Mitral valve repair, how to make volume not matter; techniques, tendencies, and outcomes, a single center experience

Manuel Giraldo-Grueso, Néstor Sandoval-Reyes, Jaime Camacho, Ivonne Pineda and Juan P. Umaña

Abstract

Background: Recent evidence has showed us that quality of mitral valve repair is strongly related to volume. However, this study shows how low-volume centers can achieve results in mitral valve repair surgery comparable to those reported by referral centers. It compares outcomes of mitral valve repair using resection versus no resection techniques, tendencies, and rates of repair.

Methods: Between 2004 and 2017, 200 patients underwent mitral valve repair for degenerative mitral valve disease at Fundación Cardioinfantil-Institute of Cardiology. Fifty-eight (29%) patients underwent resection and 142 (71%) no resection.

Results: Follow-up was 94% complete, mean follow-up time was 2.3 years. There was no 30-day mortality. Five patients required mitral valve replacement after an average of 5.3 years (Resection = 2; Noresection = 3). Freedom from severe mitral regurgitation was 98% at 6.6 years of follow-up for the no resection group, and 92.5% at 7 years for the resection group (log rank: 0.888). At last follow-up, two patients died of cardiovascular disease related to mitral valve, 181 patients (86%) showed no or grade I mitral regurgitation. Patients with previous myocardial infarction had increased risk of recurrent mitral regurgitation (p = 0.030). Within four years, we inverted the proportion of mitral valve replacement and repair, and in 2016 we achieved a mitral valve repair rate of 96%.

Conclusion: This study suggests that resection and no resection techniques are safe and effective. Recurrence of severe mitral regurgitation and need for mitral valve replacement are rare. We show that low-volume centers can achieve results comparable to those reported worldwide by establishing a mitral valve repair team. We encourage hospitals to follow this model of mitral valve repair program to decrease the proportion of mitral valve replacement, while increasing mitral valve repair.

Keywords: Mitral regurgitation, Mitral valve annulus repair, Prolapsed mitral valve

Background

Mitral valve repair (MVr) is the gold standard for the treatment of mitral regurgitation (MR) secondary to degenerative mitral valve (MV) disease. MVr was initially performed by Alain Carpentier in 1983, who developed a standardized approach to correct MR, dubbed “the French correction”. It involved leaflet resection followed by annular plication with or without sliding plasty in order to restore the coaptation surface [1].

Excellent, reproducible results led to this technique becoming the gold standard to treat mitral valve prolapse. In 1998, Tirone David et al. proposed a novel repair technique using extended polytetrafluoroethylene (ePTFE) sutures for chordal replacement, preserving leaflet tissue and improving surface of coaptation [2].

Subsequent studies have shown excellent results for both techniques in terms of mortality, morbidity, and freedom from recurrent MR [3]. Controversy remains as to which technique is superior given lack of long-term follow-up with creation of neochordae and the perception that this technique is more difficult to standardize, preventing widespread application.
In Latin America, long-term results of MVr remain unknown and the established practice is to replace rather than repair the MV. The present study was carried out to evaluate the short and long-term results of MVr using resection (R) versus noresection (NR) techniques in a low-volume center and resolve if a low-volume center can achieve MVr results comparable to those reported worldwide. We analyzed freedom from reoperation, recurrent MR, and functional status, as well as the change in the tendency of MVr and mitral valve replacement (MVR) at our institution over the study period. The findings of the study seek to improve cardiac surgery.

Methods

Patients
From January of 2004 to June 2017, 200 patients underwent MVr due to degenerative MV disease at Fundación Cardioinfantil- Institute of Cardiology, in Bogotá Colombia. Patients were identified through an institutional cardiac surgery database. Operational definitions, demographic variables, preoperative, intraoperative characteristics, and 30-day outcomes were obtained retrospectively according to the Society of Thoracic Surgeons database guidelines [4].

Fifty-eight patients (29%) were in the R group and 142 (71%) in the NR group (chordal replacement or just ring annuloplasty). Twelve patients (6%) were lost to follow up.

Interventions
Operations were performed through a conventional median sternotomy or minimally invasive techniques (right lateral minithoracotomy or periareolar approach). In the conventional approach, cardiopulmonary bypass was established through standard bicaval and aortic cannulation with moderate hypothermia. Intraoperative transesophageal echocardiography was used routinely in all patients. Access to the MV was performed through a left atriotomy. Next, segmental analysis of the MV was performed as described by Carpentier and colleagues [5]. In all patients, ring annuloplasty was performed with a semi-rigid, complete ring Fig. 1.

When the repair was performed minimally invasively, the femoral vessels were cannulated using modified Seldinger technique under echocardiographic guidance. A Chitwood clamp was used and cardiac arrest achieved using HTK or Del Nido cardioplegia. Video assistance was used routinely.

Chordal replacement was performed with 5.0 ePTFE sutures without pledgets, passed as a figure of eight through the tip of the papillary muscle, followed by a figure of eight through the free edge of the prolapsing segment. A minimum of two neochordae were placed, and sutures were added depending on the size of the prolapsing segment. The height of the neochordae was established by filling the ventricle with a cold cardioplegic solution to test the valve hydrostatically. The number of neochordae ranged from one to seven pairs (mean: 1.88). A single pair of neochordae was used in 29% and multiple in 71%. The decision to perform either a R or NR technique was left to the surgeon’s criteria.

Surgical data were obtained by systematic chart review, emphasizing the MVr technique and approach.

Data collection
Preoperative (age, previous cardiac operation, functional class, Euroscore II, left ventricular ejection fraction, previous arrhythmia, and medical history) and postoperative variables (length of stay, cross-clamp and cardiopulmonary bypass time, reoperation for bleeding and 30-day mortality) were described.

Follow up was performed by telephone or in person (clinic visits). Endpoints were recurrent MR, reoperation or death. Echocardiographic evaluations were performed postoperatively before discharge, 30 to 90 days after surgery, then annually thereafter. The severity of MR was classified as none/trivial (0), mild (I), moderate (II) or severe (III). New York Heart Association (NYHA) functional class was assessed in all the patients. Echocardiographic data were used for analysis only if there were at least two echocardiographic reports available.

We described tendencies and number of cases of MVR and MVr for degenerative MV disease from 2004 to 2016. Data were obtained from the institutional cardiac surgery database.

Statistical analysis
Baseline demographics and clinical characteristics were summarized using descriptive statistics. For continuous variables, data were presented as mean or median and standard deviations or interquartile range. Categorical variables were presented as absolute numbers and percentages. The frequency of MR was described. The difference between the groups R and NR were ascertained using chi-square test or Fisher test, and Mann-Whitney U test. The endpoint of interest was recurrent severe MR, MV reoperation or death. Patients that did not reach the endpoint were censored at the end of study time. Survival was analyzed through Kaplan-Meier method; the log-rank test was used to determine differences between groups. Statistical analysis was done with Stata SE 14 (program). A significance level of 0.05 was used throughout the analysis.
Results
Demographic data
Follow-up was 94% complete with a mean time of 2.33 years. Preoperative variables are summarized in Table 1. Of all patients, 122 (61%) were male, and the average age at operation was 58 (48–58) years for the NR group and 56 (50–65) years for the R group. Before surgery, NYHA functional class was assessed in all the patients, 21 (10.5%) were in NYHA class I, 135 (67.5%) class II and 33 (16.5%) class III. Three (1.5%) patients had a history of myocardial infarction before surgery, all of them belong to the NR group. We found differences in the left ventricular ejection fraction (LVEF) between groups; 55% (50–60%) and 60% (51–65) for the NR and R group, respectively ($p = 0.013$).

Euroscore II was calculated in all patients before surgery. 50.4% in the NR group were classified as low risk, compared to 25.9% in the R group (risk < 2%) Fig. 2.

Perioperative outcomes
Perioperative variables are summarized in Table 1. One hundred and seven patients (75%) of the NR group and 48 (84.5%) of the R group underwent isolated MVr. Mean cardiopulmonary bypass time was similar for both groups, 117 min (IQR 95–141) and 117 min (IQR 105–143) for the NR and R groups respectively. Forty-seven (33.1%) patients from NR group and 35 (60%) from R group had a posterior leaflet prolapse ($p = 0.004$). There was a statistically significant difference in the number of minimally invasive procedures performed in each group, with 51 (32.9%) in the NR group and 7 (12.1%) in the R group ($p = 0.001$). Overall 30-day mortality was 0%.

Survival outcomes
NYHA class and incidence of MR at last follow-up in 188 patients are reported in Table 2. Functional class was assessed in all the patients, most of whom showed significant improvement: 156 (83%) had NYHA class I, 25 (13%) class II, 5 (3%) class III and 2 (1%) class IV. Patients in NYHA class IV had concomitant chronic obstructive pulmonary disease (COPD). Ninety-eight patients (52%) had none/trace MR, mild MR in 70 (37%), and moderate/severe in 20 (10%).

There were only two cardiac-related deaths at last follow-up. Freedom for severe MR was 98% at 6.6 years of follow-up for the NR group, and 92.5% at 7 years of follow-up for the R group. Based on MVr technique, patients in the R group had the same likelihood of developing MR compared to patients in NR group (log rank: 0.881). Five patients required an MV replacement after an average of 5.3 years, 3 belonged to the NR group and 2 to the R group Fig. 3.

Bivariate analysis
In the bivariate analysis, patients with previous myocardial infarction had an increased risk of developing at least moderate recurrent MR ($p = 0.030$). Preoperative variables such as diabetes, dialysis, dyslipidemia, hypertension and previous arrhythmia, were not associated with an increased risk of developing recurrent MR after MVr. Patients that underwent minimally invasive repair, had a lower risk of developing recurrent MR ($p = 0.040$) Table 3.

Mitral valve surgery tendencies and repair rate
Tendencies and number of cases of MVr and MVR for degenerative MV disease are shown in Fig. 4. Within four years, we inverted the tendency and were able to maintain MVr as preferred technique of MV intervention. The MVr rates at our institution are shown in Fig. 5. Over the years there has been a constant increase in MVr rate, achieving a 96% repair rate in 2016.

Discussion
MV regurgitation is frequently caused by degenerative MV disease leading to myxomatous changes with chordal elongation with or without rupture [6–8]. R and NR techniques have shown excellent results, with low incidence of progression to severe MR and need for MVR [7–9]. In our series, five patients required MVR.
Table 1 Preoperative, clinical, and perioperative variables of the patients

| Variable                         | No resection n = 142 | Resection n = 58 | P value |
|----------------------------------|----------------------|-----------------|---------|
| **Preoperative variables**       |                      |                 |         |
| Male sex                         | 83 (58.4)            | 39 (67.2)       | 0.247   |
| Age years, median IQR            | 58 (48–66)           | 56 (48–66)      | 0.969   |
| Diabetes                         | 9 (6.3)              | 1 (1.7)         | 0.287   |
| Dyslipidemia                     | 18 (12.7)            | 11 (18.9)       | 0.252   |
| Dialysis                         | 2 (1.4)              | 3 (5.2)         | 0.147   |
| Hypertension                     | 59 (41.5)            | 20 (34.5)       | 0.354   |
| COPD                             |                      |                 |         |
| Creatinine                       | 1 (0.9–1.08)         | 0.95 (0.9–1)    | 0.821   |
| Previous myocardial infarction   | 0                    | 3 (5.2)         | 0.023   |
| Previous cardiac operation       | 4 (2.8)              | 1 (1.7)         | 0.999   |
| NYHA functional class            |                      |                 |         |
| I                                | 12 (8.7)             | 9 (17.3)        | 0.079   |
| II                               | 99 (72.3)            | 36 (69.2)       |         |
| III                              | 26 (19)              | 7 (13.5)        |         |
| Previous arrhythmia              | 48 (33.8)            | 19 (32.8)       | 0.887   |
| LVEF, median IQR                 | 55 (50–60)           | 60 (51–65)      | 0.013   |
| **Perioperative variables**      |                      |                 |         |
| Isolated ring annuloplasty       | 14 (9.8)             | 0 (0.0)         | < 0.001 |
| Isolated MV repair               | 107 (75)             | 49 (84.5)       | 0.108   |
| Non-Isolated MV repair           | 35 (25)              | 9 (15.5)        | 0.235   |
| ASD closure                      | 7 (4.9)              | 0 (0.0)         | 0.086   |
| Tricuspid repair                 | 24 (16.9)            | 9 (15.5)        | 0.809   |
| Tricuspid replacement            | 1 (0.7)              | 0 (0.0)         | 0.001   |
| Tricuspid repair+ASD closure      | 3 (2.1)              | 0 (0.0)         | 0.013   |
| Minimally invasive               | 51 (35.9)            | 7 (12.1)        | < 0.001 |
| ICU stay days                    | 1 (1–4)              | 1 (1–3)         | 0.495   |
| Post ICU stay (days)             | 3 (2–5)              | 4 (3–5)         | 0.674   |
| **Degenerative MV pathology**    |                      |                 |         |
| Posterior leaflet prolapse       | 47 (33.1)            | 35 (60.3)       | 0.004   |
| Anterior leaflet prolapse        | 23 (16.1)            | 4 (6.8)         | 0.079   |
| Bileaflet prolapse               | 17 (11.9)            | 3 (5.1)         | 0.144   |
| Elongated/ruptured chord(s)      | 29 (20.4)            | 10 (17.2)       | 0.604   |
| Annular dilation                 | 25 (17.6)            | 2 (3.4)         | 0.014   |
| Unknown                          | 1 (0.7)              | 4 (6.9)         | 0.011   |
| **Postoperative complications**  |                      |                 |         |
| Reoperation for bleeding         | 0 (0.0)              | 2 (3.4)         | 0.083   |
| Renal impairment                 | 2 (1.4)              | 0 (0.0)         | 0.503   |
| Hospital length of stay          | 8 (5–15)             | 8 (5–14)        | 0.906   |
| Mortality 30 days                | 0 (0.0)              | 0 (0.0)         |         |

Categorical data are expressed as number (%) and continuous data as median (Interquartile range)

COPD Chronic Obstructive Pulmonary Disease, ICU Intensive Care Unit, IQR Interquartile Range, LVEF Left Ventricular Ejection Fraction, NYHA New York Heart Association
after an average of 5.3 years, three belonged to the NR group and two to the R group, one patient from the NR group had an ePTFE chord rupture. Schwartz et al. [10] described similar results with a freedom from reoperation of 89% at ten years. There was no 30-day mortality in our series; Lange et al. [11] showed comparable results with 30-day mortality of 1%. We were able to achieve MVR results with R and NR techniques similar to those reported by referral institutions, despite being a low-volume center.

NR techniques, like chordal replacement, preserve leaflet mobility increasing coaptation surface and avoiding outflow tract obstruction. How to standardize length of the neochordae and the long-term durability of the repair remain subjects of debate [11, 12]. In our series survival rates of NR techniques for severe MR were 77% (CI 95% 0.38–0.93) at 6.6 years of follow-up and freedom from reoperation was 98.40%. Salvador et al. [13] reported 608 consecutive MVR with NR techniques, with a freedom from reoperation of 92% after 15 years. R techniques have exhibited excellent results [1, 11], however, these techniques sometimes sacrifice a large amount of valve tissue, resulting in leaflet restriction, and requires a skilled and experienced surgeon. New techniques, like butterfly resection, have been shown to prevent systolic anterior motion, decreasing the need for annular plication [14, 15]. In our series survival rates of R techniques for severe MR were 92.4% (CI 95% 0.69–0.98) at 8.3 years of follow-up, with a freedom from reoperation of 96%. Sakamoto et al. [16] reported the long-term results of this techniques, with a freedom from reoperation of 92.3% at 10 years.

In the matter of functional class, the results are excellent; the majority of patients showed considerable improvement after surgery. In our series, at last follow-up, 156 (82.9%) were in NYHA class I and 181 patients (86%) showed no or grade I MR, with no difference between groups. Lange et al. [11] described similar results, at last follow-up 94% of their patients showed no or grade I MR. The literature supports that the incidence of severe MR, need for reoperation, and death are equally low with R and NR techniques [11, 17–21]. However, the institutions were these investigations were conducted had high-volumes of MVR. It was uncertain if centers with low-volume could reproduce these results.

In our bivariate analysis, we found that patients that underwent minimally invasive repair had a lower risk of developing recurrent moderate MR. This could be explained by the fact that in our practice, minimally invasive MVR is performed by a single surgeon (JPU), who also has the most experience. Further analysis has also shown, that minimally invasive MVR has resulted in earlier referral of patients by cardiologists, leading to patients being healthier, with less comorbidities. Since the NR group had more minimally invasive repairs, this could explain the difference in euroscore II assessments between groups.

Table 2 Postoperative occurrence of mitral regurgitation and assessment of NYHA class

| Variable                  | No resection | Resection   | P value |
|---------------------------|--------------|-------------|---------|
| NYHA functional class     |              |             | 0.797   |
| I                         | 115 (84.5)   | 41 (78.8)   |         |
| II                        | 16 (11.7)    | 9 (17.3)    |         |
| III                       | 3 (2.2)      | 2 (3.8)     |         |
| IV                        | 2 (1.5)      | 0           |         |
| Mitral valve regurgitation|              |             | 0.267   |
| None/Trace                | 76 (56.0)    | 22 (42.3)   |         |
| Mild                      | 48 (35.3)    | 22 (42.3)   |         |
| Moderate                  | 9 (6.6)      | 6 (11.5)    |         |
| Severe                    | 3 (2.1)      | 2 (3.8)     |         |

Categorical data are expressed as number (%) NYHA New York Hear Association
Our results show that, despite low volumes in the earlier years of our experience, MVr results achieved can be comparable to those reported by referral centers worldwide, leading to an inversion in the tendency of MVR vs MVr in our Institution and an excellent MVr rates. We attribute this change to the creation of a MVr program, with a dedicated team lead by a MV surgeon (JPU) resulting in better patient selection, standardization of processes and procedures, education of referring physicians, earlier patient referral, and better postoperative care and follow-up.

To improve volume and results of the MVr program, we began to encourage targeted referral and guideline-based assessment of MV pathology. Cardiology, imaging, and critical care teams were optimally equipped and physicians were trained so an earlier referral could be achieved. All MV cases were analyzed by the MVr program before the procedure, and the repair was performed by an experienced surgeon. Cardiac anesthesiologists in charge of the cases were fully prepared to perform echocardiograms in the operating room so the quality of the MVr could be assessed before the patient was weaned of CPB. Junior cardiac surgeons were mentored and technically supported. A valvular heart clinic was created so MV patients could be properly followed and controlled.

With targeted and earlier referral, we improved patient selection and MVr rates. We were able to operate healthier patients, with less comorbidities, better functional class, younger, and with better LVEF. This was a key factor for achieving and maintaining good results, since patients with previous myocardial infarction, dyslipidemia, dialysis, and hypertension have an increased risk of developing at least moderate recurrent MR, as shown before in different studies. The literature has suggested a close relationship between preoperative comorbidities and the odds of developing recurrent MR. Fukuda et al. [24] found a close relationship between type 2 diabetes and the progression of MR. We performed an exploratory logistic binary regression, finding that previous myocardial infarction by itself increases the risk up to 18% and can be modified in the presence of variables such as age, gender, and surgical approach.

Different articles [25, 26] have shown that individual surgeon volume is a determinant of MVr rates, freedom from reoperation, and survival. A total of < 25 MVr per year has been associated with poor results and low MVr rates. When no volume-outcome relationships were available, the United Kingdom proposed a volume threshold of 25 MVr/year for surgeon, so better results

![Fig. 3](image_url) Freedom from > 3 Mitral Regurgitation. Kaplan-Meier estimate of survival function from at least > 3 mitral valve regurgitation for 188 patients with degenerative mitral valve disease.

**Table 3** Bivariate analysis identifying factors related to at least moderate MV regurgitation in 188 patients

| Bivariate analysis                  | OR     | CI 95%     | P value |
|------------------------------------|--------|------------|---------|
| Previous myocardial infarction     | 18.55  | 1602-214,857 | 0.030   |
| Diabetes                           | 0.93   | 0.112-7.747    | 1000    |
| Dialysis                           | 2.15   | 0.03-20.314    | 0.043   |
| Minimally invasive technique       | 0.22   | 0.051-1019     | 0.040   |
| Dyslipidemia                       | 1.65   | 0.508-5.420    | 0.489   |
| Hypertension                       | 1.29   | 0.509-3.299    | 0.585   |
| Arrhythmia                         | 1.01   | 0.294-3.518    | 1000    |
could be achieved. In the United States, there is no minimum volume standardized for MVr [26]. At our institution, since the creation of the MVr program, patient volume has grown and MVr rate has improved. We have been able to maintain MVr as preferred technique of MV intervention, and satisfactory results have been obtained. With the creation of a well prepared, well equipped and experienced MVr program, that has a guideline-assessment of MV pathology and is lead by an experienced MV surgeon, adequate MVr results can be accomplished in low-volume centers.

Daneshmand et al. [25] conducted a 20-year study, and concluded that MVr patients have better survival and functional outcomes, especially after 10–15 years, compared to MVR. In keeping with this, Gammie et al. [27] presented the trends of MV surgery in the United States, showing progressive adoption of MVr. In Latin America, however, trends of MV surgery remain unknown, with little data showing trends in MVr vs MVR and different studies have suggested the number of MVr should be increased [27].

This paper has some limitations, it was a retrospective study performed over a period of 15 years. Changes in surgical techniques and postoperative management of the patients might have affected the incidence of recurrent MR.

Conclusions
In conclusion, short and long-term results with either the R or the NR techniques are equivalent. Recurrence of severe MR and the need for MVR are rare. Significant symptomatic improvement can be achieved in more than 80% of the patients, and the majority will present with no or grade I MR. Risk factors for MR after surgery should be analyzed. The most reliable and durable repair technique for degenerative MV disease is the one that the surgeon feels more comfortable and has the most experience with. This study shows how low-volume centers can achieve results comparable to those reported worldwide as recently suggested by Bakaeen et al. [28]. We attribute the results presented in this paper to the creation of a MVr team, with a dedicated MVr surgeon as the leader.
Acknowledgments
We will like to thank the anesthesia department, the valvular heart disease clinic and the research department for the advisory and corrections for this manuscript.

Availability of data and materials
Database collected in the study is available from the corresponding author on reasonable request.

Authors contributions
JU, JC, NS, were the cardiac surgeons in charge of the patients. MG IP JU structured the article and wrote it. All authors read and approved the final manuscript.

Ethics approval and consent to participate
The institutional review board waived approval for this manuscript since the data was collected retrospectively and the follow up for patients either by phone or clinical visit is a regular procedure.

Institutional Review Board: Comité de Ética en Investigación Clínica.

Consent for publication
Not applicable.

Competing interests
Dr. Juan P. Umana is a consultant for Edwards Lifesciences. Other authors declare that they have no competing interests.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Author details
1Vascular Function Research Laboratory, Fundación Cardioinfantil- Instituto de Cardiología, Bogotá, Colombia. 2Cardiac Surgery, Fundación Cardioinfantil- Instituto de Cardiología, Bogotá, Colombia. 3Cardiac Surgery Department, Fundación Cardioinfantil- Instituto de Cardiología, Bogotá, Colombia. 4Director Cardiovascular Medicine, Cardiac Surgery Department, Fundación Cardioinfantil-Instituto de Cardiología, Bogotá, Colombia.

Received: 18 May 2018 Accepted: 25 September 2018

Published online: 16 October 2018

References
1. Carpenter A. Cardiac valve surgery—the “French correction”. J Thorac Cardiovasc Surg. 1983;86(3):323–37.
2. Perier P, Hohenberger W, Lakef F, Batz G, Urbanski P, Zacher M, et al. Toward a new paradigm for the reconstruction of posterior leaflet prolapse: midterm results of the “respect rather than resect” approach. Ann Thorac Surg. 2008;86(3):718–25–25.
3. Perier P, Hohenberger W, Lakef F, Diegeler A. Prolapse of the posterior leaflet: resect or respect? Ann Thorac Cardiovasc Surg. 2015;40(3):273–7.
4. Society of Thoracic Surgeons [Internet]. [cited 2017 Oct 10]. Available from: https://www.sts.org/registries-research-center/sts-national-database/adult-cardiac-surgery-database/data-collection. Accessed 07 Oct 2017.
5. Pachimo-Arath E, Lessana A, Relland JYM, Belli E, Mihaileanu S, Berrebi AJ, et al. The “physio-ring”: an advanced concept in mitral valve annuloplasty. Ann Thorac Surg. 1995;60(5):1777–86.
6. Davies MJ, Moore BP, Brainbridge MW. The floppy mitral valve. Study of incidence, pathology, and complications in surgical, necropsy, and forensic material. Br Heart J. 1978;40(5):468–81.
7. Sawazaki M, Tornari S, Saijikouji K, Imaeda Y. Controversy in mitral valve repair, resection or chordal replacement? Gen Thorac Cardiovasc Surg. 2014;62(10):581–5.
8. Tomita Y, Yasui H, Iwai T, Nishida T, Morita S, Masuda M, et al. Extensive use of polytetrafluoroethylene artificial grafts for prolapse of posterior mitral leaflet. Ann Thorac Surg. 2004;78(3):815–9.
9. Deloche A, Jebra VA, Relland JY, Chauvaud S, Fabiani JN, Perier P, et al. Valve repair with Carpentier techniques. The second decade. J Thorac Cardiovasc Surg. 1990;99(9):1001–2.
10. Schwartz CF, Grossi EA, Ribakove GH, Ursomanno P, Minnilly M, Crooke GA, et al. Ten-year results of felony plasty in mitral valve repair. Ann Thorac Surg. 2010;89(2):485–8.
11. Lange R, Guenther T, Noebauer C, Kiefer B, Eichinger W, Voss B, et al. Chordal replacement versus quadrangular resection for repair of isolated posterior mitral leaflet prolapse. Ann Thorac Surg. 2010;89(4):1163–70.
12. Kobayashi J, Sasaki Y, Bando K, Minakaya K, Nishida T, Kitauma S. Ten-year experience of chordal replacement with expanded polytetrafluoroethylene in mitral valve repair. Circulation. 2000;102(19 Suppl 3):III30–4.
13. Salvador L, Mirone S, Bianchini R, Dejesta G, Patelli F, Minniti G, et al. A 20-year experience with mitral valve repair with artificial chordae in 608 patients. J Thorac Cardiovasc Surg. 2008;135(1):1280–7.
14. Jebra VA, Mihaileanu S, Acar C, Brizard C, Grare P, Latremouille C, et al. Left ventricular outflow tract obstruction after mitral valve repair. Results of the sliding leaflet technique. Circulation. 1993;88(5 Pt 2):III30–4.
15. Grossi EA, Galloway AC, Kellenbach K, Miller JS, Esposito R, Schwartz DS, et al. Early results of posterior leaflet folding plasty for mitral valve reconstruction. Ann Thorac Surg. 1998;66(4):1057–9.
16. Sakamoto Y, Hashimoto K, Okuyama H, Ishii S, Kawada N, Inoue T, et al. Mitral valve reconstruction: long-term results of triangular resection for degenerative prolapse. Gen Thorac Cardiovasc Surg. 2008;56(2):623–7.
17. David TE, Oman A, Armstrong S, Sun Z, Ivanov J. Long-term results of mitral valve repair for myxomatous disease with and without chordal replacement with expanded polytetrafluoroethylene sutures. J Thorac Cardiovasc Surg. 1988;115(6):1279–85.
18. Falk V, Seeburger J, Ceslea M, Borger MA, Willige J, Kunte 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(1):205–6.
19. Dogan S, Aybek T, Risteski PS, Detho F, Rapp A, Wimmer-Greinacher G, et al. Minimally invasive port access versus conventional mitral valve surgery: prospective randomized study. Ann Thorac Surg. 2005;79(2):492–8.
20. Sundermann SH, Czerny M, Falk V. Open vs. minimally invasive mitral valve surgery: surgical technique, indications and results. Cardiovasc Eng Technol. 2015;6(2):160–6.
21. Svensson LG, Atik FA, Cosgrove DM, Blackstone EH, Rajeswaran J, Krishnasamy G, et al. Minimally invasive versus conventional mitral valve surgery: a propensity-matched comparison. J Thorac Cardiovasc Surg. 2010;139(4):926–32.
22. Singh RG, Cappucci R, Kramer-Fox R, Roman MJ, Klughfield P, Borer JS, et al. Severe mitral regurgitation due to mitral valve prolapse: risk factors for development, progression, and need for mitral valve surgery. Am J Cardiol. 2000;85(2):193–8.
23. Wilcken DE, Hickey AJ. Lifeline risk for patients with mitral valve prolapse of developing severe valve regurgitation requiring surgery. Circulation. 1988;78(1):10–4.
24. Fukuda N, Oki T, Iuchi A, Tabata T, Manabe K, Kagye Y, et al. Predisposing factors for severe mitral regurgitation in idiopathic mitral valve prolapse. Am J Cardiol. 1995;76(7):503–7.
25. Daneshmand MA, Milano CA, Rankin JS, Honeycutt EF, Swaminathan M, Shaw JK, et al. Mitral valve repair for degenerative disease: a 20-year experience. Ann Thorac Surg. 2009;88(6):1828–37.
26. Gammie JS, Sheng S, Griffith BP, Peterson ED, Rankin JS, O’Brien SM, et al. Trends in mitral valve surgery in the United States: results from the Society of Thoracic Surgeons adult cardiac surgery database. Ann Thorac Surg. 2009;87(5):1431–7.
27. Chikwe J, Toyoda D, Anyanwu A, et al. Relation of mitral valve surgery volume to repair rate, durability, and survival. JACC. 2017;69:2397–409.
28. Bakaeen FG, Shroyer AL, Zenati MA, Badhwar V, Thouarsi VH, Gammie JS, et al. Mitral valve surgery in the US Veterans Administration health system: 10-year outcomes and trends. J Thorac Cardiovasc Surg. 2018;155(1):105–17.