

Cite this article as: Panos A, Vlad S, Milas F, Myers PO. Is minimally invasive mitral valve repair with artificial chords reproducible and applicable in routine surgery? *Interact CardioVasc Thorac Surg* 2015;20:707–11.

Is minimally invasive mitral valve repair with artificial chords reproducible and applicable in routine surgery?

Aristotelis Panos^{a,b,c,*}, Sylvio Vlad^c, Fotios Milas^c and Patrick O. Myers^b

^a Center for Minimally Invasive Cardiac Surgery, Geneva, Switzerland

^b Cardiovascular Surgery, Geneva University Hospitals & School of Medicine, Geneva, Switzerland

^c Clinic for Cardiac Surgery, Hygeia Hospital, Athens, Greece

* Corresponding author. Center for Minimally Invasive Cardiac Surgery, 76A Av. de la Roseaie, 1205 Geneva, Switzerland. Tel: +41-22-3476420; fax: +41-22-3476420; e-mail: a.panos@bluewin.ch (A. Panos).

Received 19 September 2014; received in revised form 25 February 2015; accepted 27 February 2015

Abstract

OBJECTIVES: Traditional resectional techniques and chordal transfer are difficult to apply in video-assisted mitral valve repair. Using artificial chords appears easier in this setting. The purpose of this study was to review the effectiveness and reproducibility of neochordal repair as a routine approach to minimally invasive mitral repair, and to assess the stability of neochord implantation using the figure-of-eight suture without pledgets in this setting.

METHODS: This is a retrospective review of all patients who underwent minimally invasive video-assisted mitral valve repair from 2008 to 2013. The primary endpoints were recurrent mitral regurgitation and reoperation.

RESULTS: A total of 426 consecutive patients were included during the study period, with a mean age of 55 ± 18 years. Neochords were used in all patients, and in association with leaflet resection in 47 patients. One patient was not repairable and underwent valve replacement (repair rate, 99.8%). Fifteen patients had Grade I (3.5%) regurgitation, whereas the remainder had none. Patients were fast-tracked, with 25% extubated in the operation theatre and the remainder within 6 h. There were 5 deaths within 30 days (1.2%). Follow-up ranged 3–60 months, during which all of the patients remained with no or trace mitral regurgitation. No de-insertion or rupture of any neochords was found, and no patients required a reoperation.

CONCLUSIONS: Minimally invasive mitral valve repair using neochords provided a high rate of repair, reproducible results in a routine cardiac surgery setting and stable repair during follow-up. This has become our preferred technique for mitral valve surgery.

Keywords: Mitral valve repair • Minimally invasive cardiac surgery • Video-assisted • Neochords

INTRODUCTION

Minimally invasive video-assisted mitral valve repair is an emerging field in cardiac surgery. Although more complicated for the surgeon, it has been shown to be less traumatic for the patient and to provide faster recovery [1, 2]. In isolated posterior leaflet prolapse, a traditional variety of resectional techniques and chordae transfer are used for the repair of the prolapsed segments [3–5]. These techniques, although established, are limited in repairing extensively prolapsed valves. The use of neochords allows mitral valve repair without resection or chordal transfer with results comparable to resectional techniques [6, 7]. The application of neochords in the setting of video-assisted mitral valve repair may be challenging.

The purpose of this study was to evaluate the effectiveness and reproducibility of this method in the setting of routine surgery

and to assess the results of neochord implantation using the figure-of-eight suture without pledgets in mitral valve repair.

METHODS

Study design

This study is a retrospective review of all patients who underwent minimally invasive video-assisted mitral repair using artificial chords at our clinic between 2008 and 2013, and all were operated on by the same surgeon (Aristotelis Panos). Patients with mitral stenosis, active endocarditis, peripheral arterial disease or previous surgery in the right chest were excluded. The primary endpoints were recurrent mitral valve regurgitation and reoperation on the mitral valve. Clinical or treatment variables were

recorded to determine predictors of the endpoints. All patients underwent follow-up until death or January 2014.

Surgical techniques

The mitral valve was approached through a small antero-lateral thoracotomy (working port) and the entire procedure was accomplished under the vision of a 30°, 10 mm video assistance. CO₂ was continuously insufflated inside the thoracic cavity with a 2-l/min flow and 3–4 mmHg of pressure. The blood CO₂ was continuously monitored. Full cardiopulmonary bypass was instituted with arterio-venous femoral cannulation as well as internal jugular venous cannulation. The aorta was clamped with a Chitwood clamp. The resectional techniques consisted of triangular or rectangular resection of the prolapsed segment without annular plication, or the ‘haircut’ technique as previously described [8]. For neochords, we used the desired number of expanded polytetrafluoroethylene (ePTFE) CV 4/0 suture (W. L. Gore & Associates, Inc., Newark, DE, USA) preformed loops, which were anchored in the adequate papillary muscle (PM) by a figure-of-eight suture, without teflon felt or pledgets, and then attached to the leaflet-free margin by means of an ePTFE CV 6/0 or Prolene 5/0 suture (Fig. 1). The length of the chordae was defined perioperatively by measuring the non-prolapsed segment native chords and reproducing these measurements with the Fehling sizer.

Patients with a history of paroxysmal atrial fibrillation, or persistent atrial fibrillation, for less than 6 months and without significant left atrial enlargement underwent atrial fibrillation ablation, using the Cox-maze IV lesion set with a Medtronic unipolar endocavitary cardioablate pencil device (Medtronic, Inc., Minneapolis, MN, USA) through the same incision.

We aimed for a fast-track postoperative care protocol, with rapid extubation and mobilization.

RESULTS

Demographics and surgical technique

A total of 426 consecutive patients were included during the study period. Patient baseline demographics and characteristics are detailed in Table 1. They underwent video-assisted mitral valve repair for degenerative disease or healed endocarditis of the

posterior, anterior or both leaflets. The mean age at operation was 55 ± 18 years, with LVEF of 60 ± 8% and median NYHA class II; 66 patients (15.5%) had previously undergone cardiac surgery.

Operative characteristics are detailed in Table 2. Neochords were used in all patients, and in 47 of them an association of leaflet resection and neochords were used. These techniques include the ‘haircut’ technique and sliding plasty. All patients but 14 received rigid annuloplasty rings (Edwards Physio I for the first period and Physio II for the later); 53 patients with atrial fibrillation meeting our criteria for operation underwent a Cox-maze IV procedure.

Early outcomes

The mean aortic cross-clamp time was 106 ± 28 min and the cardiopulmonary bypass time was 133 ± 30 min. One patient, whose mitral valve appeared repairable on preoperative imaging, was found not to be repairable and his valve was replaced with a bioprosthetic valve (repair rate, 99.8%). Fifteen patients (3.5%) had residual regurgitation that required multiple mitral valve repair attempts; these patients had significantly longer cardiopulmonary bypass times, although the final result was also good without

Table 1: Baseline patient characteristics

Characteristic	Value
Patients	426
Aetiology of mitral valve regurgitation	
Degenerative mitral valve disease	411 (96.5%)
Healed endocarditis	15 (3.5%)
Mitral valve leaflets involved	
Posterior	337 (79%)
Anterior	57 (13.4%)
Both leaflets	32 (7.6%)
Age (years)	55 ± 18
LVEF	60 ± 8%
NYHA functional class (median)	II
Prior cardiac surgery	66 (15.5%)

All data are presented as mean ± standard deviation or number (percentage), unless otherwise noted.
LVEF: left ventricular ejection fraction; NYHA: New York Heart Association.

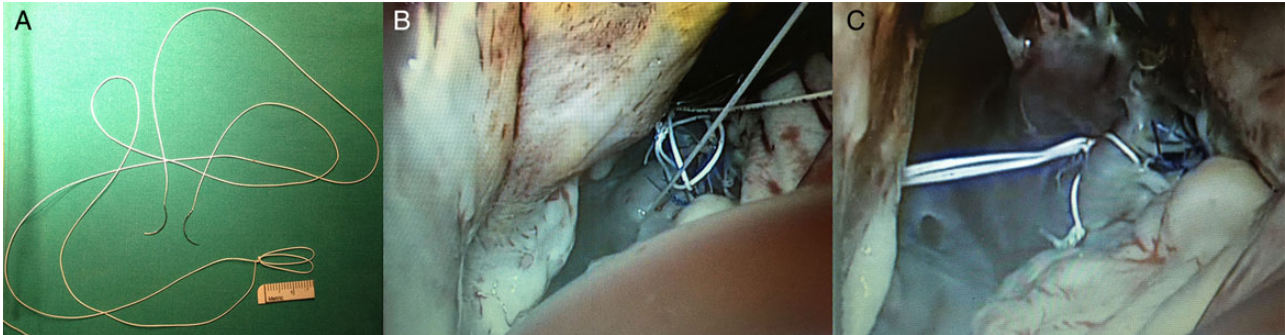


Figure 1: Operative technique to reproduce the ruptured chordae tendineae using a looping figure of eight suture. (A) Loops are created to the desired length using an ePTFE suture. The length of the chordae was determined per-operatively by measuring the non-prolapsed segment of the native chords and reproducing these measurements with the Fehling sizer. (B and C) The loops are placed at the tip of the papillary muscle head, and then attached to the leaflet-free margin by the means of the ePTFE CV 6/0 or Prolene 5/0 suture. ePTFE: expanded polytetrafluoroethylene.

Table 2: Patient operative characteristics

Characteristic	
Patients, <i>n</i>	426
Valve replacement	1 (0.2%)
Valve repair	425 (99.8%)
Neochords	425 (100%)
Leaflet resection (including haircut and sliding plasty)	47 (9.4%)
Rigid annuloplasty	411 (96.5%)
Cox-maze IV procedure	53 (12.4%)
Cross-clamp time (min)	106 ± 28
Cardiopulmonary bypass time (min)	133 ± 30
Multiple cardiopulmonary bypass run for adequate repair	15 (3.5%)
Fast-track extubation <6 h	108 (25%)
Hospital stay (days)	5 ± 1.3

All data are presented as mean ± standard deviation or number (percentage), unless otherwise noted.

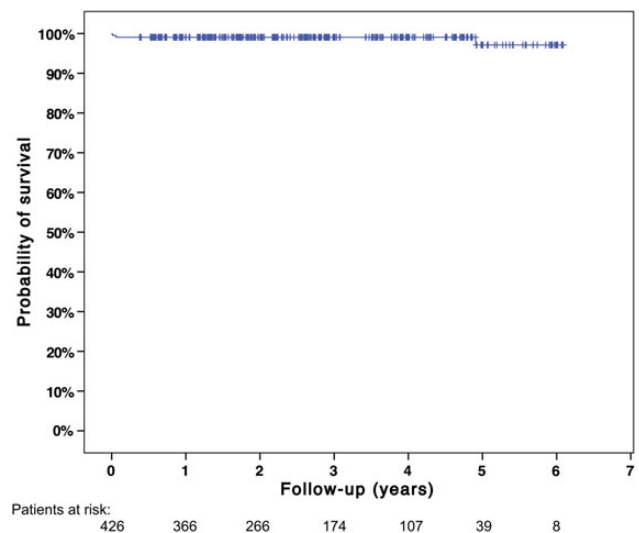
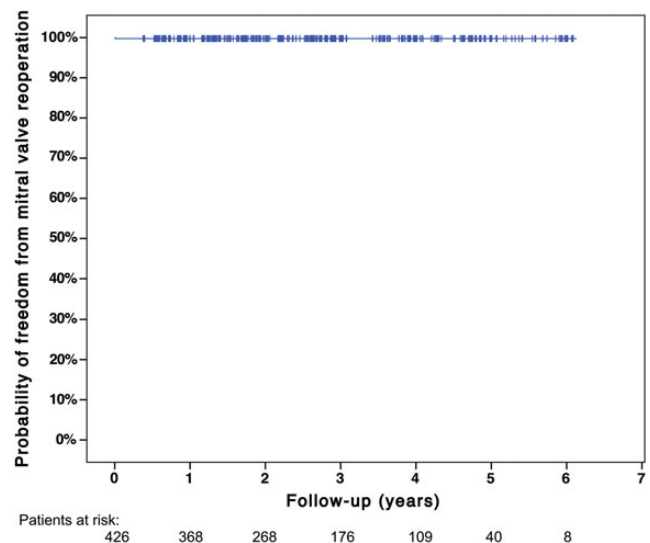
more than 1+ residual regurgitation. All the patients had fast-track extubation (ranging from 3 to 12 h postoperatively), and 108 patients (25%) were extubated in the operation theatre.

One patient died during the operation from myocardial stunning despite prolonged CPB assistance. There were 4 more deaths within 30 days of mitral valve operation (0.9%): a 65-year old patient on chronic corticotherapy died from massive haemorrhage from a tear on the suture line of the left atrium, while in the step-down ward; another patient died of massive embolic stroke to the basilar artery with subsequent herniation; the third death was attributed to pneumonia in an immunocompromised patient; the last patient was found dead at home the 24th postoperative day. There was no clear cause of death at autopsy, and the most probable cause of the death was ventricular arrhythmia.

One patient required reoperation for severe systolic anterior motion, which resolved after the replacement of the complete annuloplasty ring with a posterior partial band. Conversion to sternotomy was required in 2 patients (0.5%), one for a tear on removal of the cardioplegia cannula on the aorta and the other because it was unfeasible to defibrillate the patient externally. These two events occurred during the first year of the study period. Three patients (0.7%) had cerebral ischaemic episodes; all but one of these resolved (0.2%). No vascular or wound complications were observed. Bleeding was evaluated to 350 ± 186 ml. Five patients (1.1%) required re-exploration for bleeding (decided on the basis of >500 ml bleeding during the first hour despite correction of coagulopathy) and haemostasis was achieved through the same incision in all of them. The mean ICU time was 1.2 ± 1.1 days, and the mean hospital stay was 5 ± 1.3 days. Fifty-eight patients presented with pleural effusion (13.6%).

Late outcomes

No patient was lost to follow-up at our recall in January 2014 (100% follow-up). During a median follow-up of 31.7 (range, 1–73) months, all of the patients remained with no or trace mitral valve regurgitation. No patient required reoperation during late follow-up, and there were no late thromboembolic events. The probability of survival was 99.1 ± 0.5% and this remained stable

**Figure 2:** Kaplan–Meier analysis of survival.**Figure 3:** Kaplan–Meier analysis of the probability of freedom from mitral valve reoperation.

throughout follow-up (Fig. 2). The probability of freedom from mitral valve reoperation was 99.8 ± 0.2% at 12 months and this remained stable throughout follow-up. Among the 53 patients who underwent concomitant ablation, 36 were in sinus rhythm (68%) at 6 months and 24 (45%) at 2 years (Fig. 3).

DISCUSSION

We introduced minimally invasive mitral valve repair in our routine practice 6 years ago [9]. The aim of this study was to assess the versatility of this technique in the setting of everyday, routine cardiac surgery, and assess the results of repair exclusively using neochords or a combination of neochords and leaflet resection techniques without annular plication, along with remodelling annuloplasty. Since the beginning of this series, we decided to implant the neochords directly in the distal muscular portion of

the PM, irrespective of the fibrous tip, in a 'figure-of-eight' fashion without pledgets.

The standardization of the procedure was the first step in order to achieve an easy, fast and reproducible set-up in the operating room. The anaesthesiologist inserted a 14-Fr jugular drainage cannula (Medtronic, Inc.), which allowed good venous drainage throughout the procedure irrespective of the pull tension on the left atrium by the atrial retractor (Delacroix-Chevalier, 75011, Paris, France). The mini-thoracotomy was shifted laterally towards the anterior axillary line with the camera port in the same intercostal space as the incision, just 4–5 cm laterally. The transthoracic aortic cross-clamp was inserted one intercostal space higher, parallel to the camera.

Many studies advocate the use of artificial chords for mitral repair [6, 7, 10]. In most of these, the neochords are anchored on the tip of the PM with the help of Teflon pledgets. We decided to implant all neochords directly in the distal part of the PM in order to simplify the procedure. After more than 400 patients, we have not encountered any dehiscence of the muscle due to the absence of pledgets. We believe that the induced fibrosis precludes any tear in the long term. Furthermore, care is taken to space the figure-of-eight loops, with distinct entry and exit points into the PM head, to spread the tension. Recently, Wuethrich *et al.* presented an animal study on a porcine model comparing three anchoring techniques of ePTFE sutures at the PM [11]. They concluded that a figure-of-eight ePTFE suture placed in a wide angle at the anatomical chord position (tip of the PM) without pledgets fulfils the physiological needs and technical requirements for excellent long-term clinical results. While sutures placed at the base provide slightly higher resistance to rupture under tension, placement of sutures in this position renders PM function obsolete, resulting in incorrect loading throughout the cardiac cycle.

Our relatively high repair rate (99.8%) demonstrates that the minimally invasive technique is efficient and reproducible, and comparable to the 100% rate reported by some centres of excellence [13]. Many studies have demonstrated the reliability of the neochords in mitral valve repair in diverse settings [6, 7, 10, 12, 14], with the exception of a rare case report of neochord rupture [15]. Artificial chords are easy to prepare and insert in video-assisted minimally invasive mitral valve surgery, without a higher risk for the patient and with excellent and reproducible surgical results. Along with other technical innovations in adapting existing techniques of annuloplasty ring implantation, such as running suture traditional ring or band placement [16] or placement of the intra-annular single suture annuloplasty ring [17], we have found repair of prolapsed mitral leaflets with neochords feasible and reproducible. Resection techniques have shown excellent long-term results, and were used in conjunction with neochords in 47 of our patients (9.4%). In patients with extensive prolapsed leaflet segments, resection techniques risk resecting too much leaflet tissue to allow for an adequate repair. Neochords or non-resectional techniques can provide excellent results without requiring annular plication. Furthermore, these techniques are sometimes difficult to perform and time-consuming in the setting of minimally invasive valve surgery.

This study has several limitations. First, this was a retrospective study designed to review our results after introducing a novel and standardized approach to minimally invasive mitral valve repair. Second, the cardiopulmonary bypass and aortic cross-clamp times remained relatively long. This technique is associated with a learning curve, and longer operative times have been reported in all series of minimally invasive mitral valve repair. In addition, we aim

for a perfect result on our repairs with not even trivial leaks and very good coaptation surface. We used more loops to evenly distribute the forces exerted on the free margin of the prolapsing leaflets. Many patients also had very extended bileaflet prolapse, requiring more complex and time-consuming repairs. However, in the current era of myocardial protection, it has been clearly demonstrated that operative times have little impact on hard outcomes such as mortality, while technical performance (i.e. leaving the operative room without a significant haemodynamic lesion and having achieved what was planned) is increasingly shown to have a greater impact on these outcomes [18, 19]. Furthermore, the less-invasive nature of these repairs allows for a more rapid post-operative rehabilitation and return to daily activities. We did have a relatively high prevalence of pleural effusion (14%). Over the last 2 years, we have adapted our postoperative management, leaving chest tubes in place for a minimum of 24–36 h. Furthermore, in young patients, we introduce systematic ibuprofen 400 mg q8 h for 5 days for analgesic and anti-inflammatory effects. This approach has decreased the prevalence of pleural effusion significantly.

CONCLUSIONS

Minimally invasive mitral valve repair using neochords provided a repair rate close to 100%, reproducible results in a routine cardiac surgery setting and a stable repair during follow-up. These excellent and reproducible results have made minimally invasive mitral valve repair our preferred method for mitral valve surgery.

Conflict of interest: none declared.

REFERENCES

- [1] Modi P, Hassan A, Chitwood WR Jr. Minimally invasive mitral valve surgery: a systematic review and meta-analysis. *Eur J Cardiothorac Surg* 2008;34:943–52.
- [2] Woo YJ, Rodriguez E, Atluri P, Chitwood WR Jr. Minimally invasive, robotic, and off-pump mitral valve surgery. *Semin Thorac Cardiovasc Surg* 2006;18:139–47.
- [3] Carpentier A. Cardiac valve surgery—the 'French correction'. *J Thorac Cardiovasc Surg* 1983;86:323–37.
- [4] DiBardino DJ, ElBardissi AW, McClure RS, Razo-Vasquez OA, Kelly NE, Cohn LH. Four decades of experience with mitral valve repair: analysis of differential indications, technical evolution, and long-term outcome. *J Thorac Cardiovasc Surg* 2010;139:76–83; discussion 83–4.
- [5] Cevasco M, Myers PO, ElBardissi AW, Cohn LH. Foldoplasty: a new and simplified technique for mitral valve repair that produces excellent medium-term outcomes. *Ann Thorac Surg* 2011;92:1634–7; discussion 1637–8.
- [6] Falk V, Seeburger J, Czesla M, Borger MA, Willige J, Kuntze T *et al.* How does the use of polytetrafluoroethylene neochordae for posterior mitral valve prolapse (loop technique) compare with leaflet resection? A prospective randomized trial. *J Thorac Cardiovasc Surg* 2008;136:1205; discussion 1205–6.
- [7] Seeburger J, Falk V, Borger MA, Passage J, Walther T, Doll N *et al.* Chordae replacement versus resection for repair of isolated posterior mitral leaflet prolapse: a egalite. *Ann Thorac Surg* 2009;87:1715–20.
- [8] Chu MW, Gersch KA, Rodriguez E, Nifong LW, Chitwood WR Jr. Robotic 'haircut' mitral valve repair: posterior leaflet-plasty. *Ann Thorac Surg* 2008;85:1460–2.
- [9] Panos A, Myers PO. Routine robotic and video-assisted mitral valve repair in everyday surgery. *Cardiovasc Med* 2011;14:92–4.
- [10] Mihaljevic T, Pattakos G, Gillinov AM, Bajwa G, Planinc M, Williams SJ *et al.* Robotic posterior mitral leaflet repair: neochordal versus resectional techniques. *Ann Thorac Surg* 2013;95:787–94.
- [11] Wuethrich O, Giggisberg S, Maechler A, Vandenbergh S, Weber A, Carrel T. Tensile strength of polytetrafluoroethylene figure of eight sutures at the

- papillary muscle for chordal replacement in mitral valve repair. <http://aats.org/mitral/abstracts/2013/E6.cgi>.
- [12] Oda S, Nakano T, Tatewaki H, Hinokiyama K, Machida D, Kado H. A 17-year experience with mitral valve repair with artificial chordae in infants and children. *Eur J Cardiothorac Surg* 2013;44:e40-5.
 - [13] Castillo JG, Anyanwu AC, Fuster V, Adams DH. A near 100% repair rate for mitral valve prolapse is achievable in a reference center: implications for future guidelines. *J Thorac Cardiovasc Surg* 2012;144:308-12.
 - [14] Castillo JG, Anyanwu AC, El-Eshmawi A, Adams DH. All anterior and bileaflet mitral valve prolapses are repairable in the modern era of reconstructive surgery. *Eur J Cardiothorac Surg* 2014;45:139-45.
 - [15] Farivar RS, Shernan SK, Cohn LH. Late rupture of polytetrafluoroethylene neochordae after mitral valve repair. *J Thorac Cardiovasc Surg* 2009;137:504-6.
 - [16] Mihaljevic T, Jarrett CM, Gillinov AM, Blackstone EH. A novel running annuloplasty suture technique for robotically assisted mitral valve repair. *J Thorac Cardiovasc Surg* 2010;139:1343-4.
 - [17] Myers PO, Panos A, Kalangos A. Simplifying robotic mitral valve repair: minimizing sutures with intra-annular ring implantation. *J Thorac Cardiovasc Surg* 2010;140:1441-2.
 - [18] Nathan M, Gauvreau K, Liu H, Pigula FA, Mayer JE, Colan SD *et al.* Outcomes differ in patients who undergo immediate intraoperative revision versus patients with delayed postoperative revision of residual lesions in congenital heart operations. *J Thorac Cardiovasc Surg* 2014;148:2540-6. e1-5.
 - [19] Nathan M, Sleeper LA, Ohye RG, Frommelt PC, Caldarone CA, Tweddell JS *et al.* Technical performance score is associated with outcomes after the Norwood procedure. *J Thorac Cardiovasc Surg* 2014;148:2208-13, 2214. e1-6.