or below the nipple, while in a female patient the preferred incision site is the inframammary fold. Then, two 10.5-mm working ports are positioned. One is placed in the 4th ICS at the level of anterior axillary line and it is used for video assistance and pericardial stay sutures. The second port is placed in 6–7th ICS in the mid-axillary line and it is used for the cardiotomy vent, CO$_2$ insufflation, and pericardial stay sutures. A soft tissue retractor is then inserted into the RmT and a rib-spreader is often used. With lungs gently deflated, the pericardium is opened 3–4 cm above the phrenic nerve, taking care not to injure it; then, 2-0 silk stay sutures are placed and passed through the working ports, to obtain a better visualization of operative field.

Generally, femoral artery cannulation is achieved: the artery is exposed through a 2–3 cm transverse incision in the groin along the inguinal fold. Usually, the left femoral artery is cannulated: a single 5.0 prolene purse-string is made and, using the Seldinger technique, an arterial femoral cannula is advanced after systemic heparization.

Femoral vein cannulation is done under TEE guidance using a bicaval view and with the Seldinger technique: guidewire is advanced into the superior vena cava through the previously placed venous introducer sheath. Then, the place of puncture on the skin is enlarged with No. 11 blade, and dedicated venous dilators are inserted one by one over the guidewire. These maneuvers allow free passage of the cannula. Venous return cannula is finally positioned in femoral vein and advanced. At our early experience, an additional right jugular vein cannulation was necessary; the introduction of a double-stage low-profile venous cannula (RAP cannula, LivaNova Group, UK), that is advanced into the superior vena cava, allow to maintain an optimal venous return; therefore, the jugular vein cannulation has been completely abandoned. Moreover, use of vacuum-assisted venous return (at 40 to 60 mmHg) during CPB makes not necessary to snare cavae in all cases.

Direct ascending aorta cannulation is another option; in this case, aorta is exposed up to the left innominate vein and two concentric polyester purse-strings are placed, reinforcing the second one with two pledgets. The cannulation site must be 2–3 cm above the transverse sinus, being the landmark where the aortic cross-clamp may be placed. In this phase, the aorta can be kept steady using locking forceps to reduce the physiological motion. We recommend to place purse-strings before systemic heparinization. Aorta cannulation is performed under direct vision using two different types of flexible arterial cannula: the StraightShot aortic cannula (Edwards Lifesciences, Irvine, CA, USA), that is a port-access cannula with AutoIncisor Introducer, with a blade at the tip, and the EasyFlow cannula (LivaNova Group, UK); the principal characteristic of the later cannula is the absence of AutoIncisor mechanism and the presence of an advanced tip and obturator designed to allow an easy aortic insertion. In presence of a deep thorax, a silk suture previously placed through one of the tourniquets can facilitate the knotting inside the chest.

When the CPB is started, a combined Y-shape vent/cardioplegia catheter is placed in the ascending aorta and aorta is clamped. For aortic cross-clamping, it is possible to use different dedicated instruments: an external Chitwood clamp or flexibles clamps such as Cosgrove or

Figure 2 Mitral and aortic (13).
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Cygnet clamps (Novare Surgical Systems Inc., Cupertino, CA, USA). In our department, we generally use the CardioVision MIC-Aortic Glauber Clamp (Cardiomedical GmbH, Langenhagen, Germany): this cross-clamping instrument is provided with a completely detachable clamping limb. This clamp is mounted on a delivery shaft and applied on aorta with jaws; the clamping component is left inside the chest during the procedure and removed after declamping the aorta.

Endoaortic balloon occlusion is another option. This multifunctional device is designed to occlude the ascending aorta from inside, to vent the aortic root, to monitor aortic root pressure, and to deliver the cardioplegia solution. This balloon can occlude a wide range of aorta diameters, usually not exceeding 40 mm. This balloon is inserted through a dedicated femoral cannula (EndoReturn Arterial Cannula, Edwards Lifesciences, Irvine, CA, USA) and advanced into the ascending aorta under the echo guidance, ensuring that the balloon is correctly placed in the aorta under the origin of the brachiocephalic artery. In brief, under TEE control, the balloon is rapidly inflated to create an occlusive seal. A created gradient between aortic root and main arterial pressure is an indicator of a complete aortic occlusion. The stability of EndoClamp catheter is secured by tightening the hemostasis valve of the EndoReturn cannula. When the balloon inflation is totally accomplished, the cardioplegia solution is gradually infused. Currently, we use the EndoClamp catheter only in redo operations, when the direct aortic cross-clamping is not possible. The cardioplegia in all types of clamping is delivered into the aortic root as a single dose/shot (20 mL/kg) of cold crystalloid solution (Custodiol) or as multiple doses of warm blood cardioplegia. The surgical field is flooded with carbon dioxide at a flow rate of 0.5 L/min until closure of the left atrium.

Mitral valve is approached through the Sondergaards's groove: once the left atrium is opened, the valve is exposed using a special atrial retractor with an external mechanical arm. Special instruments developed for minimally invasive surgery are employed during the operation. When the mitral is exposed, it is analyzed for the choice of the type of surgical correction. Once the type of treatment is decided, surgeon can proceed with initial suture placement on mitral valve annulus. All known types of mitral valve disease correction (valve repair, replacement, neochordae placement, valve leaflet resection, reductive annuloplasty, leaflet patch repair/enlargement, left ventricle outflow tract myectomy, etc.) are feasible. All types of sutures that may be used during the procedure (polypropilene, braided sutures, gore-tex, etc.) may be tied using a dedicated knot pusher. At the end of mitral valve repair/replacement, a left ventricular vent is inserted and the left atrium is closed as usual using 3-0 polypropilene sutures. Then the right atriotomy is made, the tricuspid valve is exposed and repair is performed.

After rewarming and de-airing, CPB is stopped; in case of ascending aorta cannulation the arterial cannula is removed first, inducing systemic hypotension. The venous femoral cannula is used to fill the patient with residual blood and it is removed after protamine administration. A 5–10 minutes compression at the level of the cannulation site is enough to obtain an adequate hemostasis.

Finally, two 28-Fr chest Blake pericardial silicone drains (Ethicon, Sommerville, NJ, USA) are placed through the two port sites. Pericardium is closed with 2–3 single sutures. The minithoracotomy incision is then closed in anatomical layers.

Mitro-aortic and triple valve disease (*Figure 2*)
A 5–7 cm incision is performed in the 3rd ICS at 2–4 cm from the sternal edge. Two ports are placed respectively in the 3rd and 5th ICS for video assistance, vent, CO_2 insufflation and pericardial stay sutures.

Femoral artery or ascending aorta cannulation is performed as previously described. For venous return, we prefer the use of the Biomedicus multiple stage cannula (Medtronic, Minneapolis, Minn) in case of mitro-aortic valve disease, reserving the use of the double-staged RAP cannula in case of TVS.

After aorta cross-clamping and cardioplegia delivery, aortic valve is approached first using a transverse aortotomy: the native valve is removed and decalcification of the aortic annulus performed. Following that, the mitral valve

procedure (repair or replacement) is carried out opening the left atrium at the level of the Sondergaard's groove. Then, the selected aortic prosthesis is implanted; technique for sutureless valve implantation has been described elsewhere (14). Finally, the tricuspid valve is approached. Weaning from CPB, decannulation and closure are performed as previously described.

Role of team members

Surgeon

The surgeon is involved in all phases of the procedure: patient selection, CT-scan visualization, perfusion strategy, surgical procedure and postoperative management. During the surgical procedure, particular attention must be paid to venous drainage (in accordance to the perfusionist), in order to maintain empty the heart during the whole procedure.

Cardiologist

The cardiologist is generally involved in the preoperative and postoperative management. Preoperative transthoracic echocardiography could give very important informations such as: degree of aortic regurgitation (crucial evaluation for the selection of cardioplegia delivery mode); mechanism of mitral/tricuspid regurgitation; size of mitral, aortic and tricuspidal annuli; ascending aorta diameter (in case of endoaortic ballon use); left/right ventricular function, etc.

Anesthesiologist

In minimally invasive procedures, anesthesiologist is crucial for TEE evaluation before and during the procedure for valves/prosthesis and cardiac function assessment, for percutaneous venous cannulation, for eventual venous cannula displacement during atrial retraction, for guidance of an endoaortic occlusion balloon placement, and for effective de-airing control.

Perfusionist

During the surgical procedure, perfusionist must pay particular attention to arterial line pressure (especially in case of femoral artery cannulation), venous drainage and cardioplegia line pressure, to achieve an adequate protection of the ischemic heart.

Postoperative management

Postoperative management is provided according to the standard institutional protocol. In our experience, regarding chest drains removal, it could be done during the first postoperative day, to allow a faster mobilization of the patient.

Conclusions

Multiple valve surgery accounts for 8–12% of valve procedures and it is associated with high operative risk (15). Reported operative mortality is 10% for combined mitral and tricuspid valve surgery, 11% for concomitant mitro-aortic surgery, and 13.2% for aortic and tricuspid valve surgery (16).

Minimally invasive valve surgery has been associated with better outcomes compared with the standard sternotomy approach, in terms of decreased morbidity, shorter in-hospital stay, and an faster recovery; in this setting MICS has been widely accepted as a good treatment option for isolated mitral and aortic valve operations (17,18); instead, few reports have analyzed outcomes of minimally invasive double and TVS, because little experience exists in this field.

In a series from Pfannmüller et al. on 441 consecutive patients who underwent RmT mitral and tricuspid valve surgery over a 10-year period, reported operative mortality was 4%, with a low rate of re-operations for bleeding (8%) and cerebrovascular accidents (2%) (19). Reported 5-year survival was 77.2%±2.5%. Mihos et al. evaluated the outcomes of 132 patients who underwent minimally invasive mitral and tricuspid valve surgery, of which 12% underwent re-operative double valve surgery (20). Post-operative outcomes were good, including 5 (4%) in-hospital deaths, 6 (5%) re-operations for bleeding, and 4 (3%) cerebrovascular accidents. The 1- and 5-year survival rates were 93% and 88%, respectively.

In our experience on 1,604 patients undergoing minimally invasive mitral valve surgery over a 10-year period, concomitant tricuspid valve repair was performed in 234 patients (14.6 %), with good early and long-term outcomes (8).

Instead, data involving concomitant mitro-aortic and triple valve minimally invasive surgery are somewhat limited. Some series have analyzed outcomes of patients treated through a partial sternotomy (21-23). Particularly a propensity-matched analysis by Atik et al., compared the outcomes of 162 patients undergoing a J-shaped partial sternotomy (N=81) or conventional median sternotomy (N=81) (22). No significant differences were found between the two study groups in terms of operative mortality (6.2% versus 2.5%, P=0.4), acute kidney injury (4.9% versus

1.2%, P=0.4), cerebrovascular accidents (2.5% versus 2.5%, P=1.0), or re-operation for bleeding (8.6% versus 4.9%, P=0.5). 10-year survival rate was also comparable, being 82% and 76% for the partial sternotomy and complete sternotomy group, respectively (P=0.7). The authors concluded that minimally invasive surgery did not increase the risk of primary double-valve operations, but observed benefits were restricted just to less blood loss and a better cosmetic results. The main limitation of this kind of approach is the inability to reach the Sondergaard's groove, making it necessary to approach the mitral valve through a superior transseptal atriotomy, with an increased risk of atrioventricular block (24). Moreover, a partial sternotomy sparing approach for double and triple valve disease does not eliminate the risk of sternal wound infection and mediastinitis. Instead, the sternal-sparing minithoracotomy approach could be particularly appealing for elderly patients with physical impairments or patients with chronic obstructive pulmonary disease, who could therefore be submitted to an aggressive physical therapy since the risk of sternal dehiscence does not exist.

Few reports have analyzed outcomes of the RmT approach. Lamelas *et al.*, have reported a series of 169 aortic valve replacement with concomitant mitral valve surgery (25). The median aortic cross clamp and CPB times were 116 minutes [interquartile range (IQR), 91–138 minutes] and 145 minutes (IQR, 121–178 minutes), respectively. Postoperative outcomes were excellent, with a mortality rate of 3.6% (6 patients); 4 (2.4%) patients required re-operation for bleeding, and 2 (1.2%) suffered from cerebrovascular accidents. Authors reported a median in-hospital length of stay of 7 days (IQR, 6–12 days).

Our results on minimally invasive double and TVS have been also reported (10,11). Recently, we have described a series of 69 patients undergoing concomitant mitral and aortic valve surgery (10). Mean age was 66±12 years, with a median Logistic EuroSCORE of 8 (IQR, 4–15); The most frequent type of surgery was aortic valve replacement with mitral valve repair (35 patients, 50.7%); tricuspid valve annuloplasty was performed in 12 patients (17.4%). Mean CPB and cross-clamp times were 135±41 and 95±32 min, respectively. The use of the sutureless technology, employed in 48 patients (69.6%), has led to an increase of the RmT approach for the mitro-aortic disease, with a significant reduction of CPB (120±23 *vs.* 160±67 min in stented prosthesis) and cross-clamp times (85±19 *vs.* 110±40 min). Postoperatively, no operative mortality was reported; 2 patients (2.9%) suffered from cerebrovascular accidents

and 3 (4.3%) required placement of a permanent pacemaker. Conversion to full sternotomy was very low compared to the rate reported in the literature (2.6–4.0%) (26); it was required only in 1 case, due to bleeding from the ascending aorta. Finally, at our institution, in contrast to Lamelas series, where a femoral platform was utilized to establish CPB, particular attention has been paid to a central aortic cannulation through the thoracotomy. Despite good results have been reported for both perfusion techniques, some retrospective studies have shown that during minimally invasive cardiac procedures the use of retrograde perfusion could be associated with an increased neurological risk compared with antegrade perfusion (27). Therefore, the low rate of neurological complications observed in our series has to be related to the use of the central aortic cannulation.

In conclusion, double and TVS through a RmT is a feasible approach in this subgroup of high risk patients that could reduce postoperative mortality and morbidity.

Acknowledgments

Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editor (Peyman Sardari Nia) for the series "Minimally Invasive Mitral Valve Surgery" published in *Journal of Visualized Surgery*. The article has undergone external peer review.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/jovs.2018.12.12). The series "Minimally Invasive Mitral Valve Surgery" was commissioned by the editorial office without any funding or sponsorship. The authors have no other conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the local ethical committee (No. 4/17) and individual consent was waived.

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