

Mitral valve repair in papillary muscle rupture

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Papillary muscle rupture (PMR) is a significant mechanical complication following myocardial infarction (MI), a condition associated with a high mortality. It results in severe mitral valve regurgitation (MR), often accompanied by cardiogenic shock and pulmonary edema, requiring both emergent medical treatment and surgical intervention. Surgical treatment includes either chordal sparing mitral valve replacement or mitral valve repair, which is associated with a high mortality. Mitral valve repair is believed to be superior to mitral valve replacement with respect to improving left ventricular function, albeit with risk of repair failure and resulting in increased cross clamp times. Concomitant coronary revascularization may improve both short- and long-term outcomes after surgery. With advances in medical innovations in the field of transcatheter devices, these devices may serve as a bridge to recovery or treatment in the setting of acute MR due to PMR. However, long-term data will be required to establish the non-inferiority of one treatment modality over the other. Management of these patients should be guided by a dedicated mitral heart team.

Keywords: Papillary muscle rupture (PMR); myocardial infarction (MI); mitral valve repair; mitral clip; neochoordae



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Introduction

Papillary muscle rupture (PMR) is a rare mechanical complication post-acute myocardial infarction (MI). It affects 0.07–0.26% of patients following MI and accounts for 5% of mortality after an infarct (1,2). It results in severe mitral valve regurgitation (MR), which is often accompanied by cardiogenic shock and pulmonary edema, requiring urgent management (3). The risk factors for PMR include older age, female sex, history of heart failure, delayed presentation following MI and chronic kidney disease. Medical management alone is associated with a mortality as high as 75% in the first 24 hours (4). PMR was first reported by Davison in 1948 (5) and the first mitral valve replacement for PMR was reported by Austen *et al.* in 1965 (6,7). There has not been a significant change in the management of patients presenting with acute PMR who require hemodynamic and ventilatory support followed by urgent or emergent mitral valve intervention.

Anatomy of the mitral sub-valvular apparatus

The mitral valve complex consists of the mitral valve annulus, anterior/posterior mitral leaflets, the sub-valvular apparatus [chordae tendineae and papillary muscles (PMs)] and the left ventricular wall (8,9). The PMs are located between the apex and the middle third of the left ventricle. They are connected by the chordae tendineae to the ventricular surface of the mitral valve leaflets. The sub-valvular apparatus as a whole function to prevent prolapse of the mitral valve into the left atrium during systole. Multiple attempts have been made to classify PMs, however, there is marked variation in their anatomy. The classical description is the presence of two PMs, however, in a post-mortem examination of PM this configuration of two PMs was only present in 3.4% of cases, whereas 43% had two groups of PMs, 31% had three groups and 21% had four groups (10). Other variations noted were PMs with ‘separate bases and fused apex’, ‘single base and divided apex’, ‘small

projections' of PMs, long PMs, 'perforated' PMs and those with a 'base attached to a large bridge' (10). These variations in PM may have implications in the feasibility and complexity of mitral valve repair (10).

PM dysfunction due to ischemia result in MR. In acute ischemic MR, the postero-medial PM is most commonly involved as it receives a single blood supply via the posterior descending artery whereas the antero-lateral PM receives dual supply from the left anterior descending and diagonal or the circumflex artery (2,9). Jouan *et al.* described four mechanisms of ischemic mitral valve prolapse (*Figure 1*): necrosis of a separate commissural head (inserted close to the annulus) with rupture of the anchorage of the commissural chord (*Figure 1A*); necrosis of a single head PM subdivided in multiple heads with partial rupture (*Figure 1B*); necrosis of a fenestrated PM with detachment of its main insertion: "incomplete" rupture (*Figure 1C*); single PM with complete and total rupture (*Figure 1D*) (11).

Clinical assessment

Patients presenting with breathlessness and or chest pain a week following a MI should be suspected to have a PMR. It is imperative a thorough history and clinical examination is carried out. On auscultation, patients who do have murmurs can have mid, late or holosystolic murmurs. Symptoms and signs will be in keeping with acute left heart failure with rapidly progressing cardiogenic shock and hypoxia (9).

Imaging

The gold standard investigation is echocardiography which typically reveals a mobile mass attached to a flailing mitral leaflet with evidence of severe eccentric MR. Left ventricular function may be normal or low-normal with regional wall abnormalities. Transthoracic echocardiography (TTE) has a sensitivity of 65–85% while transesophageal echocardiography (TEE) has a sensitivity of 92–100% (12). TEE is important in interrogating the mitral leaflets/sub-valvular apparatus to study the pathology/etiology of the regurgitant jet and various anatomical measurements that are required for the different treatment strategies. In most cases of PMR, the patients get massive MR due to bi-leaflet prolapse (muscle giving chords to multiple segments). As a result, on echocardiography you see severe MR or hyperdynamic ventricle without evidence of severe volume

overload (very large left atrium or left ventricle), hence these patients go into acute pulmonary edema.

Pre-operative angiography is also important to determine the extent of coronary artery disease and may reveal occlusion of the infarct-related artery (7).

Mitral valve intervention

In the initial phase of presentation with acute MR, these patients require medical optimisation;

- (I) Hemodynamic support with vasoactive drugs and mechanical circulatory support;
- (II) Afterload reduction with intra-aortic balloon pump insertion (IABP);
- (III) Acute pulmonary edema managed with intravenous diuretics and ventilatory support;
- (IV) Arrhythmias treated using pharmacological or mechanical cardioversion;
- (V) Percutaneous intervention of infarct-related artery may be required;
- (VI) Monitoring for other mechanical complications of MI.

Once the diagnosis of acute MR secondary to PMR has been made, definitive management requires correction of the MR without delay. The strategy for management of these patients due to ischemic PMR is dictated by the patient's co-morbidities, the anatomy of the rupture, i.e., location and degree of the PM involvement (partial *vs.* complete), anatomy of coronary artery disease, the different intervention options available and local expertise guided by a consensus opinion from heart team discussions. Interventions to treat MR include percutaneous and surgical techniques. The practice to revascularize during concomitant mitral valve intervention in acute MR is variable.

The current gold standard treatment of PMR is surgery.

Mitral valve replacement

Chordal sparing mitral valve replacement is more commonly carried out in the setting of acute PMR. Multiple case series have been published with reported in-hospital mortality of 20–25% (13,14). Similarly, 5- and 10-year survival of 65–68% and 32–56%, respectively (15–17). Bouma *et al.* highlighted preservation of sub-valvular apparatus in mitral valve replacement is associated with better long-term survival (18).

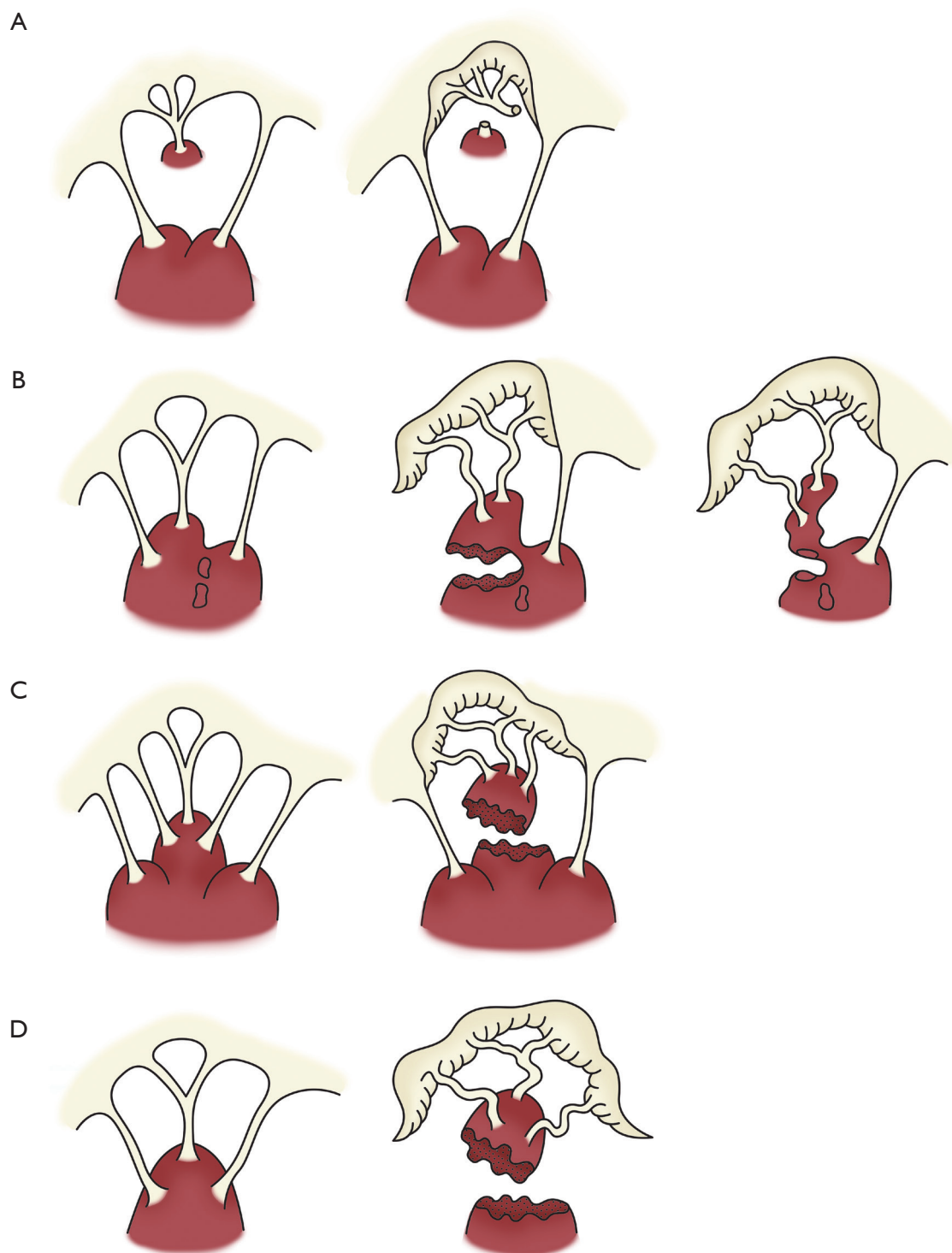


Figure 1 Mechanisms of ischemic mitral rupture. (A) Necrosis of a separate commissural head (inserted close to the annulus) with rupture of the anchorage of the commissural chord. (B) Necrosis of a single head papillary muscle subdivided in multiple heads with partial rupture. (C) Necrosis of a fenestrated papillary muscle with detachment of its main insertion: "incomplete" rupture. (D) Single papillary muscle with complete and total rupture (11).

On-pump mitral valve repair

Gillinov *et al.* in 2001 highlighted predictors of repair failure in chronic ischemic MR; presence of complex jet, lack of left internal mammary artery (LIMA) to left anterior descending artery (LAD) graft and lateral wall infarct (19). Mihos *et al.* proposed an echocardiographic-based treatment algorithm for repair over replacement (20). There have been multiple clinical trials and observational studies investigating outcomes after severe chronic ischemic MR, advocating mitral valve replacement over repair due to a higher incidence of recurrent MR in the latter group (21). There is scarcity of evidence of superiority of repair over replacement after PMR due to the rare nature of this entity.

In multiple observational studies, including case series and case reports of patients who developed PMR following an acute MI, the core principles of repair in these patients were largely based on Carpentier's reconstructive valve techniques (11,13,14,18,22-37). The different surgical techniques used to repair the mitral valve in these studies included:

- (I) Ruptured PM re-implantation to the adjacent PM: this involves re-implantation of the tip of the PM to adjacent healthy PM with a pledget re-enforced polytetrafluoroethylene (PTFE) suture. This also allows for height adjustment enabling good coaptation (27);
- (II) Ruptured PM re-implantation at the base of the PM: the ruptured PM is implanted at the base of the healthy PM using pledgeted PTFE mattress sutures (31);
- (III) Ruptured PM re-implantation in the left ventricle wall: this technique has been described by Carpentier, and involves lowering the ruptured PM to a sub-valvular level that restores the appropriate length of the chordae. A trench is created in the ventricular wall. Two mattress 4/0 sutures are passed through the cuff of the PM and through the trench as deep as possible which buries the cuff within the trench. Approximation sutures are placed to close the trench (*Figure 2*) (38);
- (IV) Use of Neochordae: pledgeted PTFE sutures are secured to the PM while the other ends are passed through the free edge of the leaflet. Once an adequate length of neochordae is achieved, allowing optimal coaptation, the sutures are then tied (38);
- (V) Chordal translocation: this technique described by Carpentier involves transfer of secondary chordae

from the ventricular aspect of the leaflet provided three conditions can be met: (I) chordae underneath the prolapse leaflet are selected; (II) the chordae are resilient; (III) annuloplasty ring is implanted to increase coaptation zone and reduced tension on the leaflet tissue and the transferred chordae (*Figure 3*) (38);

- (VI) Resection of prolapse leaflet segment: these follow the same principles as described by Carpentier for degenerative valve disease (38);
- (VII) Annuloplasty ring or bands: in the majority of observational studies, patients undergoing mitral repair for PMR, annuloplasty rings or bands were used to support the mitral valve from future annular dilatation.

The preference for mitral valve repair when compared to mitral valve replacement appeared to be higher in earlier studies reducing to 17% in the most recent case series (13), reflecting surgeons' preference for mitral valve replacement. Mitral valve repair failure rate ranged from 4% to 50% (11,13,14,18,22-37). This is likely to be due to a combination of edema, progression of tissue necrosis and lack of tensile strength in the ischemic tissues. Over the last three decades, apart from a reduction in the incidence of PMR to 0.07% from 1% to 5% as reported in the case series by Pahuja *et al.* (37), there has not been a significant improvement in surgical in-hospital mortality which has largely remained in the region of 25% (11,13,14,18,22-37). This is unsurprising as the conduct of the surgery and mechanical circulatory support has largely remained unchanged.

Off-pump transapical mitral valve repair

The transapical off-pump minimally invasive repair using the NeoChord DS1000 device (NeoChord, St Louis Park, MN, USA) is a novel technique for surgical repair of degenerative mitral valve disease (39). It allows for real time adjustment of the length of the neochords, providing optimal coaptation. Based on computed tomography reconstructions and intra-operative echocardiography, optimal incision level is determined usually at the fifth or sixth intercostal space. Successive dilatations of the left ventricular apical puncture site, the NeoChord DS1000 device (NeoChord, St Louis Park, MN, USA) is advanced over the guidewire into the left atrium and guided across the mitral valve. The posterior leaflet is captured and the neochords deployed and secured at the puncture site over Teflon strips (39).

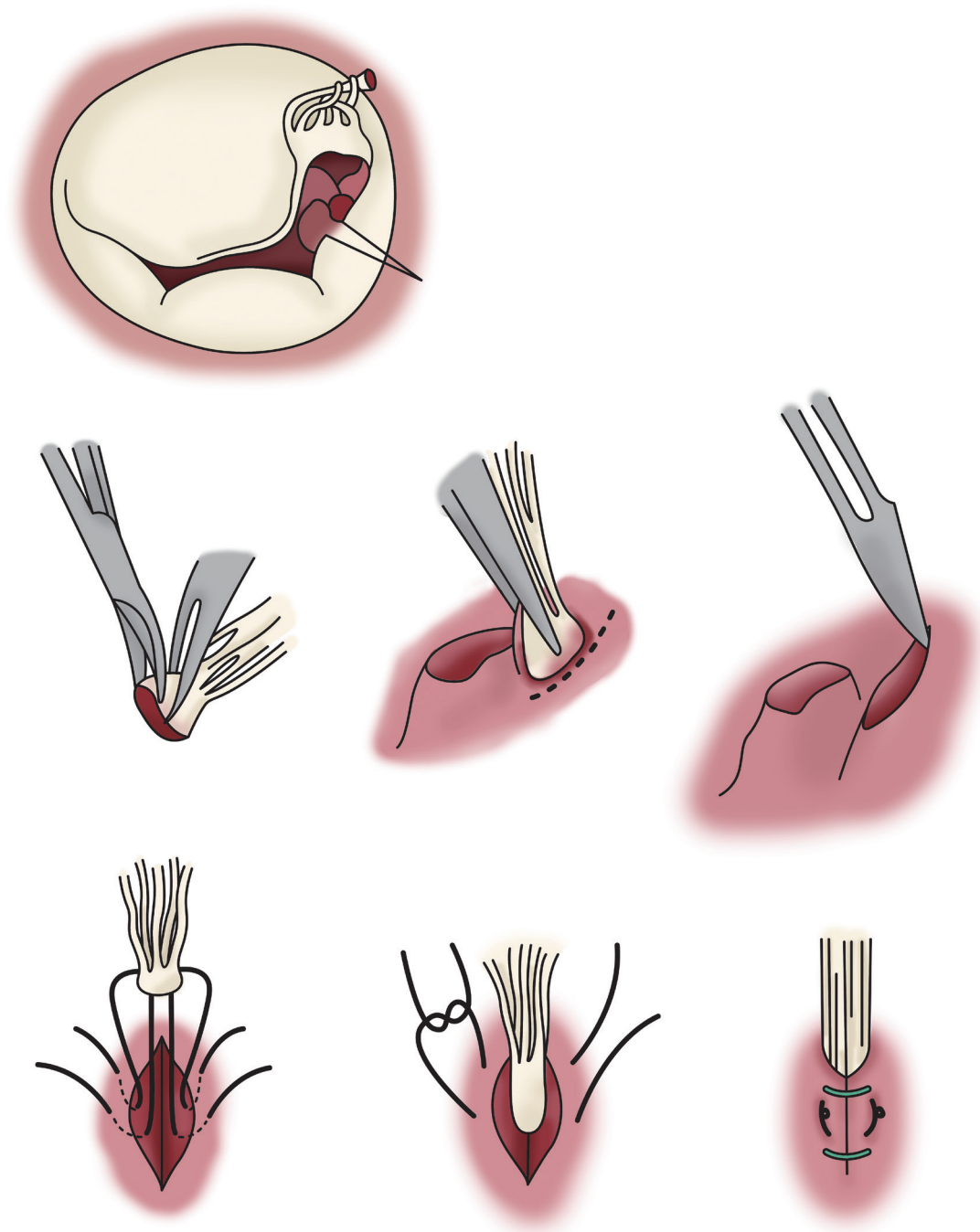


Figure 2 Implantation of ruptured papillary muscle into LV wall. A trench is created in the ventricular wall. Two mattress 4/0 sutures are passed through the cuff of the PM and through the trench as deep as possible which buries the cuff within the trench. Approximation sutures are placed to close the trench (24). LV, left ventricle; PM, papillary muscle.

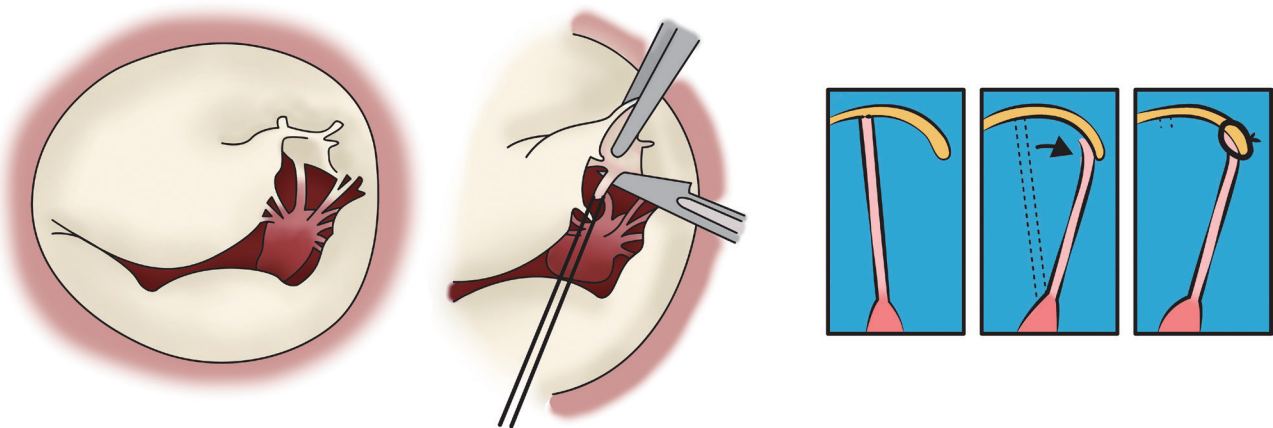


Figure 3 Chordal Translocation. Transfer of secondary chordae from the ventricular aspect of the leaflet to the leaflet edge (24).

In the case series described by Budra and colleagues, three patients developed PMR after presenting with inferior STEMI, resulting in severe MR and cardiogenic shock (40). All three patients underwent off pump neo-chord implantation ranging from two to three chords with a chord also used to secure the sub-valvular apparatus. All patients had moderate MR on discharge. They re-presented two to five months later with severe MR. The etiology of MR progression was due to rupture of native chords in two patients, entrapment of ruptured PM in the coaptation zone and rupture of artificial chordae in the other patient. Two patients underwent mitral valve replacement and one mitral valve repair with no in-hospital mortality. In the case series described by Heuts *et al.* seven patients underwent the above procedure for isolated P2 prolapse, a median of five chords were used and showed trivial MR at one-year follow-up (39). It might be that a higher number of chordae may be required to support the prolapsing leaflet in the setting of PMR, although it is a hypothetical observation. In a recent review of 203 patients following transapical off-pump NeoChord implantation, the incidence of moderate or higher residual MR at discharge was 13% (41).

The off-pump neo-chordae implantation in the case series by Budra and colleagues may serve as a bridge to recovery and subsequently to surgery in patients for whom surgery is precluded in the acute setting. Further studies will be required to determine the practicality of neo-chord implantation in PMR and their short- and long-term outcomes.

Other transapical devices include the Tendyne (Tendyne Holdings, LLC, Roseville, MN, USA) and the Intrepid (Medtronic, Minneapolis, MN, USA) which are self-expanding valves and are used in the setting of severe

MR (42). However, to date there has not been any case descriptions of these valves being used in PMR. Future studies will be required to establish the feasibility of these valves in the setting of PMR.

Trans-catheter mitral valve repair

The current era of minimally invasive procedures is continuously evolving with multiple new medical innovations since the successful introduction of the trans-catheter aortic valve. However, the complex anatomy of the mitral valve, annulus, sub-valvular apparatus and proximity to the left ventricular outflow tract makes a single device that can address all mitral pathologies somewhat challenging.

The MitraClip device (Abbott Vascular, Abbott Park, IL, USA) is based on the principle of Alfieri's stitch which is used to correct complex MR lesions (43). The MitraClip device (Abbott Vascular, Abbott Park, IL, USA) is a percutaneously implanted mechanical clip made of cobalt chromium arms covered by polyester fabric that grasp and coapt the mitral valve in a beating heart with the aid of echocardiography and fluoroscopy.

The current evidence for use of MitraClip is Class IIb in primary MR and Class IIa in secondary MR in patients who have prohibitive risks for surgery as per the 2021 European Society of Cardiology (ESC)/European Association for Cardio-Thoracic Surgery (EACTS) guidelines for management of valvular heart disease (44).

MitraClips have also been used in acute ischemic PMR in patients with significant co-morbidities precluding them from mitral valve surgery (45-53). Between two to three

clips were used in these patients creating a single orifice with mitral valve area of around 2.1 cm², with a mean trans-mitral gradient ranging from 2 to 6 mmHg. All patients were successfully weaned from mechanical and inotropic support with trivial to moderate MR on discharge with no mortality (45-53).

These case reports (45-53) highlight novel use of MitraClip in PMR with successful outcomes in a patient population that were destined for extremely high-risk surgery or conservative management. It is pertinent to mention the slightly elevated trans-mitral gradients likely related to reduction in the mitral valve area. MitraClip-related mitral stenosis is associated with worse long-term outcomes and survival (54).

Further follow-up will be required to determine the long-term sequelae of MitraClip (Abbott Vascular, Abbott Park, IL, USA) although it appears a viable option in the short-term in addressing patients with cardiogenic shock due to PMR with no mortality in the high-risk patient cohort.

Revascularisation in PMR

In these critically ill patients, coronary angiography may be associated with ventricular arrhythmias and hemodynamic compromise. Nevertheless, coronary angiography allows for identification of significant coronary artery disease that can be addressed during the same procedure and reduce the cross-clamp times allowing for a hybrid approach. Chevalier *et al.* showed a significant difference in survival in patients who underwent concomitant coronary artery bypass graft (CABG) along with mitral surgery. Similarly, a more recent case series by Massimi *et al.* also highlighted concomitant CABG being an independent predictor of survival (13,28). However, the benefit of concomitant revascularisation remains debatable.

Conclusions

In conclusion, in patients presenting with acute severe MR due to PMR, the optimal management strategy should be guided by dedicated mitral heart team discussions taking into consideration the clinical state of the patient, comorbidities, pathology of the valve and local technical expertise to ensure a successful patient outcome.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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