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REVIEW

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Mitral valve surgery after failed transcatheter intervention for mitral regurgitation: surgical techniques, challenges and outcomes

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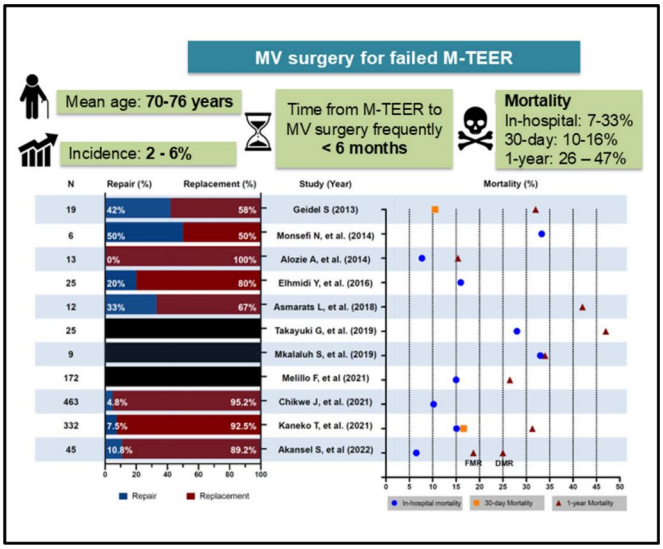
Mitral Valve Surgery After Failed Transcatheter Intervention for Mitral Regurgitation: Surgical Techniques, Challenges, and Outcomes

Summary

MV surgery after failed M-TEER is a complex but increasingly necessary procedure, associated with high mortality and morbidity. MV repair is the preferred strategy, but is technically possible in only a minority of patients. Such aspects need to be taken into consideration in the lifetime management of MV patients. In addition, MV surgery after failed M-TEER should be performed in high-volume Heart Valve Centres.



DMR degenerative mitral regurgitation; **FMR** functional mitral regurgitation; **M-TEET** mitral transcatheter edge-to-edge repaire; **MV** mitral valve

Summary

OBJECTIVES: This review article aims to examine the surgical approach to patients with failed mitral transcatheter edge-to-edge repair (M-TEER), focusing on operative challenges, decision-making and contemporary outcome data. Technical considerations, including device removal and the management of complex mitral valve (MV) anatomy, are discussed.

METHODS: We performed a comprehensive literature review and gathered the experience from high-volume centres in the surgical management of failed M-TEER.

RESULTS: MV surgery after failed M-TEER is a complex but increasingly necessary procedure as the use of M-TEER grows. It occurs in up to 6% of patients, with a median age of 70–76 years at the moment of failure and a median time to failure of <6 months. MV surgery following M-TEER is associated with high mortality and morbidity, with a reported 30-day mortality ranging from 10% to 40% and 1-year survival below 60%. Functional device failure, structural device failure, MV disease progression and infective endocarditis are frequent mechanisms of M-TEER failure. Surgical MV repair is the preferred management strategy; however, due to the technical and anatomical complexity, MV replacement is performed much more frequently (MV repair rates <10%).

CONCLUSIONS: MV surgery after failed M-TEER poses technical challenges due to the presence of altered anatomy, the need for concomitant procedures and the patient's comorbidities. While surgical intervention carries increased risks, it remains the definitive treatment for failed M-TEER, offering durable relief from MR. Due to the technical complexities associated with these procedures, strong consideration should be given to transferring patients requiring MV surgery after failed M-TEER to high-volume MV centres.

Keywords: Mitral regurgitation • Mitral valve repair • Mitral valve replacement • Mitral transcatheter edge-to-edge repair

ABBREVIATIONS

CT	Computerized tomography
HF	Heart failure
MR	Mitral regurgitation
MS	Mitral stenosis
M-TEER	Mitral transcatheter edge-to-edge repair
MV	Mitral valve
MVARC	Mitral Valve Academic Research Consortium
STS	Society of Thoracic Surgeons
TEE	Transesophageal echocardiography
TR	Tricuspid regurgitation

INTRODUCTION

Mitral regurgitation (MR) is one of the most prevalent valvular diseases worldwide, contributing significantly to morbidity and mortality, particularly in elderly populations [1]. Primary mitral valve (MV) disease, including MV prolapse and flail, is one of the

leading causes of MR in industrialized countries [2]. Secondary MR, which arises from ventricular or atrial remodelling due to ischaemic or non-ischaemic cardiomyopathy or atrial fibrillation, presents distinct pathophysiological challenges compared to primary MR and also has a high prevalence worldwide [3]. Surgical MV repair in specialized heart valve centres remains the gold standard for primary MR and the most durable treatment option. It also plays a role in select patients with secondary MR, particularly those with atrial secondary MR [4–6]. However, the increasing prevalence of MR in ageing and high-risk populations has driven demand for less invasive interventions such as mitral transcatheter edge-to-edge repair (M-TEER) that minimize perioperative risks [7–11].

M-TEER offers a viable treatment alternative for patients deemed high risk or inoperable by the Heart Team. Compared with MV surgery, M-TEER is less invasive, typically does not require an intensive care unit stay and can often be performed as a same-day procedure. While procedural success rates range from 68% to 89% at 30 days [12, 13], the growing adoption of M-TEER has revealed notable limitations. Recurrent or residual MR after M-TEER, partial leaflet detachment, progressive degeneration or mitral stenosis (MS) can necessitate surgical intervention. An estimated 2–6% require MV surgery within 1 year after M-TEER [14, 15]. The mortality and morbidity of MV surgery after M-TEER are not negligible, with 30-day and 1-year mortality rates of 16.6% and 31.3%, respectively, and only a minority of patients (<10%) able to undergo MV repair [16]. Surgical treatment after failed M-TEER poses significant technical challenges, including navigating altered anatomy and device-related complications, but remains the definitive option for restoring valve function in these complex cases. This invited expert review explores the surgical techniques, challenges and outcomes associated with MV surgery following failed M-TEER. The selection of the literature presented in this article is based on the expertise of the authors.

M-TEER FAILURE

M-TEER has transformed the treatment of high-risk patients with MR. This technique approximates the anterior and posterior leaflets, thereby reducing MR and creating a double-orifice valve [9]. M-TEER is particularly beneficial in patients with secondary MR, where the combination of a high-risk profile and leaflet tethering often complicates surgical repair. Current valve disease guidelines [17, 18] recommend M-TEER for patients with severe primary MR deemed inoperable or at high surgical risk, based on Heart Team evaluation. For secondary MR, guidelines recommend optimal medical therapy, with surgical or transcatheter interventions reserved for patients who remain symptomatic [17, 18]. M-TEER is specifically indicated in high-risk patients with ventricular secondary MR, reduced ejection fraction, persistent symptoms despite optimal medical therapy and favourable anatomy (i.e. patients who fulfill the COAPT [8] inclusion criteria) [17, 18]. Early studies such as the EVEREST II trial demonstrated the feasibility of M-TEER using the MitraClip device (Abbott Structural Heart, USA) in a mixed population of primary and secondary MR patients, with a 6% mortality at 12 months in both the surgical and M-TEER groups [19]. However, long-term results revealed a significant risk of recurrent MR, with the need for reintervention in up to 20% of cases. More recent short- and long-term data suggest an improvement in MR reduction after M-TEER, especially with the latest generation devices, though outcomes depend on factors such as device type, operator experience and industry-sponsored studies or real-world registries [20–22].

Failure of M-TEER can occur via several mechanisms, broadly classified into 4 categories: (i) functional device failure, (ii) structural device failure, (iii) MV disease progression and (iv) infective endocarditis [23, 24].

Functional device failure

- *Insufficient MR reduction:* This is the most common cause of M-TEER failure. Residual MR can occur when the device fails to adequately approximate the MV leaflets or when an insufficient number of devices are used (usually to avoid creating a severe MS). This issue is particularly common in patients with large primary MR pathologies (e.g. residual prolapse in patients with Barlow's disease), significant leaflet tethering with large jet, leaflet calcification or marked annular dilation with planar coaptation (frequently observed in atrial secondary MR). Persistent MR has a significant negative impact on mortality and rehospitalization during follow-up [25–27].
- *MS:* M-TEER-related MS is associated with poor long-term outcomes, severe symptoms and increased mortality [27]. A mean transvalvular pressure gradient ≥5 mmHg or a MV area <1.5 cm^2 is considered postprocedural MS as defined by The Mitral Valve Academic Research Consortium (MVARC) criteria [28]. The reported incidence of postprocedural MS varies widely, ranging from 1% in the TRAMI registry [29, 30] to 35% in other observational studies [27, 31–33]. A baseline MV area (MVA) ≤4 cm^2 has been reported as the most important preprocedural risk factor for postprocedural MS along with the presence of annular and leaflet calcifications [27, 33, 34].

Structural device failure

- *Single leaflet device attachment (SLDA):* A common cause of recurrent MR after M-TEER is the partial or complete device detachment from 1 leaflet, which leads to incomplete coaptation, leaflet lesion and a persistent regurgitant jet at the site of detachment.
- *Leaflet injury:* Grasping leaflets during the procedure can rarely injure leaflet tissue, leading to perforation or tear, typically identified intraoperatively. The reported incidence of this complication is up to 2% [34, 35]. However, delayed MV injury can occur even after an initially successful M-TEER procedure. The incidence of this complication is underestimated when only using transthoracic echocardiography and has been observed in up to 8% of patients undergoing transesophageal echocardiography (TEE) at 6 months [36]. In a series of 47 patients requiring surgery after M-TEER, leaflet tears were observed in 29% of primary MR cases, and 18% of secondary MR patients had a new prolapse or flail due to spontaneous chordal rupture or iatrogenic damage [37].
- *Chordal rupture:* Entrapment of the clip within the leaflets or subvalvular apparatus can result in acute or late chordal rupture, leading to residual or recurrent MR [38].
- *Device embolization:* Though rare (0.1–0.7% in registries) [26, 39], this feared complication occurs due to the complete

detachment of the device from both leaflets. Retrieval of large devices may pose significant problems and require surgery [40].

MV disease progression

Another cause of recurrent MR after M-TEER, particularly at the mid- to long-term, is the MV disease progression. In patients with primary MR, this occurs due to a new prolapse or flail. In patients with ventricular secondary MR, it occurs due to continued left ventricular remodelling with progressive leaflet tethering, and in patients with atrial secondary MR due to continued mitral annular dilatation.

Endocarditis

MV infective endocarditis after M-TEER is an infrequent event with a reported incidence of up to 2.6% [41, 42]. However, the diagnosis of infective endocarditis in M-TEER patients can be challenging, potentially resulting in underdiagnosis and delays in appropriate therapy [43].

OUTCOMES FOLLOWING MV SURGERY AFTER FAILED M-TEER

Contemporary studies reporting outcomes following MV surgery after failed M-TEER are summarized in Table 1 and Fig. 1. Early reports from the EVEREST II trial [19] showed that after 5 years of follow-up, a total of 28% of patients underwent MV surgery (77% within the first 6 months after M-TEER) [19]. A more recent systematic review and meta-analysis, comprising 20 studies published until 2019 with a total of 172 patients, reports a much lower incidence of MV surgery for failed M-TEER, ranging from 2% to 6% [14].

Two contemporary large registries of patients undergoing MV surgery for failed M-TEER report a mean age ranging from 73 to 76 years, and a median Society of Thoracic Surgeons (STS) predicted risk of mortality score of 4.0–6.5% [15, 16]. In the CUTTING-EDGE registry, the median time interval from M-TEER to MV surgery was 3.5 months (0.5–11.9 months), and the reported 30-day mortality rate was 16.7% [16]. An analysis from the STS database, including 463 patients, indicated that MV surgery after M-TEER is associated with significant in-hospital mortality, particularly in older patients and those with higher comorbidities [15]. The observed in-hospital mortality rate was 10.2% in patients undergoing MV surgery, with a ratio of observed to expected mortality of 1.2 (95% confidence interval 0.8 to 1.9). In a volume/outcomes sub-analysis from the STS database with an expanded cohort of 591 patients at 227 hospitals, the in-hospital mortality was 2.6% in high-volume centres (>10 cases) versus 12.4% in low-volume centres (<10 cases) [15].

The CUTTING-EDGE international registry provides additional insights, showing that the primary indication for surgery after M-TEER is recurrent MR, with a high prevalence of MV replacement over repair (92.5% vs 7.5%) (16; 44), and higher-than-expected 30-day mortality after MV surgery, with an observed-to-expected ratio of 30-day mortality of 3.6 (95% CI: 1.9–5.3), 3.8 (95% CI: 2.1–5.5) in the MV replacement group, and 1.7 (95% CI: 0.7–3.3) in the MV repair group [50]. MV replacement compared to repair was associated with a higher 30-day (17.7% vs 4.0%) and 1-year mortality (33.3% vs 10.5%) and lower 2-year survival (hazard ratio for replacement: 4.24 [95% CI 1.04–17.31], $P = 0.044$) [50].

The 30-day and 1-year mortality rates were 16.6% and 31.3%, respectively, highlighting the substantial risks of this patient population. The low feasibility of durable MV reconstruction after M-TEER, often necessitating valve replacement due to the complexity of the surgical anatomy after M-TEER failure, underscores the importance of careful initial patient selection for M-TEER. Younger or lower-risk patients who have a higher chance of requiring another MV procedure during their lifetime are therefore not appropriate candidates for a transcatheter therapy. A stratified analysis by MR aetiology of patients undergoing MV surgery for failed M-TEER in the CUTTING-EDGE international registry showed an incidence of primary and secondary MR of 47% and 53.0%, respectively [51]. Furthermore, there was a numerically higher 30-day mortality (20.4% vs 12.7%; $P = 0.072$) and a significantly higher 1-year mortality (38.3% vs 23.2%; $P = 0.019$) in patients with secondary MR compared with patients with primary MR [51]. Furthermore, surgical MV repair rates after failed M-TEER are lower in patients with secondary MR compared to primary MR (4.8% vs 6.8%) [15].

The presence of concomitant tricuspid regurgitation (TR) and right ventricular dysfunction is often observed among patients undergoing M-TEER. Patients with moderate or more TR undergoing M-TEER more frequently present with M-TEER failure, and the interval from the index M-TEER to subsequent MV surgery is shorter compared to patients with mild TR, as reported in another sub-analysis from the CUTTING-EDGE registry [52]. This analysis also demonstrated a higher 30-day and 1-year mortality among patients with moderate or more TR undergoing MV surgery for failed M-TEER compared to patients with mild TR (30-day mortality: 24.2% vs 13.8%, $P = 0.043$; 1-year mortality: 45.3% vs 22.3%, $P = 0.003$). Furthermore, moderate or more TR and right ventricular dysfunction, but not concomitant tricuspid surgery, were associated with an increased cumulative mortality. Additional predictors of mortality after MV surgery for failed M-TEER were age >80 years, urgent surgery and increased creatinine levels [15].

SURGICAL MANAGEMENT AFTER FAILED M-TEER

Preoperative imaging and surgical planning

Given their complexity and increased risk, patients with failed M-TEER need to be thoroughly discussed by a multidisciplinary Heart Team. In patients deemed at very increased surgical risk, conservative medical treatment should be considered as an alternative to a surgical approach. However, in highly symptomatic patients with a poor response to medical treatment, surgery might be the only remaining option to reduce symptoms and improve quality of life. If the Heart Team decides in favour of MV surgery, a thorough surgical planning may increase understanding of the underlying pathology and increase the possibility of clip removal without extensive leaflet damage with subsequent successful MV repair. Preoperative transoesophageal echocardiography (TEE) and cardiac computerized tomography (CT) scan are essential for surgical planning, as they allow detailed visualization of the MV, leaflet motion and the M-TEER device position and the presence of leaflet calcification. TEE is

Table 1: Summary of contemporary studies[a] reporting outcomes following MV surgery after failed M-TEER

Authors	Year	Type of study	Population	Main results
Geidel and Schmoeckel [44]	2013	Cohort, retrospective	19 patients undergoing MV surgery for failed M-TEER, mean age 74 years, EuroSCORE II 12-26%	• MV repair in 8/19 (42%) patients • All patients required other concomitant surgical procedures • 30-day mortality 10.5% • 1-year survival 68%
Monsefi *et al.* [45]	2014	Cohort, retrospective	6 patients undergoing MV surgery for failed M-TEER, mean age 75 years	• Median time from M-TEER to MV surgery 106 days • MV repair in 3 patients, MV replacement in 3 patients • In-hospital mortality 33.3%
Alozie *et al.* [43]	2014	Cohort, retrospective	13 patients undergoing MV surgery for failed M-TEER	• All patients underwent MV replacement • In-hospital mortality 7.7% • Survival rate at 2 years 77%
Elhmidi *et al.* [46]	2016	Cohort, retrospective	25 patients undergoing MV surgery for failed M-TEER	• MV repair in 5 (20%) patients and MV replacement in 20 (80%) patients • In-hospital mortality 4/25 (16%)
Asmarats *et al.* [41]	2018	Systematic review	10 reports, 12 patients with MV infective endocarditis after M-TEER. Mean EuroSCORE II 45%	• Early infective endocarditis (<12 months) in 9 (75%) patients • *S. aureus* most frequent causal microorganism (60%) • MV replacement performed in 67% patients • Early mortality 42%
Takayuki *et al.* [47]	2019	Cohort, retrospective	25 patients undergoing MV surgery for failed M-TEER. Mean age 73 years	• Median time from M-TEER to MV surgery 54 days • In-hospital mortality 28% • Actuarial estimated 1-year survival 53%
Mkalaluh *et al.* [48]	2019	Cohort, retrospective	9 patients undergoing MV surgery for failed M-TEER. Mean age 61 years	• Median time from M-TEER to MV surgery 45 days • In-hospital mortality 33% • 1-year survival 66%
Melillo *et al.* [14]	2021	Systematic review and meta-analysis	20 reports, 172 patients. Mean age 70 years	• In-hospital mortality 15% • Postoperative stroke 6% • 1-year mortality 26.5%
Chikwe *et al.* (STS Database) [15]	2021	Cohort, retrospective	STS-database analysis of 463 patients, median age 76 years, median STS-predicted mortality 6.5%	• Repair rate 4.8% in secondary MR and 6.8% in primary MR • In-hospital mortality 10.2% • Ratio O/E mortality 1.2 • In centres performing more than 10 cases, the in-hospital mortality was 2.6%; in centres performing less than 10 cases, it was 12.4% • Predictors of mortality are secondary MR, age >80 years, increased creatinine, urgent surgery
Kaneko *et al.* (CUTTING-EDGE Registry) [16]	2021	Cohort, retrospective	International registry with 332 patients from 34 centres. Mean age 73 years, median STS-predicted mortality 4.8%	• Median time from M-TEER to MV surgery 3.5 months • MV replacement was performed in 92.5% of patients • The 30-day mortality was 16.6% • The 1-year mortality was 31.3% • Estimated 3-year mortality was 31.7%
Akansel *et al.* [49]	2022	Cohort, retrospective	Single-centre experience, 45 patients who underwent minimally invasive MV surgery for failed M-TEER. Median age 78 years. Median EuroSCORE II was 4.4%	• All patients with functional MR (n = 36) underwent MV replacement • 50 % repair rate in patients with degenerative MR • 1-year survival 81.3% and 75.0% in patients with functional and degenerative MR, respectively

[a]Case reports or small case-series excluded.

M-TEER: mitral transcatheter edge-to-edge repair; MV: mitral valve; MR: mitral regurgitation; O/E: ratio observed to expected; STS: Society of Thoracic Surgeons.

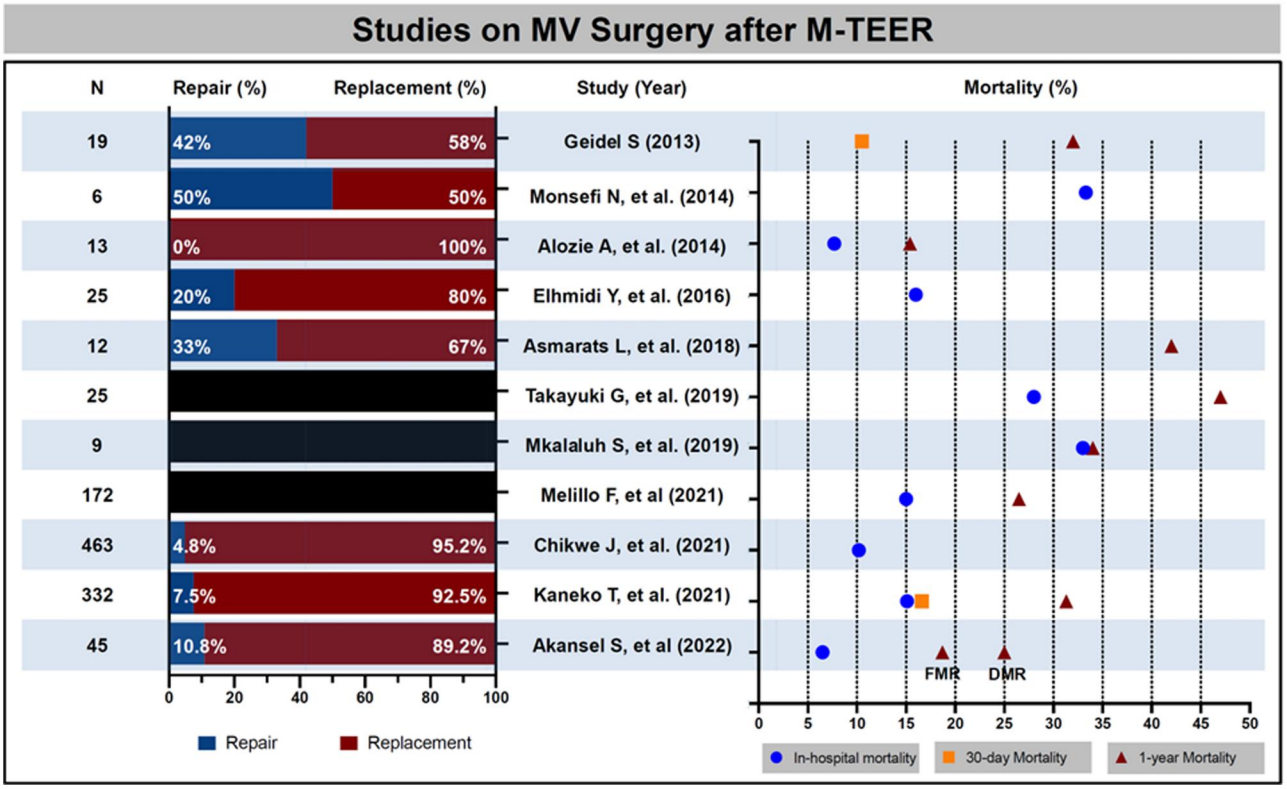


Figure 1: Frequency of mitral valve repair and replacement and in-hospital, 30-day and 1-year mortality reported in different studies analysing patients with MV after failed M-TEER. DMR: degenerative mitral regurgitation; FMR: functional mitral regurgitation.

particularly useful intraoperatively for real-time assessment of residual MR and leaflet coaptation, as well as evaluation of the extent and pathology of residual (non-clipped) leaflet tissue. In addition, the cardiac surgeon must carefully assess the device's impact on the MV apparatus, oftentimes with the help of 3D TEE reconstruction.

Surgical approach

Exposure of the MV and its pathology is typically more complex post-TEER due to the presence of fibrotic tissue, adhesions from the M-TEER device and distortion of the leaflet anatomy. Most patients undergo MV surgery after M-TEER through a median sternotomy [53], but a minimally invasive approach is also possible based on local expertise [49, 54].

Device removal

One of the principles of MV surgery after M-TEER is the complete removal of the device(s). Removing the M-TEER device without damaging the leaflet tissue can be technically challenging due to the frequently observed fibrous encapsulation of the device(s) (Fig. 2). Device dissection from the MV leaflets without inducing excess leaflet injury requires meticulous, piecemeal removal of the M-TEER device, especially if it is embedded in fibrotic tissue. Different alternative device removal techniques are summarized in Table 2. A few M-TEER device removal techniques have been proposed in the literature [54–56]. These

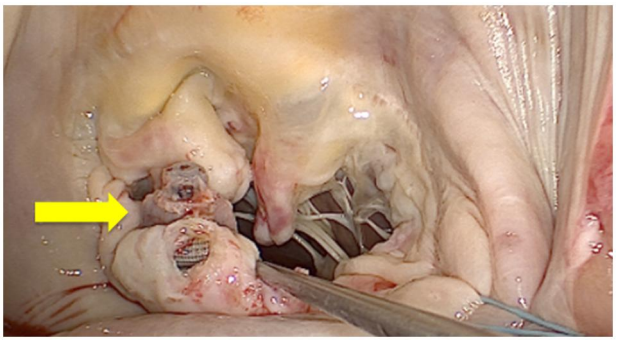


Figure 2: Fibrous encapsulation of a PASCAL device (arrow).

techniques depend on the degree of fibrous encapsulation and the type of the M-TEER device:

MitraClip (Abbott).

I. *Suture-and-snare technique*: A polypropylene suture is placed through the loop of the lock harness, which is located between the grippers and act as a lock (Fig. 3A). Then forward pressure is applied with a snare towards the lock while retracting the suture to unlock the locking mechanism. After releasing the device, the MV leaflets can be carefully detached (Fig. 4A–E).
II. *Internal arms grasping technique:* The grippers are grasped using forceps and pulled away from the arms. The hooks of the grippers are then carefully separated from the leaflets. Then, the

device is pushed towards the apex and pulled back with another forceps to remove it from the leaflets (Supplementary Material, Fig. S1A and B).

PASCAL (Edwards Lifesciences). In general, since the PASCAL device has a nitinol-based soft-locking system, any of the following removal techniques can be combined with the use of a cold saline solution, which increases the malleability of the device, thus facilitating its removal (Fig. 3B).

I. *Suture-securing technique*: the inner paddles of the device are tied up to the central spacer with a polypropylene suture. While the central spacer is held in place using forceps, the leaflet is gently pushed out from the central spacer. After the anterior leaflet has been released from the internal paddle, the partially opened device should be gently pushed towards the heart's apex. The manoeuvre should also be repeated for the posterior mitral leaflet (Fig. 5A–D).
II. *Walking-down method*: The paddles and inner paddles are grasped and pushed towards the central spacer using a forceps, and the hooks of the clasps are separated from the anterior leaflet. The leaflet is held and gently pushed away from the central spacer. After the leaflet has been released from the inner paddle, the partially opened device should be gently pushed towards the heart's apex. The manoeuvre should also be repeated for the posterior leaflet (Supplementary Material, Fig. S2A and B).
III. *Elevator method*: First, the central spacer is grasped using a forceps. The clasp and the inner paddle on the anterior leaflet are then gently pushed away from the central spacer. The forceps grasping the inner paddle are gently introduced deeper. The device is then pushed towards the apex and released from the anterior leaflet. The manoeuvre should also be repeated for the posterior leaflet (Supplementary Material, Fig. S3A–C).

Table 2: Alternative device removal techniques tailored to the degree of device encapsulation and the type of device

Clinical scenario	Technique
MitraClip	
Newly implanted	Suture placing through the loops of the lock harness and application of forward pressure with a snare towards the lock while retracting the suture to unlock the mechanism
Implanted long ago	Dissection of fibrous tissue, grasping internal arms and separating hooks from the leaflet
PASCAL	
Newly implanted	Suture securing technique: suturing internal paddles to central spacer, pushing external paddles away from the central spacer Elevator technique: grasping internal arm and introducing deeper to separated hooks from the leaflet
Implanted long ago	Walking-down method: dissection of fibrous tissue between the arms, grasping central spacer, pushing internal arm away from the central spacer, detachment of internal arm from the leaflet

Table modified from Akansel *et al.* [54].

If the surgeon decides to resect that segment of the MV leaflet where the M-TEER is attached (e.g. during quadrangular/triangular resection), the device can be excised along with the surrounding tissue. In cases where the device has induced localized leaflet trauma, leaflet resectional techniques can also allow valve repair in the presence of excess tissue.

MV repair versus replacement

The surgical strategy should be tailored to the underlying valve pathology at the index procedure and the extent of damage of the MV leaflets (Fig. 6). Repair is the preferred surgical strategy if feasible, particularly if the anatomy permits sufficient leaflet mobility and minimal annular or leaflet distortion. If device removal is not possible due to excessive adhesions and/or entanglement with the subvalvular apparatus or if excessive leaflet injury occurs during device removal, then MV replacement must be performed. Geidel and Schmoeckel [44] reported that MV repair

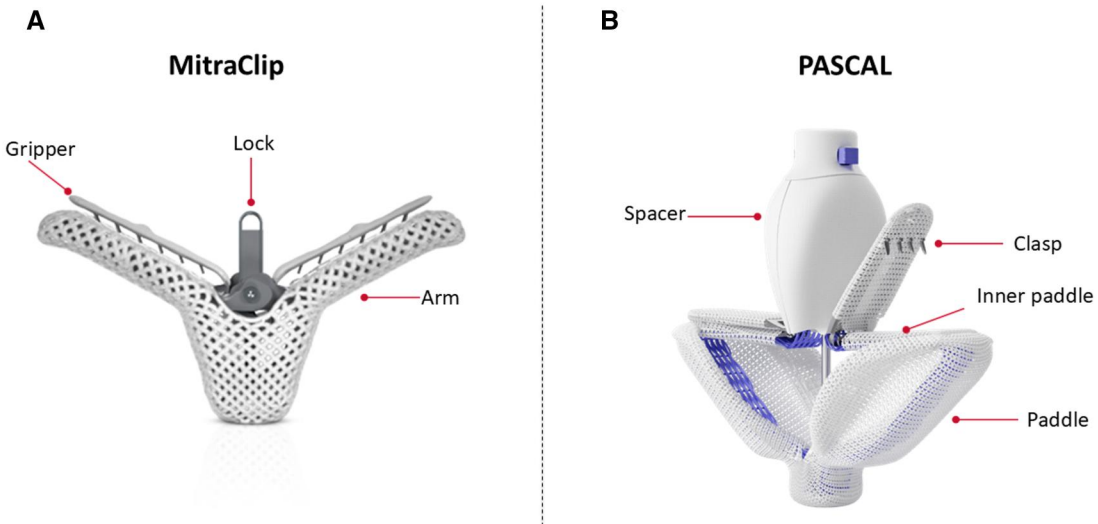


Figure 3: M-TEER devices and their components. (**A**) MitraClip and (**B**) PASCAL.

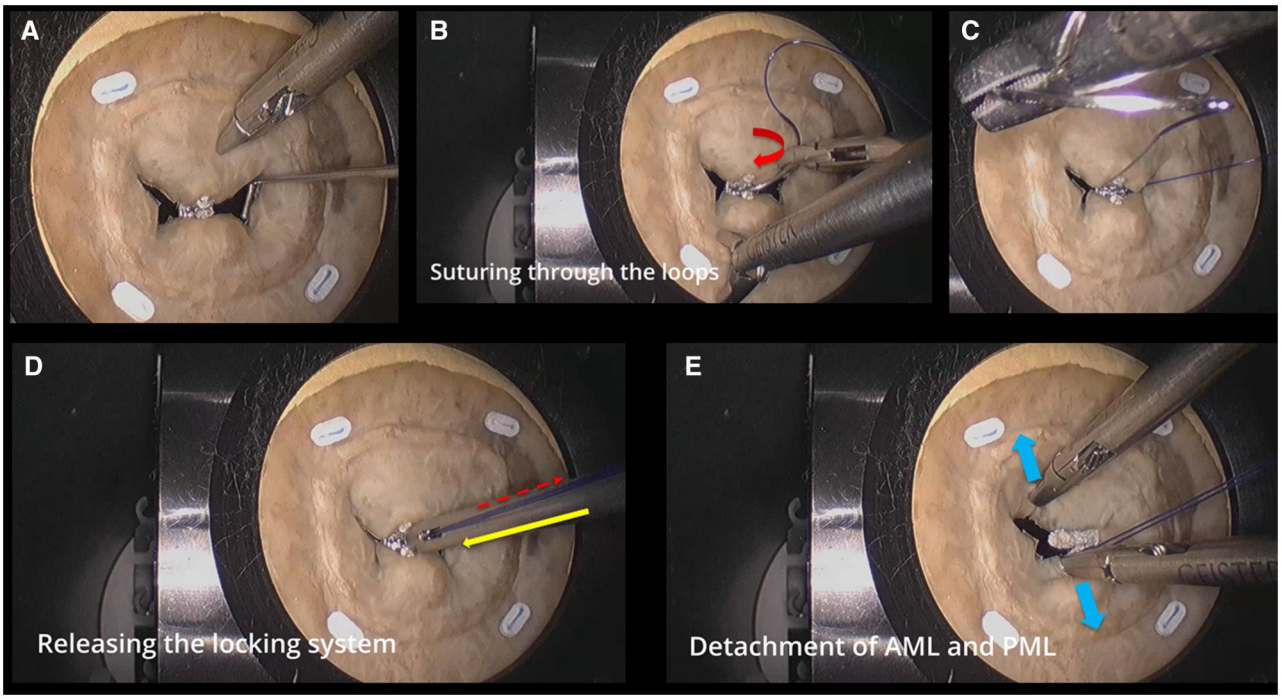


Figure 4: Simulator-based mitral valve dummy—didactic representation of MitraClip removal. *Suture-and-snare technique.* (**A**) Mitral valve with failed MitraClip in situ, (**B** and **C**) suture (polypropylene) placed through the loops of the lock harness of the MitraClip (arrow), (**D**) application of forward pressure with a snare towards the lock (continuous line arrow) while retracting the suture (dotted arrow) to unlock the locking mechanism and release the device and (**E**) detachment of the leaflets by carefully pulling the leaflet away from the MitraClip (arrows).

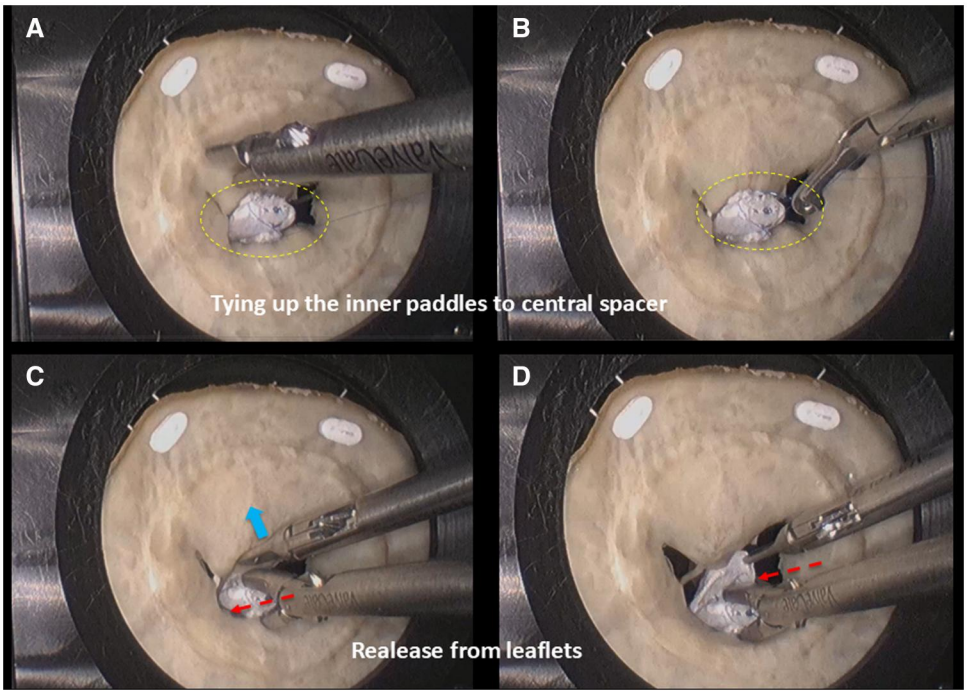


Figure 5: Simulator-based mitral valve dummy—didactic representation of PASCAL removal. *Suture-securing technique.* (**A, B**) After suturing and tying up the inner paddles to central spacer with a polypropylene suture (dotted circle), (**C**) the device is released from the anterior and posterior leaflets by grasping the central spacer and pulling it back with forceps (arrow). (**D**) After the anterior leaflet has been released from the inner paddle, the partially opened device should be gently pushed towards the heart's apex (dotted arrow). The manoeuvre should also be repeated for the posterior leaflet.

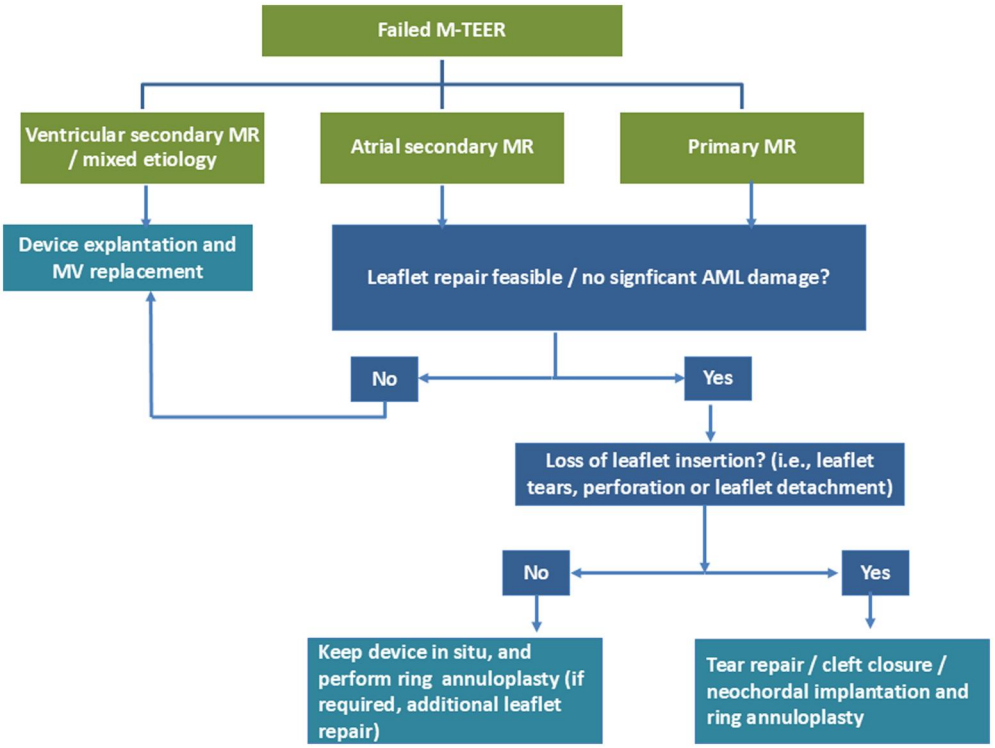
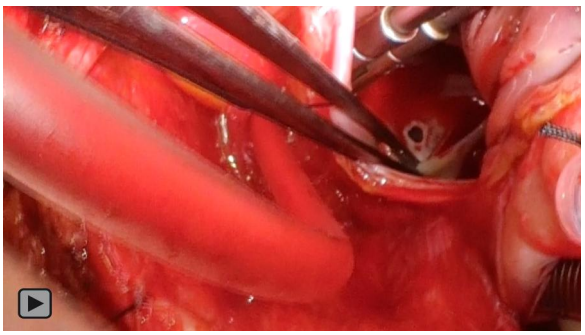
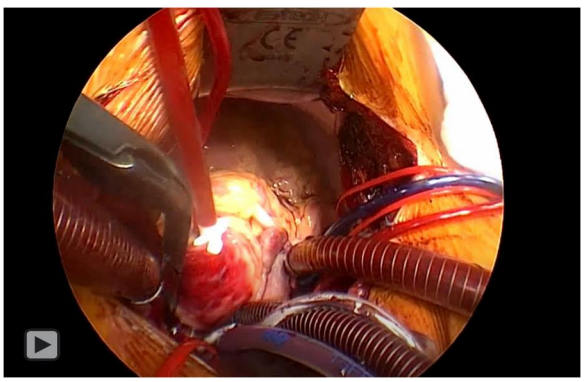


Figure 6: Surgical approaches according to different clinical scenarios. Modified from Akansel *et al.* [49, 54]. AML: anterior mitral leaflet; MR: mitral regurgitation; M-TEER: mitral transcatheter edge-to-edge repair.



Video 1: A 55-year-old male patient, 18 months after MitraClip (A3-P3) with recurrent symptomatic mitral regurgitation moderate-severe at 6 months post mitral transcatheter edge-to-edge-repair. Status post mechanical Bentall 30 years prior. Reoperative sternotomy and right atrial access via a residual iatrogenic ASD extended to the fossa ovalis. Partial MitralClip detachment noted with tear of anterior leaflet (A3). Complex mitral valve re-repair: removal of MitralClip, repair of defect in A3, plication suture to posteromedial commissure, P2-P3 quadrangular resection with non-detachment sliding leaflet plasty and resuspension with an ePTFE. True-sized 38 mm Physio Flex annuloplasty ring. Online access to the video: https://youtu.be/Sl9PG_jO1A8



Video 2: MitraClip removal and MV repair in a patient with failed M-TEER and severe mitral annular calcification. Online access to the video: https://youtu.be/7e327b_EVO4

was feasible in 83% of cases when only 1 device was implanted, 33% when 2 devices, and 0% when 3 or more devices were implanted. Careful device removal without leaflet damage is key to allowing a successful repair. Videos 1 and 2 show 2 cases of patients who underwent device removal and MV repair after failed M-TEER. Repair becomes technically challenging in cases of significant leaflet fibrosis, device encapsulation, leaflet/annular calcification, multiple failed devices and significant leaflet distortion. In these scenarios, MV replacement is often the most reliable option. Furthermore, in patients with secondary ventricular MR, we suggest performing MV replacement given the strong association with recurrent MR after MV repair for secondary ventricular MR. Additionally, given the frequently increased operative risk of patients with secondary ventricular MR, a less complex procedure such as MV replacement is preferred to reduce surgical times and possibly improve outcomes.

Possible MV repair techniques include resection of the destroyed leaflet segment and/or neochordae implantation. The use of small pericardial patches in selected cases may enable valve repair in cases of insufficient tissue. Minor MV leaflet injuries after device removal can be repaired using 4–0 or 5–0 Gore-Tex, Polypropylene or Nylon monofilament sutures. Annuloplasty is crucial in these cases to restore annular geometry. Current registries report low repair rates in these patients (<10%) [16, 50], which is probably explained by the complexity of the MV anatomy, the need for concomitant procedures (e.g. tricuspid repair, CABG, Maze) and patient

comorbidities necessitating a faster operation. Centre and surgeon volumes have been identified as important factors in increasing the likelihood of MV repair and reducing perioperative risks and morbidity [15, 16]. Therefore, to increase the likelihood of successful repair and improve outcomes, MV surgery after failed M-TEER should be performed in heart valve centres by high-volume MV surgeons.

Timing of surgery

The timing of surgery is important for patient outcomes. Urgent surgery is indicated for acute device detachment or leaflet perforation/tear and resulting severe symptomatic MR with acutely decompensated heart failure (HF). Elective surgery can be considered in patients with residual but stable MR, allowing time to optimize the patient's clinical condition, including guideline-directed medical therapy of HF.

UPCOMING CHALLENGES

The rapidly increasing adoption of transcatheter aortic valve implantation (TAVI) has now led to TAVI explant with redo surgical aortic valve replacement being the fastest growing cardiac operation in the USA, with significant mortality and morbidities [57, 58]. Similarly, misinterpretation of the increasing body of evidence supporting the use of M-TEER may lead to misuse of this transcatheter procedure in lower risk patients, and likely an eventual increase of patients requiring MV surgery for failed M-TEER, as the real-world data show the suboptimal MR reduction at mid-term [59]. Therefore, multidisciplinary clinical decision-making and appropriate patient selection need to be strongly based on the inclusion criteria from the clinical trials and the recommendations from clinical practice guidelines to avoid overusing M-TEER (and its consequences in case of failure) in patients with primary MR who more likely would benefit from either surgery. TMVR may be an option in some of these patients who are ineligible for M-TEER, but the technology has been limited by high screen failure rates due to unfavorable anatomy, device limitations and the need for long-term anticoagulation and the risk of valve thrombosis. Given the frequent need for high-risk MV replacement when M-TEER fails, transcatheter therapies should be limited to higher risk or inoperable patients with primary MR and patients with ventricular SMR under optimized medical therapy. Furthermore, in patients with complex anatomies, M-TEER should be performed in high-volume centres by experienced operators to reduce the number of failed procedures.

CONCLUSIONS

MV surgery after failed M-TEER is a complex but increasingly necessary procedure as the use of M-TEER grows. MV surgery following M-TEER is associated with high mortality and morbidity. MV repair is the preferred strategy; however, due to the technical and anatomical complexity, MV replacement is performed much more frequently. Cardiac surgeons must be prepared to address the technical challenges posed by the presence of M-TEER devices on the MV with the resulting altered anatomy, the need for concomitant procedures and the patients' increased comorbidities. While surgical intervention carries increased risks, it remains the definitive treatment for failed M-TEER, offering durable relief from MR. Due to the technical complexities associated with these procedures, however, strong consideration should be given to transferring patients requiring MV surgery post M-TEER to high-volume MV centres.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

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DATA AVAILABILITY

No new data were generated or analysed in support of this manuscript.

Author contributions

Mateo Marin-Cuartas: Conceptualization; Formal analysis; Methodology; Project administration; Supervision; Validation; Visualization; Writing—original draft; Writing—review & editing. **Syed Zaid:** Conceptualization; Validation; Visualization; Writing—review & editing. **Jörg Kempfert:** Writing—review & editing. **Michael A. Borger:** Writing—review & editing. **Serdar Akansel:** Writing—review & editing. **Thilo Noack:** Writing—review & editing. **David Holzhey:** Writing—review & editing. **Tsuyoshi Kaneko:** Writing—review & editing. **Isaac George:** Writing—review & editing. **Gorav Ailawadi:** Writing—review & editing. **Robert L. Smith:** Writing—review & editing. **Arnar Geirrson:** Writing—review & editing. **Ahmed El-Eshmawi:** Writing—review & editing. **Dimosthenis Pandis:** Writing—review & editing. **Suzanne de Waha:** Writing—review & editing. **Nikolaos Bonaros:** Writing—review & editing. Fabien Praz**:** Writing—review & editing. **Maurizio Taramasso:** Writing—review & editing. Michele De Bonis**:** Writing—review & editing. **Lenard Conradi:** Writing—review & editing. Christian Hagl**:** Writing—review & editing. **Nicolas Doll:** Writing—review & editing. **Mahmoud Wehbe:** Writing—review & editing. **Alexey Dashkevich:** Writing—review & editing. **Manuela de la Cuesta:** Writing—original draft; Writing—review & editing. **Jagdip Kang:** Writing—review & editing. **Zara Dietze:** Writing—review & editing. **Philipp Kiefer:** Conceptualization; Formal analysis; Supervision; Validation; Writing—review & editing. **Gilbert H.L. Tang:** Conceptualization; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Writing—original draft

Reviewer information

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Review