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Review

Preservation of the mitral valve apparatus: evidence synthesis and critical reappraisal of surgical techniques

Thanos Athanasiou [a,b,*], Andre Chow [b], Christopher Rao [a], Omer Aziz [b], Fotios Siannis [d], Ayyaz Ali [c], Ara Darzi [b], Francis Wells [c]

[a] *Department of Cardiothoracic Surgery, St. Mary's Hospital, London, UK*
[b] *Department of Biosurgery and Surgical Technology, Imperial College London, UK*
[c] *Department of Cardiothoracic Surgery, Papworth Hospital, Cambridge, UK*
[d] *MRC Biostatistics Unit, Cambridge, UK*

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Summary

Sub-valvular apparatus preservation after mitral valve replacement is not a new concept, yet to date there has been no quantification of its clinical effectiveness as a procedure and no consensus as to which surgical preservation technique should be adopted to achieve the best immediate and midterm clinical outcomes. This systematic review of current available literature aims to use an evidence synthesis and meta-analytic approach to compare outcomes following replacement of the mitral valve with (MVR-P) or without preservation (MVR-NP) of its apparatus. It considers all the relevant anatomical, experimental, echocardiographic, and clinical studies published in the literature and appraises all reported mitral valve sub-valvular apparatus preservation techniques. The results of this review strongly suggest that MVR-P is superior to MVR-NP with regards to the incidence of early postoperative low-cardiac output requiring inotropic support, and early or mid-term survival. They also suggest that the operative decision should be individualised based on patient's anatomy, pathology and ventricular function and therefore surgeons should be familiar with more than one surgical preservation technique. Finally, this paper highlights the need for further high quality research focusing particularly on the long-term assessment of quality of life and health utility following MVR-P.

Keywords: Meta-analysis; Chordal preservation; Mitral valve replacement

1. Background

In 1961, the first reported mitral valve replacement (MVR) procedure with implantation of the Starr—Edwards prosthetic valve was published, and involved the complete excision of mitral leaflets, chordae tendineae and the tips of the papillary muscles [1]. The early days of MVR were complicated by an increased incidence of low cardiac output (LCO) syndrome and associated mortality, but since then several strategies have been implemented to decrease the prevalence of LCO syndrome including: revising the indications for MVR, improving myocardial protection strategies, wider application of mitral valve repair techniques, the use of selection criteria for the type of inserted mitral prosthesis, and sub-valvular apparatus preservation (SAP) whenever repair is not possible.

1.1. Historical perspectives of SAP

In the 1960s Lillehei and colleagues demonstrated a reduction in operative mortality from 37% with conventional techniques to 14% with chordal-sparing techniques [2—4]. Several publications followed that raised objections regarding the additional operative procedure and ischaemic time, combined with the potential for a retained valvular apparatus to interfere with the high-profile ball-valve prosthesis. Concerns were also voiced regarding a tendency towards insertion of a smaller prosthesis if leaflet tissue was preserved and its long-term consequences [5—9].

Renewed interest in MVR chordal-sparing techniques was stimulated by the report of Miller et al. in 1979 [10], stating operative survival was enhanced with SAP due to a decreased risk of ventricular rupture. This was followed by David et al. [11—14] and Hetzer et al. [15,16] demonstrating improved

Abbreviations: AL, anterior leaflet; CI, confidence intervals; OR, odds ratio; LCO, low cardiac output; LVOTO, left ventricular outflow obstruction; PL, posterior leaflet; SAP, sub-valvular apparatus preservation; MVR, mitral valve replacement; MVR-BL, mitral valve replacement with bileaflet preservation of valve apparatus; MVR-P, mitral valve replacement with preservation of the valve apparatus; MVR-PL, mitral valve replacement with preservation of posterior valve apparatus; MVR-NP, mitral valve replacement with no preservation of valve apparatus; HR, hazard ratio.

* Corresponding author. Address: Department of Biosurgery and Surgical Technology, Imperial College London, 10th Floor QEQM Building, St. Mary's Hospital, London W2 1NY, UK. Tel.: +44 207 886 1310; fax: +44 207 886 1810.
E-mail address: tathan5253@aol.com (T. Athanasiou).

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outcomes and left ventricular function with chordal preservation. Despite further reports of improved long-term survival following MVR with chordal preservation [17,18], this effect has, to date, been neither systematically assessed nor has it been translated into standard clinical practice.

1.2. Anatomical and functional considerations for SAP

The sub-valvular apparatus consists of the left ventricular free wall, two papillary muscles, and the chordae tendineae. The two papillary muscles (anterolateral and posteromedial) give off the chordae tendineae, which insert onto the ventricular surfaces of the anterior and posterior mitral leaflets. During ventricular systole the sub-valvular apparatus prevents the mitral leaflets from prolapsing into the left atrium. The papillary muscles and chordae tendineae also contribute effective left ventricular contraction by using a process known as 'annulo-ventricular continuity'. According to this, left ventricular geometry and function depend upon dynamic relationships between the left ventricular wall and mitral valve annulus. During diastole, the papillary muscles and chordae moderate left ventricular distension, whereas during systole they moderate wall tension. As the papillary muscles contract during the isometric phase of the cardiac cycle, the closed mitral valve is brought down into the left ventricle causing a reduction in longitudinal axis, but increasing the short axis [19]. This causes increased myocardial fibre stretch, generating greater tension, contraction, and stroke volume. The arrangement of the sub-valvular apparatus also causes 'ventricular torsion deformity' during the cardiac cycle. Interruption of the papillary—annular complex thus causes impairment of normal left ventricular stress—strain patterns [20].

Patients with chronic mitral regurgitation have progressively worsening left ventricular function, demonstrated by increasingly impaired left ventricular contractility and increasing left ventricular filling pressures. This is initially helped by the addition of the left atrial regurgitant volume to the forward stroke volume, helping to improve forward output and ejection fraction. However as the left ventricle dilates, wall tension increases as by Laplace's law leading to increasing systolic wall stress. Following MVR there is an increase in left ventricular afterload due to loss of the low resistance pathway to the left atrium. This situation is worsened by a reduction in preload caused by elimination of the regurgitant volume. This may be further complicated by some residual gradient across the prosthesis. These factors may all contribute to the LCO syndrome seen in mitral regurgitation patients following MVR.

Mitral stenosis on the other hand usually results in a small left ventricle with a fused and calcified mitral valve. Excision and replacement of the valve in this setting does not produce the increased afterload with reduced preload picture of MVR for mitral regurgitation. Loss of the annulo-ventricular continuity however, may still cause progressive left ventricular dilatation and reduction of ventricular function in the long-term.

1.3. Animal studies

Several animal studies have been performed to assess the physiological effects of chordal transection on a normal heart. Hansen et al. [21] assessed left ventricular systolic function in a canine model showing that transection of all the chordae tendineae resulted in an immediate and profound decrease in left ventricular function. The same team demonstrated that transection of the chordae tendineae to the anterior mitral leaflet reduced the left ventricular function significantly more than transection of chordae attached to the posterior leaflet [22]. Sarris et al. [23] demonstrated in a swine model that the effects of chordal transection can be reversed by reattaching the papillary muscles.

This work was extended into animal models subjected to MVR by David et al. [11,12], who compared MVR-P with MVR-NP in a canine model. In the preservation group left ventricular ejection fraction was improved, and left ventricular function improved with volume loading whilst in the group with divided chordae tendineae, function improved more slowly and ceased to improve after loading at an earlier point. Finally, Gams et al. [19] and Moon et al. [20] demonstrated that whilst chordal preservation is superior, no significant differences were found between anterior or posterior preservation groups.

1.4. Human echocardiographic (physiological) studies

Several groups have used echocardiography to assess cardiac function following MVR. Okita et al. [24] evaluated 148 patients with mitral regurgitation or stenosis who had undergone MVR either with complete chordal preservation or division. For patients with mitral regurgitation, complete chordal preservation gave superior left ventricular ejection fraction, contractility index, fractional shortening and performance. However, these differences were not apparent in patients with mitral stenosis. Yagyu et al. [25] studied 75 patients undergoing MVR with preservation of the posterior mitral complex. The preservation group showed lower left atrial pressures, and higher left ventricular stroke work indexes and function curves than those with chordal transection within the first 24 h post bypass. Once again this tendency was more prominent in patients with mitral regurgitation than mitral stenosis.

Ghosh et al. [26] studied 79 patients undergoing MVR with complete chordal transection or posterior chordal preservation. The latter was found to be superior in terms of end systolic and diastolic dimensions. Similar results were presented by Rozich et al. [27] in their series of 15 patients. Patients with chordal preservation (anterior, posterior, or complete) had superior left ventricular end systolic and diastolic volumes, as well as end-systolic stress and ejection fraction. More recently, these results have been confirmed by Cingoz et al. [28] in 94 patients using a complete chordal preservation technique during MVR.

1.5. Clinical studies

A number of comparative clinical studies have been published comparing MVR-P to MVR-NP. This paper aims to review the results of these studies, using an evidence synthesis and meta-analytic approach to compare outcomes following MVR-P versus MVR-NP. Where possible, it also aims to compare the different types of MVR-P procedures namely mitral valve replacement with preservation of posterior valve apparatus (MVR-PL) and mitral valve replacement with bileaflet preservation of valve apparatus (MVR-BL). Finally, this paper also aims to review and appraise a number of MVR-P techniques described in these papers.

2. Methods

2.1. Literature search

A literature search (Medline, Ovid, Embase, Google Scholar, Cochrane Collaboration Controlled Trials Registry, and Health Technology Assessment Database) was performed on all studies (of all languages) published between 1964 and 2007 reporting on MVR-P versus MVR-NP. The mesh search headings used were 'preservation of subvalular apparatus', 'chordae tendineae/*surgery', 'heart valve prosthesis implantation/*methods' and 'comparative study'. All cross-references, quoted papers, review articles, and meta-analyses were identified and their references scanned. The 'related articles' function used to further broaden the search and all abstracts, studies, and citations scanned were reviewed.

2.2. Data extraction

Two reviewers (CR and TA) independently extracted the following data from each study: first author, year of publication, study population characteristics, study design, inclusion and exclusion criteria. If the same author published more than one paper reporting on the same patient group at different follow-up periods, the patient and study demographics were extracted from first paper, and outcomes of interest were extracted from most informative article. In case of discrepancy the first author was contacted for clarification.

2.3. Inclusion criteria

In order to enter this analysis studies had to:

1. Compare MVR-P, MVR-PL or MVR-BL with MVR-NP or compare MVR-PL with MVR-BL.
2. Report on at least one clinical outcome of interest.

2.4. Exclusion criteria

The following criteria were used to exclude studies from our analysis:

1. Studies where either intervention could not be defined.
2. Studies where outcome of interest was not reported or was impossible to calculate from published results.
3. Studies with zero for the outcome of interest in both cells of the cross-tabulation table for the intervention.

2.5. Outcomes of interest and definitions

The postoperative outcomes compared were: '30-day mortality', 'hazard ratio (HR) of mortality at 1 year', 'HR of mortality at 5 years', use of postoperative inotropic support (for low cardiac output). The type of preservation technique used was also extracted and although not suitable for meta-analysis, these were grouped and described.

2.6. Statistical methods

Meta-analysis was performed in line with Cochrane Collaboration recommendations and Quality of Reporting of Meta-analyses guidelines [29,30]. Statistical analysis for categorical variables was carried out using odds ratio (OR) or hazard ratio (HR) as the summary statistic. The odds ratio represents the odds of an adverse event occurring in the treatment (MVR-P, MVR-PL, MVR-BL) group compared with the reference (MVR-NP) group. An odds ratio of less than one favours the treatment group, and the point estimate of the odds ratio is considered statistically significant at the $p = 0.05$ level if the 95% confidence interval does not include the value 1. Analysis to combine odds ratios for the outcomes of interest were performed as described previously [31,32].

For time to death, the logarithm of the hazard ratio (HR) with 95% CI was used [33].[1] Two ways of estimating the HR and its variance were used: first, if the number of events (D) and the total patient follow-up years (Y) is given or can be calculated from the Kaplan–Meier curves, the hazard ratio for each group equals D/Y and its variance equals D/Y^2. The log HR is the logarithm of the ratio of the hazard rates for the two groups. The variance of the log HR can be calculated as $1/D_1 + 1/D_2$, where D_1 and D_2 are the numbers of events for the two groups. Second, if only the event-free rate (S) and its standard error (SE) for a certain time (T) are given, the hazard rate is $-\log(S)/T$ and the variance of S is the square of its standard error. The variance of the hazard rate can be calculated by using the variance of S by combining the formulas for the variance of a logarithm and the variance of a constant.

In this study a random effects model was used as described previously [34]. In the tabulation of our results, squares indicate point estimates of treatment effect (odds ratio or hazard ratio), with 95% confidence intervals indicated by horizontal bars. The diamond represents the summary odds or hazard ratio from the pooled studies with 95% confidence intervals (Figs. 1 and 2). Finally, subgroup analysis was performed to assess heterogeneity.

Analysis was conducted by using the statistical software Intercooled Stata version 7.0 for Windows (Stata Corporation, USA), Review Manager Version 4.2 (Cochrane Collaboration, Software Update, Oxford).

3. Results

3.1. Studies included

The literature search identified 24 [11–14,18,28,35–52] comparative studies matching the selection criteria including 2933 patients (1603 (55%) MVR-P, 1330 (45%) MVR-NP). Two

[1] Green S, Higgins J, editors. Meta-analysis of counts and rates. Cochrane Handbook for Systematic Reviews of Interventions 4.2.5 [updated May 2005]; Section 8.6.7. http://www.cochrane.dk/cochrane/handbook/handbook.htm [(accessed 9/13/2005)].

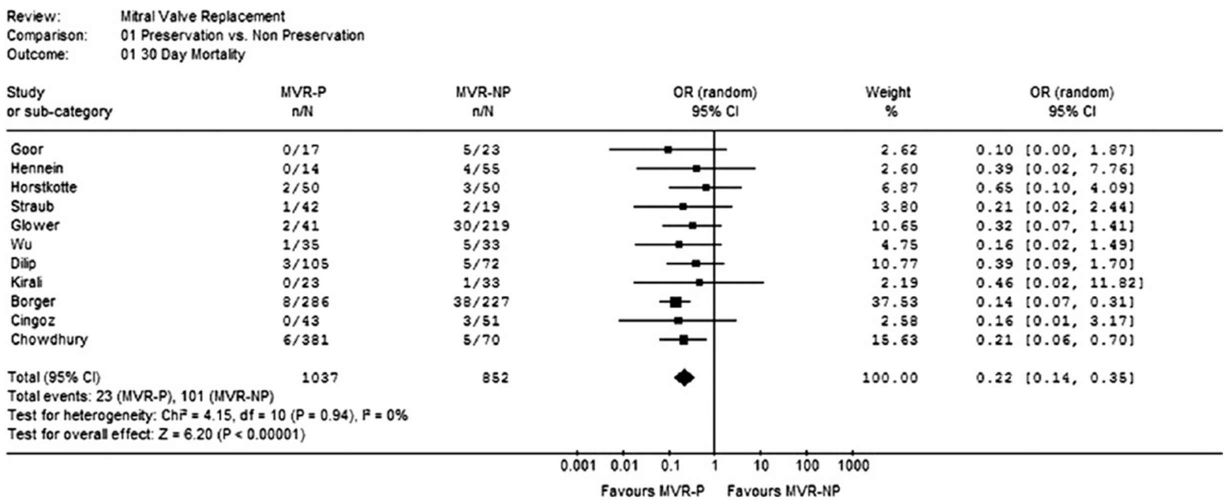

Fig. 1. Forrest plot of postoperative mortality; comparison of preservation versus non-preservation of the sub-valvular mitral apparatus.

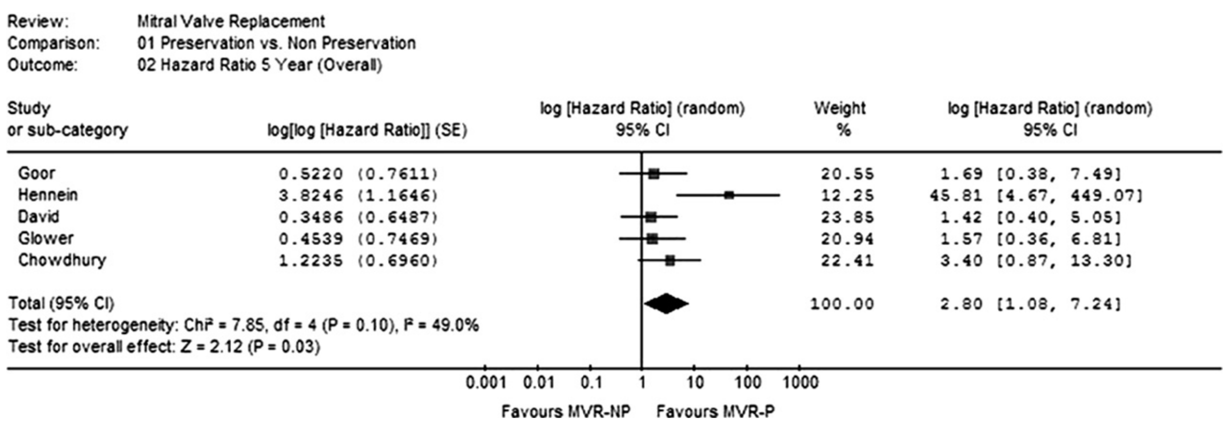

Fig. 2. Forrest plot of mid-term (5 year) mortality; comparison of preservation versus non-preservation of the sub-valvular mitral apparatus.

groups namely David et al. [11—14,47] and Straub et al. [38,48—50] each published multiple studies reporting on the same outcomes, but were included because they reported these outcomes at different follow-up periods in each of these studies. This paper therefore reports on the results of 17 groups over the 24 studies as shown in Table 1. On review of the data extraction there was 100% agreement between all three reviewers. Study design was retrospective in 16, prospective non-randomised in four, and prospective randomised in four studies. Fig. 1 shows the results from meta-analysis of 30-day perioperative mortality and Fig. 2 shows the meta-analytic outcome for overall mortality hazard ratio when all studies were considered (Table 2).

3.2. Meta-analysis of 30-day perioperative mortality and inotropic requirements

Perioperative mortality was significantly lower in the MVR-P than in the MVR-NP group (2.6% vs 12.1%, OR 0.22 [0.14—0.35]) as shown in Fig. 1, although it was not clear whether the type of preservation technique affects survival. Subgroup analysis showed that perioperative mortality was significantly lower in both posterior preservation, and bileaflet preservation groups compared with nonpreservation, (2.2% vs 7.7%, OR 0.36 [0.16—0.84]) and (1.5% vs 9.8%, OR 0.20 [0.07—0.55]), respectively. Meta-analysis of the studies that compared MVR-BL preservation with MVR-PL preservation suggested that whilst perioperative mortality may be slightly lower following bileaflet preservation this was not significant (OR 0.43 [0.11—1.72]). The incidence of inotropic requirements was significantly lower in the MVR-P than in the MVR-NP group (12.6% vs 52.4%, OR 0.16 [0.06—0.42]).

3.3. Meta-analysis of overall mortality hazard ratio

The overall mortality hazard ratio following MVR-NP was higher than MVR-P at 1 year (HR 6.16 [2.65—14.32]) and 5 years (HR 2.80 [1.08—7.24]) as shown in Fig. 2. The same pattern was seen for valve-related mortality hazard at 1 year (HR 1.95 [0.71—5.34]) and 5 years (HR 2.21 [1.10—4.44]). Similar trends were apparent in the few comparisons of bileaflet and posterior preservation techniques with non-preservation techniques. Only one study directly compared

Table 1
Characteristics of clinical studies included in meta-analysis

Principle author	Chowdhury	Muthialu	Cingoz	Borger	Dilip	Yun	Kirali	Wu	Glower	Hassouna	Lee	David	Straub	Dubiel	Horstkotte	Hennein	Goor
Year	2005	2005	2004	2002	2001	2002	2001	2000	1998	1998	1996	1995	1995	1994	1993	1990	1988
Country	India	India	Turkey	Canada	India	USA	Turkey	China	USA	Egypt	UK	Canada	Germany	Sweden	Germany	USA	Israel
Study design	PNR	R	PNR	R	PNR	PR	PR	PR	R	R	R	R	R	R	PR	PNR	R
Pathology	Mixed/MS	Mixed	Mixed	Redo	Mixed	Mixed	MR	Mixed	Mixed	MR	Mixed	Not stated	Mixed	Mixed	Mixed	Mixed	Ischaemic
Non-preservation	70	262	51	286	72		33	33	219		68	84	19	5	50	55	23
Preservation	381	98	43	227	105	36	23	35	41	96	318	70	42	7	50	14	17
Posterior	124	76			105	15	23		15	60						5	17
Bileaflet	257	22	43			21		35	26	36						9	
Total number	451	360	94	513	177	36	56	68	260	96	386	154	61	12	100	69	40
Matching criteria	1,4,5,6,7,8	3,8	1,2,3,7,8,12,13		1,2,8,11,13	1,3,8	1,3,5,10,12	1,2,6,7,8,11,13		1,8,11	1,4,5,6,7,8	1,6,8,9,11		1,6,8,11	1,7,8	1,4,11,12,14	
Exclusion criteria	1	2,3	1,3,5,6	3		3,4	1,3,5,7	1,3,5,6		3,5					3,5,6		

Abbreviations: MR: mitral regurgitation, MS: mitral stenosis, PNR: prospective non-randomised, PR: prospective randomised. R: retrospective matching criteria: 1 = demographics, 2 = weight, body mass index or surface area, 3 = aetiology, 4 = type of mitral valve pathology, 5 = other valvular pathology, 6 = ischaemic heart disease, 7 = concurrent arrhythmia, 8 = heart failure, 9 = type of valve, 10 = other concurrent cardiac pathology, 11 = echocardiographic parameters, 12 = pulmonary hypertension, 13 = cardiothoracic ratio, 14 = left ventricular failure.
Exclusion criteria: 1 = redo mitral operation, 2 = previous, concurrent or cardiac surgery during follow-up period, 3 = ischaemic heart disease, 4 = mitral stenosis, 5 = other valvular pathology, 6 = acute rheumatic fever, 7 = infective endocarditis.

long-term mortality following bileaflet and posterior preservation [39].

It is important to note that no significant heterogeneity was identified between studies in any of the above-mentioned outcomes of interest.

3.4. Critical appraisal of MVR-P techniques

A number of surgical techniques for chordal preservation have been described. In his original descriptions of mitral leaflet preservation during MVR, Lillehei employed a running suture to bind the posterior leaflet to the annulus. It is important to note that of his series of 23 patients, he preserved both anterior and posterior leaflets in only two cases, principally due to concerns about interference of the preserved tissue with the mechanism of the high-profile caged ball-valve prosthesis. In this section we attempt a critical appraisal of preservation techniques to clarify concepts, rules and technical characteristics important for surgical decision-making during MVR-P.

3.5. Important anatomical concepts for MVR-P

In preserving the sub-valvular apparatus and annulo-ventricular continuity and thereby maximising the chances of successful MVR-P three main concepts must be appreciated. It is important to note that these are strongly related to each other:

1. Preserving valve tissue rather than resecting because tissue maintenance reduces the risk of ventricular rupture.
2. Preserving symmetry of the mitral annulus will allow better contact between the valve prosthesis and mitral annulus and consequent avoidance of paravalvular leak.
3. Preserving natural chordae tension allowing more physiological systolic and diastolic function of the left ventricle.

In summary, by adhering to these concepts surgeons should aim for a bileaflet preservation technique with reattachment of the chordae close to their anatomical positions, and without causing significant distortion of the symmetry of the mitral annulus.

3.6. Important practical tips for MVR-P

Surgeons should also keep in mind the following rules applying to MVR-P:

1. Use of bileaflet mechanical valves is routine practice; there is no uniform view on using an anatomic or anti-anatomic orientation.
2. Safe insertion of prosthetic valves may require resection; retained structures must not inhibit prosthetic valve function [53–55] (less problematic with low-profile mechanical valves) and sufficient tissue must be resected to permit insertion of a suitably sized prosthesis to avoid patient-prosthesis mismatch.
3. Excess chordal tension must be avoided to reduce the risk of chordal rupture [56]

Table 2
Patient characteristics in the clinical studies included in the meta-analysis

Principle author	Chowdhury	Muthialu	Cingoz	Borger	Dilip	Yun	Kirali	Wu	Glower	Hassouna	Lee	David	Straub	Dubiel	Horstkotte	Hennein	Goor
Year	2005	2005	2004	2002	2001	2002	2001	2000	1998	1998	1996	1995	1995	1994	1993	1990	1988
Age (years) MVR-P	33 ± 19[a] 35 ± 23[b]	47[a] 38[b]	46.3 ± 4.7	57 ± 13	30.5 ± 1.1[a]	59 ± 11[a] 56 ± 13[b]	33.8 ± 18.4[a]	29.9 ± 8.3[b]	57 ± 14	25.7 ± 0.6[a] 23.2 ± 1.1[b]	61.6 ± 11.5	59 ± 15	60.6 ± 6.9	63 ± 4	54.8 ± 12.1[a]	52 ± 16[a] 47 ± 21[b]	63(52—78)
Age (years) MVR-NP	39 ± 15	37	44.3 ± 4.1		35.2 ± 1.5		31.5 ± 15	32.5 ± 9			62.7 ± 10.3	57 ± 12	59.8 ± 7.4	70 ± 4	54.3 ± 11.6	52 ± 14	
%Male MCR-P	64.5%[a] 62.2%[b]	40%[a] 63%[b]	44%[b]	30%	50%[a]	27%[a] 71%[b]	39%[a]	46%[b]	21%	40%[a] 44%[b]	36.8%	63%	38%	71%	34%[a]	60%[a] 66%[b]	80%
%Male MCR-NP	60%	66%	33%		50%		45%	55%			33.6%	56%	58%	40%	45%	62%	
NYHA class III MVR-P	59%[a] 61%[b]	71%[a] 45%[b]	88%[b]		65%[a]		43%[a]	26%[b]			59%	46%	67%	100%		40%[a] 78%[b]	45%
NYHA class III MVR-NP	71.4%	63%	84%		68%		30%	30%			50%	56%	47%	100%		74%	
NYHA class IV MVR-P	41.2%[a] 37.3%[b]	13%[a] 50%[b]	9%[b]	44%	7%[a]		4%[a]	74%			16.2%	30%	30%			60%[a] 0%[b]	6.1%
NYHA class IV MVR-NP	28.6%	27%	10%		13%		3%	70%			14.5%	24%	53%			15%	
LVEF (%) MVR-P			52.7 ± 3.9[b]		60.3 ± 8.2[a]		62.3 ± 10.3[a]		55 ± 10	49.2 ± 0.55[a] 46.0 ± 0.46[b]				60 ± 3	56 ± 6[a]	44 ± 13[a] 50 ± 14[b]	38
LVEF (%) MVR-NP			51.45 ± 4.27		56.7 ± 11.3		59.3 ± 7.7							67 ± 4	55 ± 14	46 ± 13	
FS (%) MVR-P		31 ± 1[a] 31 ± 2[b]	35.9 ± 3.4[b]				34.2 ± 7.4[a]			34 ± 1[a] 37 ± 1[b]						31 ± 8[a] 31 ± 9[b]	
FS (%) MVR-NP		34 ± 2	34.9 ± 2.8				32.1 ± 5.2									34 ± 10	
Preop AF MVR-P	62%[a] 72.3%[b]		70%[b]	62%	35%[a]			80%	68%		77.9%		83%	60%			
Preop AF MVR-NP	62.8%		61%		32%			73%			72.2%		79%	71%			

Abbreviations: MVR-P: mitral valve replacement with preservation of the valve apparatus, MVR-NP: mitral valve replacement with no preservation of valve apparatus, LVEF: left ventricular ejection fraction, FS: left ventricular fractional shortening, AF: atrial fibrillation.

[a] Posterior leaflet preservation group.

[b] Total chordal preservation group.

4. Left ventricular outflow obstruction should be prevented, asystolic anterior motion of the retained anterior mitral leaflet can occur [57—60].
5. MVR-P can be difficult in the presence of calcified, rigid leaflets especially common with rheumatic valve disease.
6. Use a technique that is simple, reproducible and appropriate for the patient's individual anatomy, pathology and ventricular function.

3.7. Types of MVR-P techniques

A classification and outline of the currently used preservation techniques is presented in Fig. 3 and described below:

1. Standard posterior leaflet preservation is achieved with reefing/plication of the leaflet tissue in the valve sutures. If there is an excess of posterior leaflet tissue, the central portion can be excised and the residual chordal-bearing free-edge included in the mattress sutures [61].
2. Complete retention of leaflet tissue with a reefing technique has been described by Van der Salm et al. [62]. Yu et al. [63] have advocated complete retention of the anterior leaflet with maintenance of even chordal tension to preserve normal left ventricular geometry. In cases with a small mitral annular diameter, the group incises the central portion of the anterior leaflet from edge to base to permit insertion of a suitable size of prosthesis.

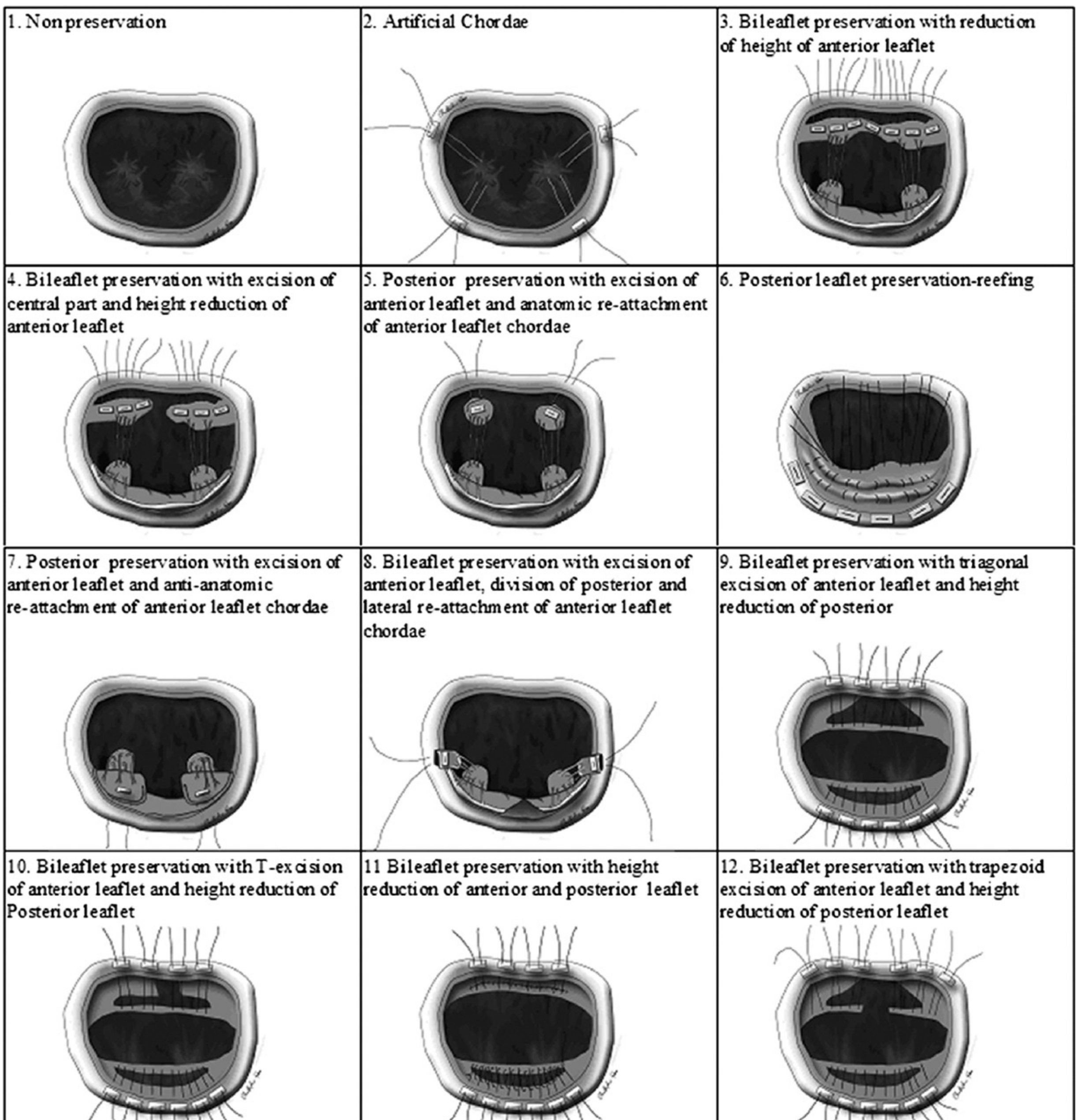

Fig. 3. Surgical techniques used for preservation of the valvular mitral continuity.

3. Variant techniques to handle the anterior leaflet and different types of chordae re-attachment to the mitral annulus: Feikes et al. [64] describe reattaching the primary chordal bundles to the posterior annulus; however, this non-anatomical technique may alter the distribution of LV wall stresses and hence regional afterload. Miki's group [65] excise the mid-portion of the anterior leaflet and reattach the separated anterior and posterior segments at their respective commissures to preserve chordal force in a more anatomical direction. This technique can be combined with an incision of the mid-portion of the posterior leaflet to permit insertion of an adequate size of prosthesis. Khonsari and Sintek [66] describe excision of the majority of the anterior leaflet with reattachment of the primary chordal bundles (in 2—5 segments) to their anatomical positions on the mitral annulus. David's technique involving resection of a trapezoidal segment from the anterior leaflet also preserves the anatomical direction of chordal traction. Other groups [67,68] have reported good results with modifications of these techniques. Sasaki et al. [69] have raised concerns regarding potential size mismatch between the anterior leaflet free-edge and the annulus. They excise a central elliptical portion of the anterior leaflet preserving a 5—10 mm rim of tissue bearing primary and secondary chordae. To minimise annular deformation and paravalvular leak, they detach this remnant at the anterolateral commissure, leaving it attached at the posteromedial commissure. They then suture this counter-clockwise from the posteromedial commissure with pledgetted mattress sutures.
4. Preservation in rheumatic mitral stenosis. In heavily diseased valves, particularly in rheumatic mitral stenosis, the sub-valvular apparatus may not be readily amenable to preservation. Aagard et al. [70,71] have reported successful decalcification of valve tissue and sharp dissection of adhesions between anterior and posterior leaflets. Amano et al. have employed an ultrasonic tool to debride and decalcify heavily diseased leaflets [72].
5. Use of neochordae: Various groups [73] describe the use of expanded PTFE sutures as 'neochordae'. Four mattress sutures (equivalent to eight neochordae) are inserted from papillary muscle to annulus as a figure-of-eight in the 2, 5, 7 and 10 o'clock positions. Tension is adjusted until the sutures are just taut. Such techniques have been proposed to eliminate the risk of preserved valvular apparatus interfering with the implanted valve mechanism.

3.8. What type of MVR prosthesis should be used?

Both bileaflet mechanical prostheses and bioprostheses have been used in conjunction with chordal-sparing techniques to minimise the risk of obstruction of the prosthesis by the retained sub-valvular apparatus. Safe implantation of a Monostrut valve can be achieved if sutures are placed to ensure that the posterior leaflet is folded under the posterior aspect of the sewing ring [74]. In vitro echocardiographic studies of tissue and mechanical valves reveal that some form of flow restriction due to retained sub-valvular apparatus does occur with both prosthesis types [75]. It is increased if both anterior and posterior leaflets are retained and is more marked with mechanical valves. A more dramatic flow limitation or 'pseudostenosis' has been attributed by one group to thrombosis on retained sub-valvular apparatus [76], but this remains an isolated report.

4. Discussion

Over the past 40 years, mitral valve repair techniques and the resulting concepts for valve preservation have altered the surgical techniques used for MVR. Although various aspects of MVR-P have been discussed [77,78], there has to date been no quantification of the effect that MVR-P has when compared to MVR-NP. This study suggests that MVR-P is superior to MVR-NP both in terms of early and 5-year survival. There was insufficient evidence available to determine whether bileaflet preservation (MVR-BL) is a more effective preservation technique compared with posterior preservation (MVR-PL). Further long-term follow-up data comparing preservation techniques is clearly needed, as well as data comparing function or quality of life after MVR-P.

The main cause of death after mitral valve surgery is myocardial failure. The reduced inotropic use and perioperative mortality associated with MVR-P demonstrated in this study have significant implications for the management of 'higher risk' MVR patients such as the elderly, patients with dilated cardiomyopathy, multiple valve disease, those undergoing re-do surgery, or patients with severely impaired left ventricular function. In this group, employing preservation techniques could potentially reduce their operative mortality. In fact SAP may not only impact left ventricular function, but also regional and global right ventricular function, even in areas remote from the area of anterior papillary muscle such as the ventricular septo-apical region of the right ventricle [79]. This effect may be of importance as many patients undergoing MVR also suffer from right ventricular dysfunction, pulmonary hypertension, and volume overload.

The choice of which MVR-P technique to use ultimately depends upon the individual patient and surgeon. Factors to be considered are the simplicity and reproducibility of the technique, as well as the anatomical and pathological characteristics of the mitral valve and the degree of left ventricular dysfunction. In patients with mitral stenosis the sub-valvular apparatus is diseased due to thickening and fusion creating constrain in the function of the left ventricle. The efficiency of SAP in this group of patients is reduced compared to mitral regurgitation. The excess valvular calcification seen in these patients makes it difficult to preserve a significant part of the mitral valve and requires intervention on the sub-valvular apparatus at the leaflet and papillary muscle level to achieve better results. Despite the fact that existing evidence advocates SAP, it is not performed routinely. Surgeons are reluctant to use preservation techniques as it is argued that left ventricular outflow obstruction (LVOTO) may occur as preserved tissue interferes with prosthetic valve function, and SAP often prevents an adequately sized prosthetic valve from being used. It has been also reported that some of the preservation techniques may cause alterations of the left ventricular geometry causing rupture of the papillary muscles, systemic embolisation, or dehiscence of mitral leaflets from the transposed position. Others have emphasised the risk of LVOTO in patients with septal hypertrophy undergoing anterior leaflet preservation [80]. Despite these concerns the current evidence suggests that SAP does result in better outcomes and surgeons should apply relevant techniques that have been described in the literature for eliminating LVOTO obstruction after SAP.

4.1. Study limitations

The evidence synthesis and meta-analysis techniques used in this study carry several limitations. First, the studies included were of varying design. Second the allocation of intervention was not consistent, and ranged from prospective randomised to retrospective. Third, there was a variation in selection criteria used by individual surgeons to allocate patients to each group. Fourth, the two groups were not always fully matched for important risk factors. Finally, it is important to appreciate the effect of publication bias.

4.2. Future areas to research

It is important that certain areas are addressed with regards to MVR-P. Firstly, primary data on long-term quality of life after MVR is needed. Second, further research is clearly needed into comparing bileaflet (MVR-BL) versus posterior leaflet (MVR-PL) preservation techniques. Other areas of interest include the assessment of right ventricular and tricuspid valve function following MVR with bileaflet or posterior leaflet preservation compared with no leaflet preservation. Further work is also required to investigate the different subgroups of patients with mitral regurgitation due to varying causes (ischaemic disease, re-do surgery or degenerative disease).

5. Conclusions

Mitral valve preservation is an important concept in mitral valve surgery and therefore must be considered. Surgeons should be familiar with a number of preservation techniques as the current evidence suggests that early and long-term clinical outcome can improve by maintaining ventricular-mitral continuity. Preservation techniques require echocardiographic quality control and follow-up to diagnose early any complications related to the technique.

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