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# The outcomes of reoperation for congenital mitral valve diseases in children

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## Abstract

**Backgrounds** We aimed to study the outcomes of mitral valve (MV) reoperations in children with congenital MV diseases and to summarize our treatment experience.

**Methods** In this single-center retrospective study, we enrolled 24 patients aged < 18 years who underwent MV reoperation from among 265 patients who underwent MV repair between January 2013 and July 2023. MV reoperations were based on the types of MV disease. Cox regressions were used to analyze the risk factors for death and second MV reoperation.

**Results** A total of 5 patients underwent second MV reoperations. 3 patients experienced early death, and 1 experienced late death. The 3- and 5-year survival rates of the entire cohort were 86.6% ± 7.3% and 72.1% ± 14.5%, respectively. Patients who had the double-orifice MV technique applied during MV reoperation were significantly more prone to receive mechanical MV replacement ($P < 0.0001$). The use of double-orifice MV technique during MV reoperation was identified as an independent risk factor for second MV reoperation ($HR = 8.136$, 95%$CI = 1.099–60.240$; $P = 0.040$).

**Conclusions** The reoperation of the MV in children with congenital MV diseases poses a formidable challenge, manifested by a high postoperative mortality rate and re-intervention rate. Patiently and meticulously repair based on the types of MV disease has demonstrated the capacity to enhance and sustain stable valve function and cardiac function in the vast majority of children. The use of the double-orifice MV technique did not achieve ideal therapeutic results in children with complex valve lesions.


**Keywords** Congenital mitral valve disease, Mitral valve repair, Mitral valve reoperation, Double-orifice mitral valve technique, Mechanical mitral valve replacement

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## Background

Contrary to the booming pursuit of research on mitral valve (MV) diseases in adults, the scientific interest and financial investments going into research of pediatric MV diseases are lacking, particularly because of the paucity of cases and difficulty in producing suitable medical devices for pediatric patients. Although some scholars suggest that the treatment approach for pediatric MV disease can derive from the existing experience of adult MV cases, this extrapolation seems like an oversimplification of the pediatric illness as children are not a smaller replica of adults and presents several methodological challenges in treatment. Currently, the main treatment methods for pediatric MV disease are still MV repair and replacement.

Although there is a strong tendency to favor repair over replacement [1–3], in some extremely complex cases, surgeons have no choice but to adopt this final or "bail-out" approach regardless of the drawbacks and limitations, such as lifelong anticoagulation and valve-patient mismatch [4–7].

In this study, we analyzed the outcomes of MV reoperations in children with congenital MV diseases and to summarize our treatment experience.

## Methods

### Study design

We performed a retrospective analysis of all patients aged < 18 years who underwent MV reoperation after MV repair from January 2013 to July 2023 at the Children's Hospital of Fudan University in Shanghai, China (Fig. 1). Patients diagnosed as having single ventricle physiology, rheumatic MV disease, or secondary MV diseases (e.g., abnormal origin of coronary arteries and Kawasaki disease) were excluded from the analyses.

The composite primary outcomes were freedom from second MV reoperation and death. Time to the second MV reoperation was measured since the first MV reoperation. For patients who did not need to undergo the second MV reoperation, the time was censored at the last follow-up date or the time of death.

### Follow-up

Transthoracic echocardiography (TTE) was performed at 24 h postoperatively, at 3 months, at 1 year, and annually. Death during hospitalization or within 30 days of surgery represented early death. Death after 30 days and death after discharge represented late death. Complications like delayed chest closure, pulmonary hypertensive crisis, pericardial effusion, and infection were recorded. Clinical examinations and echocardiography findings were used to collect follow-up data.

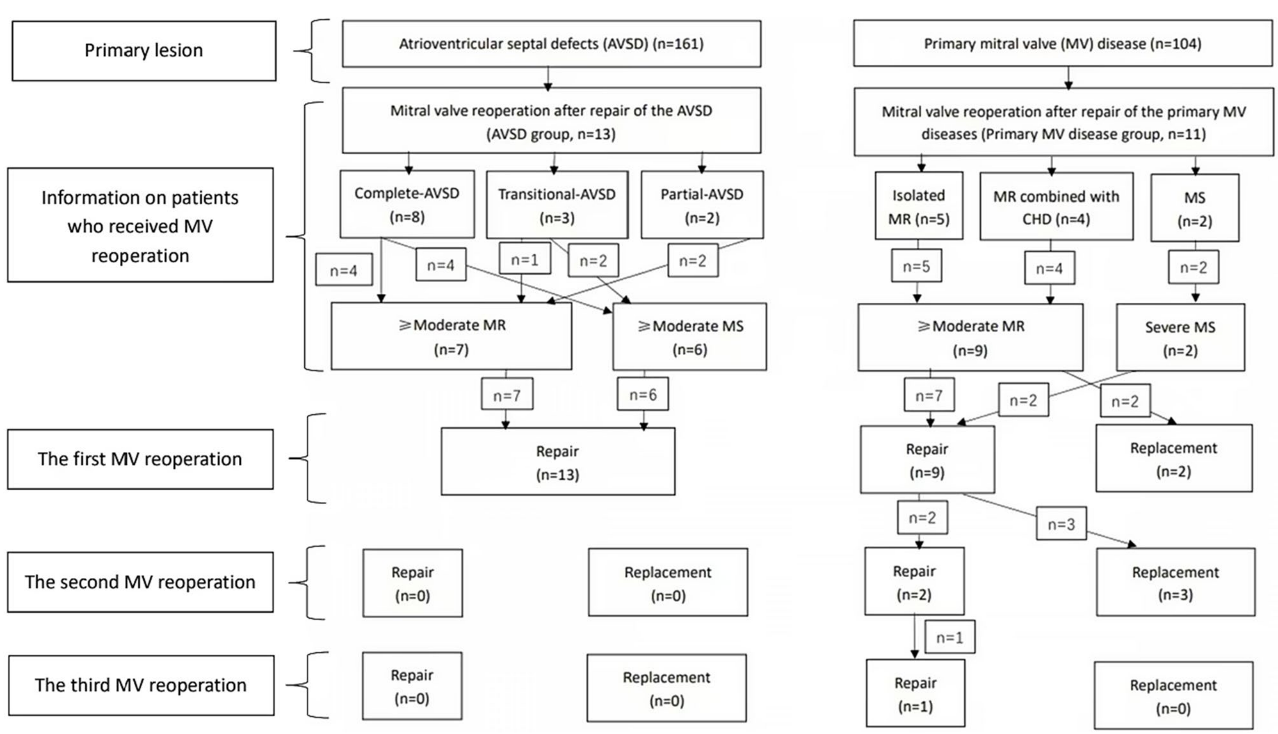


**Fig. 1** A flow chart showing the type of diseases and surgical procedures of patients who underwent mitral valve reoperation. MR, mitral valve regurgitation; MS, mitral valve stenosis; CHD, congenital heart disease

**Table 1** Demographical characteristics and clinical data

| Characteristics | Total cohort (*n* = 24) |
|---|---|
| Male, *n(%)* | 10 (41.7) |
| Patient age (months), median (IQR) | 47.35 ± 45.74 |
| Patient weight (kg), median (IQR) | 11.0 (7.4–18.3) |
| Length of time from initial surgery | 10.5 (0.9–46.8) |
| Grade of pulmonary hypertension before initial surgery | |
| None | 2 (8.3) |
| Mild | 8 (33.3) |
| Moderate and above level | 14 (58.3) |
| Preoperative grade of MV regurgitation before MV reoperation | |
| Mild | 3 (12.5) |
| Moderate and above level | 21 (87.5) |
| Preoperative grade of MV stenosis before MV reoperation | |
| Mild | 17 (70.8) |
| Moderate | 4 (16.7) |
| Severe | 3 (12.5) |
| Preoperative grade of TV regurgitation before MV reoperation | |
| Mild | 17 (70.8) |
| Moderate | 4 (16.7) |
| Severe | 3 (12.5) |
| Method of MV reoperation | |
| MV repair | 22 (91.7) |
| MV replacement | 2 (8.3) |
| Undergo the second MV reoperation | 5 (20.8) |
| Death | 4 (16.7) |
| Early death | 3 (12.5) |
| Late death | 1 (4.2) |
| Follow-up time (months) | 16.5 (1.8–39.0) |

Data are reported as mean ± SD, median (IQR), or n (%)

Abbreviations: AVSD, atrioventricular septal defect; IQR, Interquartile range; MV, mitral valve; TV, tricuspid valve

### Statistical analysis

Normally distributed continuous variables were presented as mean ± standard deviation (SD), and others were presented as median (interquartile range, IQR). Categorical variables were tabulated by frequencies and percentages. To identify the risk factors for second MV reoperation and death, the univariable and multivariable Cox regression analyses were performed. A *P* value of < 0.05 was considered to indicate statistical significance. IBM SPSS statistics 25.0 (SPSS, Inc., Chicago, IL, USA) was used for all statistical analyses. Images were created with Microsoft Office Word (Microsoft Software, Inc., Redmond, WA, USA) and GraphPad Prism 8 (GraphPad Software, Inc., La Jolla, CA, USA).

**Table 2** Surgical techniques of mitral valve repair

| Variables | #No. of Cases (%) |
|---|---|
| Total cohort (*n* = 24) | |
| Cleft closure | 14 (58.3) |
| Annuloplasty | 6 (25.0) |
| Leaflet augmentation | 4 (16.7) |
| Supravalvular ring resection | 4 (16.7) |
| Double-orifice mitral valve technique | 4 (16.7) |
| Papillary muscle splitting | 3 (12.5) |
| Mechanical mitral valve replacement | 2 (8.3) |
| Artificial chordae reconstruction | 1 (4.2) |
| Partial incision of valve leaflet | 1 (4.2) |
| Leaflet plication | 1 (4.2) |

#Surgical techniques were implemented either separately or in combination

## Results

### Patient characteristics

Notably, 24/265 patients received MV reoperations at a median age of 47.35 ± 45.74 months and weight of 11 kg (IQR, 7.4–18.3 kg; Table 1). The length of time since initial surgery and the mean follow-up period were 10.5 months (IQR, 0.9–46.8 months) and 16.5 months (IQR, 1.8–39.0 months) in the total cohort.

Among these 24 patients, 14 (58.3%) were detected with moderate and above level pulmonary hypertension before initial surgery. ≥Moderate MV regurgitation occurred in 21 (87.5%) patients while severe MV stenosis was detected in 3 (12.5%) patients before MV reoperation. Totally, 22 patients (91.7%) received MV repair and 2 patients (8.3%) received mechanical MV replacement. 5 patients received the second MV reoperation and 4 patients died including three early death and one late death (Table 1).

### Surgical techniques

During MV reoperation, leaflet cleft was discovered in 14 patients (58.3%) and these patients underwent cleft closure. The other major surgical techniques employed were annuloplasty (*n* = 6, 25%), leaflet augmentation (*n* = 4, 16.7%), supravalvular ring resection (*n* = 4, 16.7%), double-orifice mitral valve technique (*n* = 4, 16.7%) and papillary muscle splitting (*n* = 3, 12.5%). Two patients (8.3%) underwent mechanical MV replacement due to the inability to repair the valve. Additionally, a small number of techniques, such as artificial chord reconstruction (*n* = 1, 4.2%), partial incision of valve leaflet (*n* = 1, 4.2%) and leaflet plication (*n* = 1, 4.2%) were also applied as required (Table 2).

## Perioperative data

The median duration time was 107.5 min (IQR, 90.3-148.3) and 70.5 min (IQR, 46.0-76.8) for the cardiopulmonary bypass (CPB) time and the cross-clamp time, respectively. The median length of stay in the intensive care unit was 6.5 days (IQR, 4.0–11.0), and the median duration of postoperative mechanical ventilation was 60.0 min (IQR, 30.0-144.3).

Postoperative complications occurred in 10 patients (41.6%), including infection ($n=8$), pericardial effusion ($n=3$), pulmonary hypertensive crisis ($n=2$), and delayed chest closure ($n=2$). 13 patients (54.2%) was detected with moderate and above level MV regurgitation (MR), while 5 patients (20.8%) was detected with moderate and above level MV stenosis (MS) at 24 h postoperatively (Table 3).

#### Death after MV reoperation

Four patients died after surgery. The Kaplan–Meier curves revealed 1-, 3-, and 5-year survival rates of 86.6% ± 7.3%, 86.6% ± 7.3%, and 72.1% ± 14.5%, respectively, in the total cohort (Fig. 2A).

Herein, 1 patient died of respiratory and circulatory failure on the third day after surgery. In addition, 1 patient died of cardiopulmonary insufficiency on the first day postoperatively; 1 patient died of heart failure after 2 months of hospitalization with suspected cardiomyopathy, and 1 patient died of heart failure and disseminated intravascular coagulation. Multivariable Cox regression analysis revealed no independent risk factor for death after MV reoperation (Table 4).

#### The second MV reoperation and subsequent operations

24 patients underwent a total of 30 surgical procedures (Fig. 1). During MV reoperations, 22 MV repairs and 2 MV replacements were carried out. The indications included severe MR ($n=13$), moderate to severe MR ($n=7$), moderate MR ($n=1$) as well as severe MS ($n=2$)

**Table 3** Perioperative data of MV reoperations

| Variables | Total cohort ($n=24$) |
|---|---|
| CPB time (min) | 107.5 (90.3-148.3) |
| Cross-clamp time (min) | 70.5 (46.0-76.8) |
| Postoperative mechanical ventilation time (h) | 60.0 (30.0-144.3) |
| ICU stay days after surgery (day) | 6.5 (4.0–11.0) |
| Complications, n (%) | |
| Pulmonary hypertensive crisis | 2 (8.3) |
| Delayed chest closure | 2 (8.3) |
| Infection | 8 (33.3) |
| Pericardial effusion | 3 (12.5) |
| Moderate and above level MR at 24 h after MV reoperation, n (%) | 13 (54.2) |
| Moderate and above level MS at 24 h after MV reoperation, n (%) | 5 (20.8) |

Data are reported as the Median (IQR) or *n(%)*

Abbreviations: MV, mitral valve; CPB, cardiopulmonary bypass; ICU, intensive care unit; MR, mitral valve regurgitation; MS, mitral valve stenosis

and moderate MS ($n=1$). Moreover, 5 patients underwent the second MV reoperation (2 MV repairs and 3 MV replacements), and 1 patient went on to have the third MV reoperation.

Freedom from the second MV reoperation at 1 and 3 years were both 70.4 ± 11.4% respectively in the total cohort (Fig. 2B). Multivariable Cox regression analysis confirmed that the adoption of the double-orifice MV technique in MV reoperation ($HR=8.136$, 95%$CI=1.099$–60.240; $P=0.040$) was associated with the need for the second MV reoperation (Table 4).

#### MV replacement and double-orifice MV technique

Mechanical MV replacement was performed in 5 patients (20.8%), including 3 patients with isolated MR diseases and 2 patients with MR combined with congenital heart disease (Table 5). Among these 5 patients, 3 patients had previously undergone MV reoperation using the double-orifice MV technique mainly for complex valve lesions. We further discovered that patients who underwent MV reoperation using the double-orifice MV technique were significantly more likely to need and undergo mechanical MV replacement (Fig. 2C, $P<0.0001$).

#### Treatment effects of MV re-repair only

For patients who only underwent MV re-repair and had a follow-up period of ≥ 1 year, the treatment effects were assessed by MR and MS grades and by left ventricular end-diastolic diameter (LVEDD), left atrium diameter (LAD), left ventricular ejection fraction (LVEF), and left ventricular end-diastolic volume (LVEDV)(Fig. 3A to F).

Compared to the number of patients with moderate or less MR preoperative, the number was significantly increased at 24 h ($P=0.008$) and 3 months postoperatively ($P=0.031$). The number of patients with mild MS preoperatively did not significantly differ with the number at any postoperative time point.

In addition, we witnessed a sustained decline in the LAD value and the gradual recovery of the LVEF value. Compared with its preoperative values, the LVEDD was significantly decreased at 24 h postoperatively ($P=0.044$), and then, the value gradually increased and reached the preliminary stability near the preoperative level at 1 year postoperatively. For the LVEDV, there was a noticeable decrease in the volume at 24 h postoperatively compared with its preoperative value; however, the difference was not significant ($P=0.054$). Then, the value gradually increased and reached the preliminary stability at at 1 year postoperatively; however, the stable value remained below the preoperative levels. Overall, the left heart function and the MV function were improved in the short term after surgery.

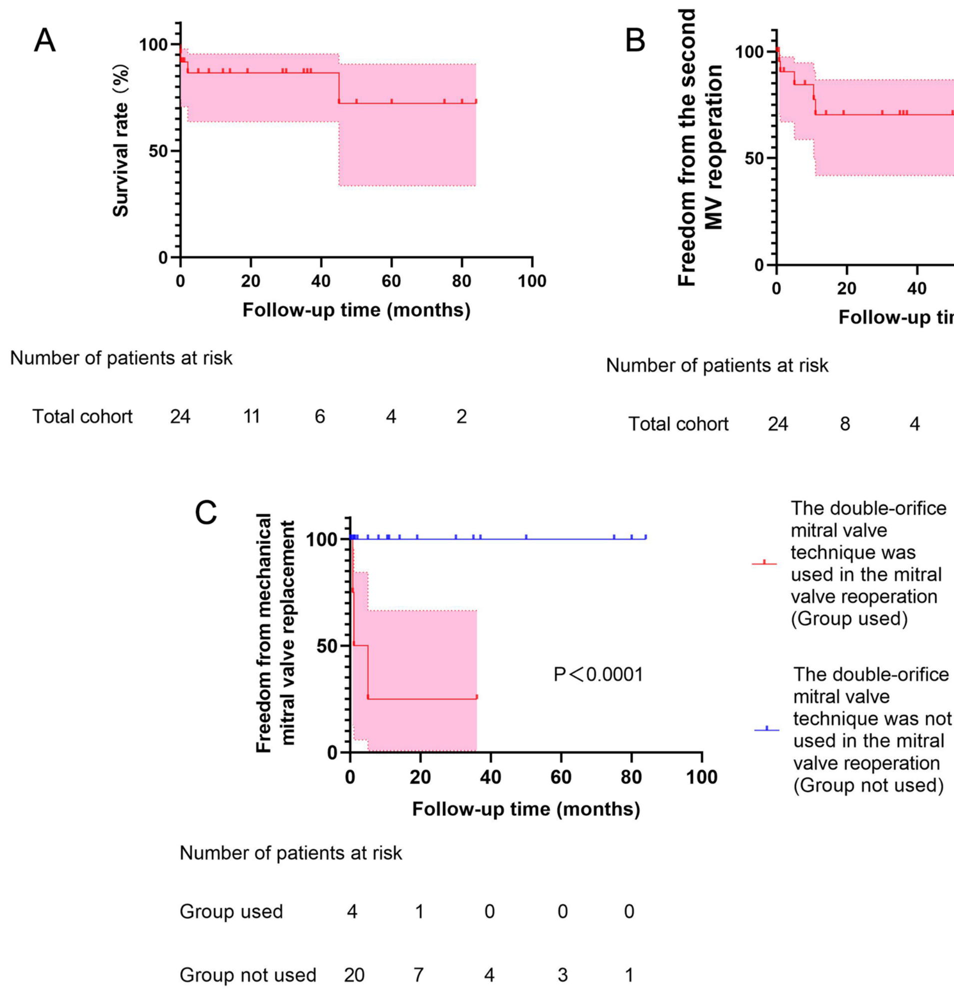


**Fig. 2** Kaplan–Meier survival rate (**A**) and freedom from the second MV reoperation (**B**) in the total cohort. Kaplan–Meier freedom from mechanical mitral valve replacement with (red line) and without (blue line) the use of the double-orifice MV technique (**C**). Confidence intervals are indicated as dotted lines. Significant differences were noted for freedom from mechanical mitral valve replacement. MV, mitral valve

## Discussion

We retrospectively evaluated the surgical outcomes of 24 patients who underwent MV reoperations. In total, four deaths were recorded, consisting of three early deaths and one late death. 22 patients (91.7%) underwent MV repair in their MV reoperations, while 2 patients (8.3%) received MV replacements. Five patients (20.8%) required a second MV reoperation, including 2 patients (8.3%) undergoing MV repair and 3 patients (12.5%) undergoing mechanical MV replacement. Our analysis revealed that use of the double-orifice MV technique during MV reoperation was a significant risk factor ($P = 0.040$) for the necessity of a second MV reoperation. Moreover, it was found to significantly elevate the likelihood of receiving mechanical MV replacement ($P < 0.0001$).

Currently, scholars have reached a consensus on MV repair being the preferred treatment as it has reportedly shown good therapeutic effect on 90% of pediatric patients [8]. In our cohort, among 22 patients who underwent MV repair, 17 patients (77.3%) did not require further surgical intervention. We specifically evaluated 10 patients who had MV re-repair only and were followed up for a minimum of 1 year. At 24 h postoperatively, the MR degree in all 10 patients was successfully controlled at moderate level or less, which may be ascribed to the relatively uncomplicated nature of their MV lesions. Even at 1 year postoperatively, 6 patients still maintained satisfactory MV anti-regurgitation function. Overall, at 1-year follow-up, the MR degree was well controlled at mild level in 6 patients (60%), and the MS degree was well controlled at mild level in 8 patients (80%), respectively.

Despite some minor deviations from the normal echocardiography values [9–13], the left ventricular function of the patients demonstrated improvement at 24 h postoperation. In those patients with pre-surgical myocardial impairment, this improvement persisted, and the left ventricular function remained stable at 1 year after the operation (Fig. 3A to F). Adopting the MV repair method

**Table 4** Univariable and multivariable risk factors for death and the second MV reoperation

| Variables | Death | | | | | | Second MV reoperation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Univariable Analysis | | | Multivariable Analysis | | | Univariable Analysis | | | Multivariable Analysis | | |
| | HR | 95% CI | *P* value | HR | 95% CI | *P* value | HR | 95% CI | *P* value | HR | 95% CI | *P* value |
| Age at MV reoperation | 0.948 | 0.878–1.024 | 0.174 | | | | 1.005 | 0.984 −1.026 | 0.660 | | | |
| Weight at MV reoperation | 0.865 | 0.655–1.141 | 0.304 | | | | 0.981 | 0.886–1.086 | 0.708 | | | |
| Sex (male = 0) | 0.814 | 0.114–5.802 | 0.837 | | | | 1.382 | 0.231–8.282 | 0.723 | | | |
| ICU stay after surgery | 1.039 | 0.973–1.110 | 0.258 | | | | 1.024 | 0.939–1.117 | 0.591 | | | |
| Delayed chest closure | 6.210 | 0.556–69.301 | 0.138 | | | | | | | | | |
| Infection | 1.602 | 0.204–12.550 | 0.654 | | | | 4.576 | 0.749–27.947 | 0.099 | | | |
| Pericardial effusion | 7.366 | 1.020–53.201 | **0.048** | 4.997 | 0.296–84.426 | 0.265 | | | | | | |
| Adopted double-orifice MV technique in MV reoperation | 1.201 | 0.123–11.681 | 0.875 | | | | 10.686 | 1.738–65.684 | 0.011 | 8.136 | 1.099–60.240 | **0.040** |
| Mixed mitral valve pathology | 0.370 | 0.038–3.566 | 0.390 | | | | 1.437 | 0.240–8.617 | 0.692 | | | |
| Discovered cleft leaflet during MV reoperation | 0.282 | 0.029–2.721 | 0.274 | | | | 0.580 | 0.096–3.490 | 0.552 | | | |
| Isolated MR diseases | | | | | | | 9.064 | 1.422–57.764 | 0.020 | 6.961 | 0.841–57.596 | 0.072 |
| CAVSD disease | 0.572 | 0.058–5.658 | 0.633 | | | | | | | | | |
| MR combined with CHD | 11.039 | 0.996–122.359 | **0.050** | 7.679 | 0.314-187.754 | 0.211 | 4.465 | 0.392–50.805 | 0.228 | | | |
| MS diseases | 2.683 | 0.273–26.390 | 0.397 | | | | 1.895 | 0.209–17.182 | 0.570 | | | |
| Severe MR before MV reoperation | 1.112 | 0.152–8.120 | 0.917 | | | | | | | | | |
| Moderate and above level MR before MV reoperation | | | | | | | 0.907 | 0.100–8.206 | 0.931 | | | |
| Severe MS before MV reoperation | 7.366 | 1.020–53.201 | **0.048** | 13.190 | 0.991-175.629 | 0.051 | | | | | | |
| Moderate and above level MS before MV reoperation | | | | | | | 1.224 | 0.202–7.409 | 0.826 | | | |
| Moderate and above level pulmonary hypertension before MV reoperation | 1.228 | 0.172–8.753 | 0.837 | | | | 0.387 | 0.063–2.371 | 0.305 | | | |
| Moderate and above level MR at 24 h after MV reoperation | 0.258 | 0.026–2.528 | 0.245 | | | | 0.510 | 0.085–3.072 | 0.462 | | | |
| Moderate and above level MS at 24 h after MV reoperation | | | | | | | 1.537 | 0.254–9.313 | 0.640 | | | |

*Abbreviations*:= CPB, cardiopulmonary bypass; ICU, intensive care unit; CAVSD, complete atrioventricular septal defect; MR, mitral valve regurgitation; MS, mitral valve stenosis; CHD, congenital heart diseases; MV, mitral valve; HR, hazard ratio; CI, confidence interval

**Table 5** Surgical information for pediatric patients undergoing mechanical mitral valve replacement

| Patients | No.1 | No.2 | No.3 | No.4 | No.5 |
|---|---|---|---|---|---|
| Type of diseases | Isolated MR | Isolated MR | Isolated MR | MR combined with CHD | MR combined with CHD |
| Intraoperative findings during the initial MV operation | ① Prolapse as well as thickening in A2 area of the anterior MV ② Cleft leaflet in A3 area of the anterior MV and in P2 area of the posterior MV ③ Thin and tender in P3 area of the posterior MV | Cleft leaflet in the anterior MV leaflet (1.5 cm in length) and in the posterior MV leaflet (tiny) | ① Significantly enlarged mitral annulus ② Valve dysplasia, with both anterior and posterior valves differentiating into two leaflets, and both posterior leaflets developing smaller | Significant prolapse in the P2 area of the anterior MV | ① Significant prolapse of the anterior MV ② The posterior MV has less tissue, shorter chordae tendineae, and limited mobility ③Misalignment of anterior and posterior MV |
| Surgical method of the initial MV operation | ① Cleft closure (Anterior & Posterior MV) ② Annuloplasty | ① Cleft closure (Anterior & Posterior MV) ② Annuloplasty | ① Annuloplasty | ① Wedge shaped resection of prolapsed valve tissue & closure of the cutting edge ② Annuloplasty | ① Posterior MV is enlarged with bovine pericardial flap (25 mm * 20 mm) ② Suture of artificial chordae tendineae for anterior MV ③ Annuloplasty |
| Intraoperative findings during MV reoperation | ① Misalignment of anterior and posterior MV ② Lack of tissue in the anterior MV & anterior MV leaflet prolapse ③Lack of tissue in the posterior MV & posterior MV leaflet curling | ① Tear at the end of the originally sewn cleft ② Thickening and curling of the leading edge of the MV leaflet | ① Thickening and prolapse in A2 area of the anterior MV (with only one set of papillary tendon tension) ② A1 and A3 area of the anterior MV are poorly developed and have very small valve tissue that is difficult to repair ③ The posterior MV splits into two, with P2 absent and only P1 & P3 present, and the valve is extremely poorly developed ④ Anterior and posterior papillary muscle fusion & posterior papillary muscle dysplasia | Severe tearing in A3 area of the anterior MV | Tear of the tissue around constriction suture of the MV annulus, resulting in reduced annuloplasty effect |
| Surgical method of MV reoperation | Mechanical MV replacement | ① Cleft closure ② **Double-orifice MV technique** | ① Fixation of anterior and posterior valve annulus with artificial vascular strips to limit anterior valve prolapse ② **Double-orifice MV technique** | ① Cleft closure ② **Double-orifice MV technique** | Mechanical MV replacement |
| Intraoperative findings during the second MV reoperation | / | Poor morphology of the MV leaflets | Poor morphology of the anterior MV leaflet | Formation of vegetation in the posterior MV | / |
| Surgical method of the second MV reoperation | / | **Mechanical MV replacement** | **Mechanical MV replacement** | **Mechanical MV replacement** | / |

*Abbreviations*: CHD: congenital heart diseases; MR: mitral valve regurgitation; MV: mitral valve

in MV reoperations could produce a favorable therapeutic effect in the early stage. Therefore, it is advisable to recommend this approach as the primary treatment option.

Despite the generally favorable outcomes of MV repair, 3 patients still underwent mechanical MV replacement during the second MV reoperation. This was due to the irreparability of the valve leaflets, most of which occurred shortly after the adoption of the double-orifice MV technique. This result was inconsistent with the relatively promising findings of the double-orifice MV technique reported in other studies [14, 15]. A variety of factors may account for this divergence, which are elaborated in detail as follows.

First, the types of MV lesions exhibited remarkable disparities among diverse studies, and the technique was used during MV reoperation rather than initial operation. Quarti et al. [15] reported that within a 30-month follow-up duration, no MV reoperation was required in MV prolapse patients who underwent the double-orifice MV technique. Nevertheless, in the present study, among the 4 patients who adopted this technique, 3 patients presented with cleft leaflets and 1 patient had a combination of MV prolapse and MV dysplasia. These cases were predominantly characterized by valve lesions rather than

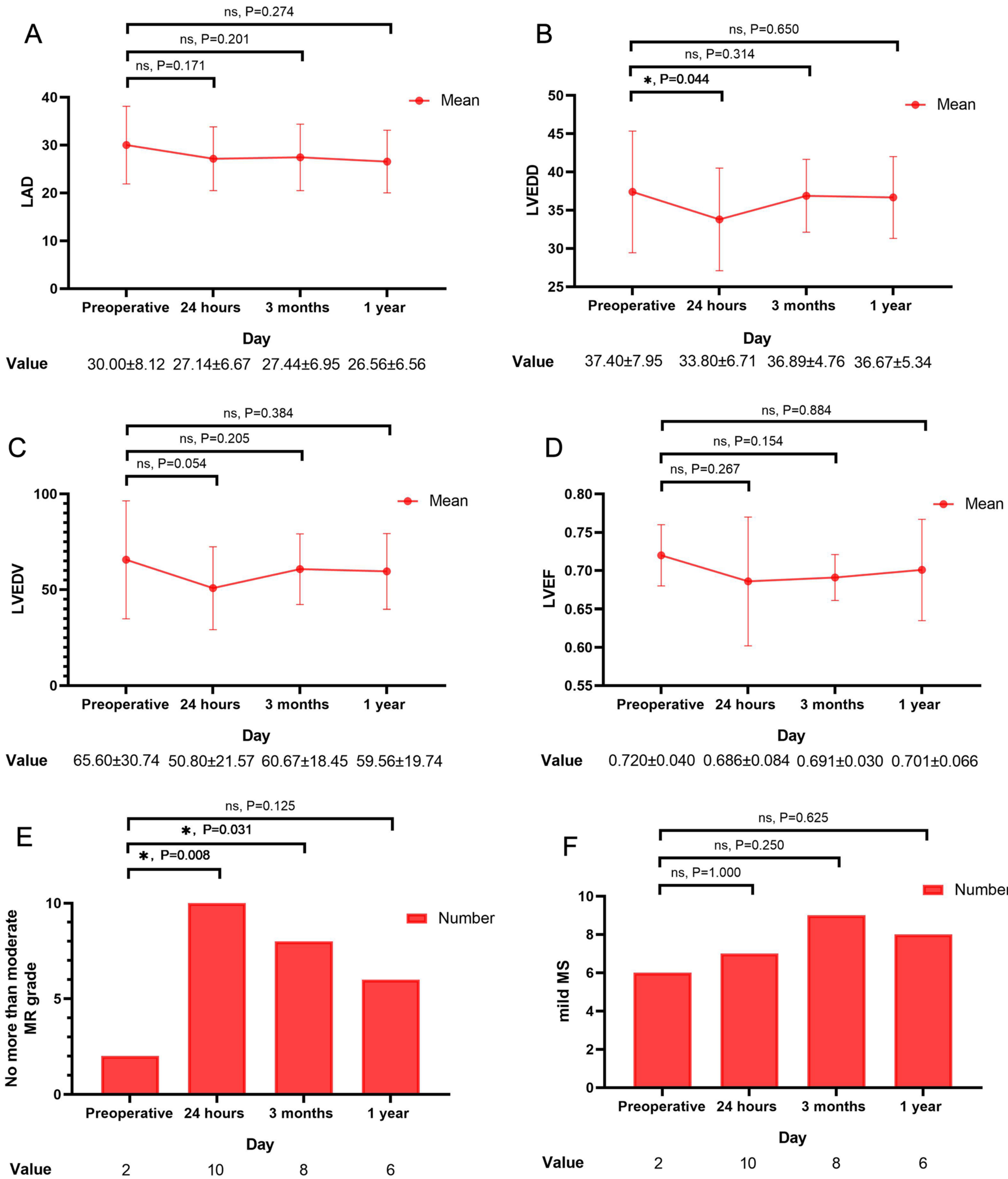


**Fig. 3** Follow-up LAD (**A**), LVEDD (**B**), LVEDV (**C**), LVEF (**D**) results of patients who had mitral valve re-repair only ($n = 10$). Follow-up results of patients with no more than moderate MR grade (**E**) and patients with mild MS grade (**F**) who had mitral valve re-repair only ($n = 10$). Patients included in the analysis should have a follow-up period of at least 1 year. Significant decrease was discovered at postoperative 24 h compared with preoperative ($P = 0.044$). Compared to the preoperative number of patients with moderate or less MR, there was a significant increase at postoperative 24 h ($P = 0.008$) and at 3 months ($P = 0.031$). LAD, left atrium diameter; LVEDD, left ventricular end-diastolic diameter; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction; MR, mitral valve regurgitation; MS, mitral valve stenosis

abnormalities in the chordae tendineae and papillary muscles. Performing the double-orifice MV technique on these already repaired, structurally impaired valves with possibly altered valve geometry may have led to the unsatisfactory surgical results.

Second, the tension of the suture is also decisive. Redaelli et al. had previously validated that higher tension emerged at the edge-to-edge suture during diastole [16]. In the study conducted by Zhang et al., a reinforced mattress stitch using a Gore-Tex suture and Dacron pledgets was applied on the anterior and posterior annulus corresponding to the edge-to-edge suturing site and then passed through the MV leaflets to mitigate the tension of the edge-to edge suture [17]. Reportedly, if required, annuloplasty can be carried out concurrently to enhance the long-term efficacy [18]. In our study, taking into account the cleft leaflet lesions and the thin and delicate texture of the valves, we were unable to adopt Zhang et al.'s approach of threading sutures through the MV. This was to prevent potential large-scale damage to the valve structure resulting from uneven force distribution.

Finally, the double-orifice MV technique is, in fact, not a suitable option for specific types of MV lesions. Mo et al. do not recommend its use for the following lesions: severe hypoplasia of the MV, characterized by thin and elongated leaflets; severe stenosis of the mitral annulus; funnel-shaped lesions resulting from the fusion of anterior and posterior leaflets of the MV; and uncontrolled subacute infective endocarditis [19]. Based on our practical experience, excellent therapeutic outcomes can be attained for the majority of complex MV lesions through personalized, meticulous, and highly patient-oriented repair strategies. Nevertheless, in pediatric patients with complex valve lesions, the double-orifice MV technique has not yielded the desired therapeutic results.

### Limitations

Our study is conclusive, albeit with some limitations. First, it was a single-center study with limited patients. Second, the number of patients was relatively small for risk factor evaluation. Finally, the differences among the surgeons' selection of repair methods may have influenced the outcomes.

## Conclusions

The reoperation of the MV in children with congenital MV diseases poses a formidable challenge, manifested by a high postoperative mortality rate and re-intervention rate. MV function and cardiac function in patients who underwent MV re-repair only was ideal in the short term after surgery. Patients for whom the double-orifice MV technique was used in complex MV reoperations were more likely to need further interventions, such as mechanical MV replacement at early stages after surgery.

### Abbreviations

| | |
|---|---|
| CPB | cardiopulmonary bypass |
| IQR | interquartile range |
| LAD | left atrium diameter |
| LVEDD | left ventricular end-diastolic diameter |
| LVEDV | left ventricular end-diastolic volume |
| LVEF | left ventricular ejection fraction |
| MR | mitral valve regurgitation |
| MS | mitral valve stenosis |
| MV | mitral valve |
| TTE | transthoracic echocardiography |

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### Author contributions

HFZ and MY designed this study. YXC and YPS are responsible for collecting data, writing articles, conducting statistical analysis, reviewing articles, and creating images. GC, YPM, HZ, HFZ and MY are responsible for surgery, perioperative treatment and postoperative follow-up. All authors reviewed the manuscript. All authors read and approved the final manuscript.

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### Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

### Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Research Ethics Board of the Children's Hospital of Fudan University [Approval no. (2024)211]. Exemption of informed consent from patients with the consent of the ethics committee.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

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