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SYSTEMATIC REVIEW

Intraoperative transesophageal echocardiography following mitral valve repair: a systematic review

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Abstract
Objective: We aimed to examine the recent evidence and search for novel assessments on intraoperative TEE following mitral valve repair that can impact short and long-term outcomes.
Methods: The Ovid MEDLINE, PubMed, and EMBASE databases were searched from January 1, 2008, until January 27, 2021, for studies on patients with severe Mitral Valve Regurgitation (MR) undergoing Mitral Valve (MV) repair surgery with intraoperative Transesophageal Echocardiography (TEE) performed after the repair. Additional searches were conducted using Google search engine, Web of Science, and Cochrane Library.
Results: After reviewing 302 records, 8 retrospective and 22 prospective studies were included (n = 30). Due to clinical and methodological diversity, these studies are noncomparable and data were not amenable to quantitative synthesis.
Conclusion: Although technological advances allowed the objective assessment of geometric and dynamic alterations of the MV, the impact of the use of these technologies on short- or long-term outcomes was not studied. There is uncertainty and conflicting evidence on the ideal method and metrics to evaluate MV patency post-repair. Few isolated studies validated methods to assess coaptation surface and LV function post-repair.

Introduction

Mitral valve Regurgitation (MR) is described as retrograde blood flow from the left ventricle into the left atrium during cardiac systole, due to a malfunction in any of the mitral valve apparatus components. Carpentier's classification is used to describe the mechanism of MR and is divided into Mitral Valves (MV) with normal leaflet movement (Class I), excessive leaflet movement or redundant tissue (Class II), or restrictive leaflet movement due to leaflet disease (Class III-a) or ventricle disease (Class III-b).[1] The leading causes of MR are degenerative, rheumatic, and ischemic heart disease. The prevalence of rheumatic heart disease is declining in high-income countries; however, degenerative, and ischemic heart disease remain significant.[2] Significant MR is

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associated with increased mortality and heart failure rehospitalization.[3]

Surgical repair of the MV is the preferred approach for the regurgitant mitral valve as it carries favorable outcomes compared with valve replacement.[4] Nonetheless, surgical repair of MR can be challenging, and many factors need to be considered to ascertain the feasibility of repair.[5]

If feasible, patients with significant mitral valve regurgitation often undergo a thorough preoperative assessment of the mitral valve apparatus to select an appropriate repair strategy. A comprehensive approach to intraoperative TEE examination of MV before Cardiopulmonary Bypass (CPB) was previously described and found useful for determining the mechanism of MR.[6] Post-CPB intraoperative TEE examination of the mitral valve, on the other hand, is vital since it offers an initial assessment of the adequacy of surgical repair. Observational studies have shown an association between the preoperative evaluation of MV pathology, intraoperative echocardiographic findings of surgical repair and long-term outcomes.[7-9]

We aimed to conduct a systematic review that examined the recent evidence and searched for novel assessments on intraoperative TEE following mitral valve repair that can positively impact short and long-term outcomes.

Methods

We followed the Cochrane and PRISMA standards for conducting and reporting systematic reviews.[10,11]

Data sources

A systematic search was conducted for studies published from January 1, 2008 to January 27, 2021. Initial search engines consisted of Ovid MEDLINE, PubMed, and EMBASE. Additional searches were conducted using Google search engine, Web of Science, and Cochrane Library. The search was limited to human studies published in the English language. At the reference manager stage, duplicates, letters, editorials, and pediatric studies were excluded. The complete search strategy is provided in the supplementary material.

Study selection

We included studies that investigated intraoperative TEE evaluation of the MV repair after separation from CPB in surgeries with either sternotomy or thoracotomy. A PRISMA flow diagram detailing the study selection process can be found in Figure 1.

We excluded: Case reports (n = 24) and review articles (n = 22); Studies not related to MV repair (n = 50); Studies investigating non-conventional mitral valve repairs due to MR (n = 59). These studies included Percutaneous MitraClip or other edge-to-edge interventions; Studies in which intraoperative TEE examination was not used to guide the outcome after surgical repair of the mitral valve (n = 97); Studies investigating pre-CPB predictors of complications or failure after MV repair (n = 6); Studies without details on the intraoperative TEE assessment of the MV repair (n = 13); and Pediatric studies (n = 1)

One Reviewer (RZ) screened titles and abstracts and excluded ineligible records. Two reviewers (II and AF) independently confirmed exclusions. The full texts of included records were further assessed for eligibility by one Reviewer (RZ) and confirmed by the two independent reviewers (II and AF). Disagreements were resolved by consensus. General study characteristics and outcome data were extracted by two reviewers (RZ and AP) and verified by reviewers II and AF. Among reviewers, both methods and content expertise were represented.

Critical appraisal and risk of bias assessment

Many publications describe a comprehensive and detailed intraoperative pre-repair evaluation of the MV with TEE, but a summarized and generic evaluation post-CPB. Thus, we employed a generic MV repair assessment when critically appraising the studies (to decrease the risk of bias in our assessment) and did not include studies without relevant information about the post-repair TEE exam. Review articles were also excluded.

Studies included were evaluated for selection bias (including attrition bias), confounding, measurement bias, and obvious outcome reporting bias. Retrospective studies have the potential risk of selective outcome reporting. Publication bias could also not be detected because data were not amenable to quantitative synthesis.

Results

We reviewed a total of 323 records, of which 21 were additional duplicates, and 302 records underwent title and abstract screening. Subsequently, 50 records were selected and underwent full-text screening. The final systematic review included 30 studies of intraoperative TEE post-MV repair and study characteristics are presented in Table 1.

Of the 30 studies included, 22 were prospective studies, and 8 were retrospective studies and a summary of the design and findings is presented in Table 2, including the intraoperative TEE approach and examination that was used in each study, the intraoperative TEE findings, and the significant results. Although most of the echocardiographers adhered to the intraoperative guidelines in evaluating the mitral valve, we noticed that no specific stepwise approach was utilized for the post-CPB assessment of the MV.

Clinical and methodological diversity

None of the studies included can be considered a Randomized Clinical Trial (RCT), once they are all observational, performed either retrospectively or prospectively. Although these studies share the assessment of the repaired MV using TEE, there are significant differences among them. Of the 30 studies included, 8 studies are non-comparative and describe findings in a series of cases, and the remaining 22 comparative studies investigate a broad spectrum of variables and parameters, using software analysis from different vendors.

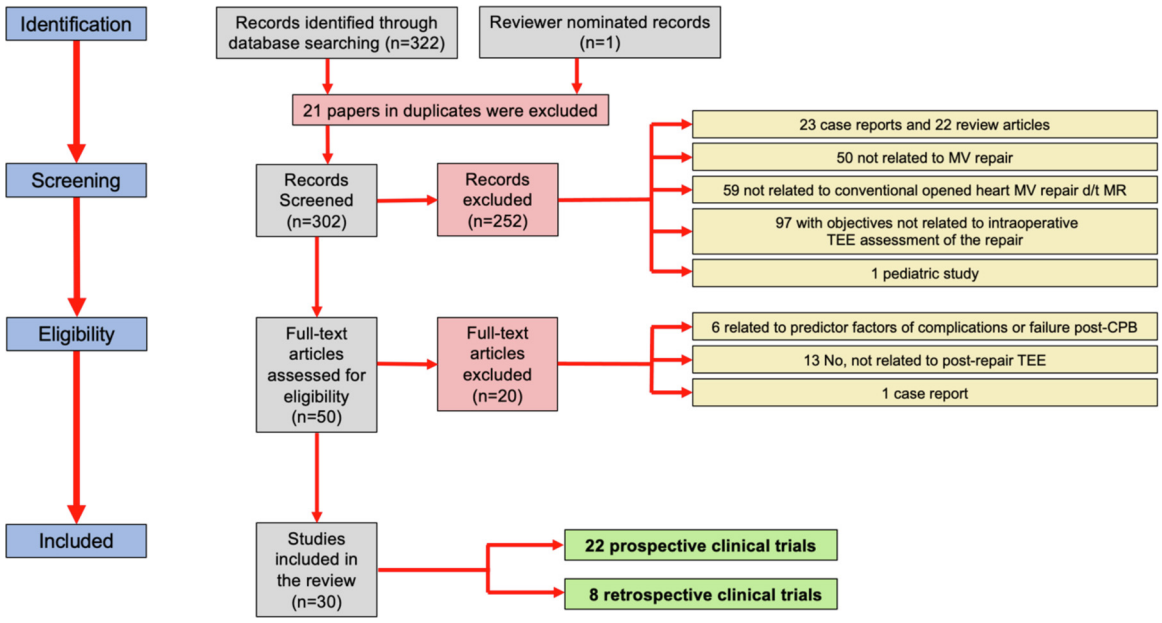

Figure 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram.

Mitral valve pathology

All studies included patients with MR, however the baseline MV pathology for included patients is not homogeneous, with some studies including patients with degenerative disease only, others including patients with functional ischemic disease only, and others including both. We also found studies without documentation of the baseline MV pathology, and studies including any cause of MR (degenerative, ischemic, rheumatic, endocarditis, unknown).

Evidence synthesis

Most studies were non-comparative or descriptive in design rather than analytic, from which no estimates of effects could be generated. Furthermore, as presented above, we found clinical and methodological diversity across studies, and they included different baseline MV pathologies. Therefore, these studies are non-comparable and unfortunately data meta-analysis was not feasible. We adopted a qualitative approach to evidence synthesis and presented a narrative review of our findings.

Discussion

Intraoperative TEE provides an undisputed and important source of information for surgeons and anesthesiologists in mitral valve repair surgeries.[6,12,13] Guidelines on MR assessment and review articles on intraoperative TEE for MV repair surgery have been published, emphasizing the effect of afterload on the echocardiographic assessment of MR and the importance of assessing the valve under optimized hemodynamic conditions similar to patient's baseline vital signs. These studies also demonstrate excellent correlation between TEE and surgical findings in both simple[14] and complex pathologies,[15] providing a structured comprehensive approach on how to perform a post-CPB exam that addresses separation from CPB, MV assessment (competency, patency and restoration of leaflet coaptation), Left Ventricular (LV) global and regional function, Left Ventricular Outflow Tract (LVOT) assessment for MV systolic anterior motion, and presence of new aortic insufficiency.[6,16-21]

This systematic review aimed to examine the recent evidence and search for novel intraoperative TEE assessments post-repair that can impact short and long-term outcomes following the surgery. The search strategy used included all studies involving the utilization of TEE in the intraoperative period of surgeries in the MV, and we noticed heterogenicity amongst centers in the use of TEE post-CPB for decision-making Figure 2. presents a flowchart with a proposed stepwise approach for intraoperative assessment of MV repair post-CPB that can be used to evaluate the quality of the repair and guide decisions.

Technological advances

Of the 30 studies included in this review, 19 used novel 3D-TEE analytical software with different objective-derived measurements to assess[22-25] and investigate multiple geometric and dynamic changes of the repaired mitral valve[26-31] and mitral valve apparatus.[30,32-35] This technology was also used to compare geometric and dynamic changes using full versus partial annuloplasty rings[36,37] and full rings of different shapes[38] and different characteristics.[39,40] (Table 1) Although these studies used analytic software and offered objective evaluation of the MV post-repair, they are all descriptive in nature, and further randomized clinical trials are necessary to investigate the association between the objective-derived data and long-term outcomes.

Grapsa et al. used speckle tracking software analysis of the MV apparatus to calculate papillary muscles' strain and showed that patients with isolated posterior mitral leaflet prolapse are less likely to have any residual MR post-repair when the global papillary muscle strain of both papillary muscles is close or equal to zero.[41] Although promising, this

Table 1 Included studies characteristics.

Study	Country	MV Pathology	Design	Sample size	Analysis
Bartels et al. (2014)[24]	USA	Patients with no MV disease, degenerative and functional MR.	Cohort, retrospective case-control study	80	Comparative
Ben Zekry et al. (2016)[30]	USA	Patients with no MV disease and patients with degenerative MR.	Cohort, prospective observational study	30	Comparative
Grewal et al. (2009)[25]	USA	Patients with no MV disease, degenerative and functional MR.	Cohort, prospective observational study	57	Comparative
Ma et al. (2008)[20]	China	Patients with various MV pathologies	Case series, prospective observational study	24	Non-comparative
Ma et al. (2018)[34]	China	Patients with no MV disease and patients with degenerative MR.	Cohort, retrospective study	136	Comparative
Maffessanti et al. (2011)[21]	Italy	Patients with no MV disease and patients with degenerative MR.	Cohort, prospective observational study	74	Comparative
Mahmood et al. (2010)[36]	USA	Patients with degenerative and functional MV disease.	Cohort, prospective observational study	36	Comparative
Mahmood et al. (2008)[26]	USA	Patients with no MV disease and patients with MV disease of various pathologies	Case series, prospective observational study	102	Non-comparative
Mahmood et al. (2009)[35]	USA	Patients with degenerative and functional MV disease.	Case series, prospective observational study	75	Comparative
Maslow et al. (2014)[27]	USA	Patients with degenerative and functional MV disease.	Case series, prospective observational study	50	Comparative
Nishi et al. (2016)[37]	Japan	Patients with no MV disease and patients with degenerative MR.	Cohort, prospective observational study	44	Comparative
Owais et al. (2014)[38]	USA	Patients with no MV disease and patients with degenerative MR.	Cohort, prospective observational study	48	Comparative
Pan et al. (2008)[22]	China	Patients with degenerative MR.	Case series, prospective observational study	6	Comparative
Tautz et al. (2020)[23]	Germany, Swiss	Patients with normal and abnormal MV.	Case series, prospective observational study	10	Non-comparative
Veronesi et al. (2012)[31]	USA, Italy	Patients with no MV disease and patients with degenerative MR.	Cohort, prospective observational study	53	Comparative
Wang et al. (2011)[13]	China	Patients with degenerative MV disease.	Case series, prospective observational study	22	Comparative
Ender et al. (2010)[54]	Germany	Patients with MR, pathology not disclosed.	Case series, prospective observational study	110	Non-comparative
Grapsa et al. (2015)[39]	USA, UK	Patients with degenerative MV disease.	Case series, prospective observational study	64	Non-comparative
Guo et al. (2018)[52]	China	Patients with degenerative MV disease.	Case series, prospective observational study	48	Non-comparative
Kang et al. (2013)[44]	South Korea	Patients with MR (pathology not disclosed), Mitral Stenosis (MS) or combined MR + MS.	Case series, retrospective study	26	Comparative
Karamnov et al. (2020)[45]	USA	Patients with degenerative MV disease.	Case series, retrospective study	20	Comparative

Table 1 *(Continued)*

Study	Country	MV Pathology	Design	Sample size	Analysis
Maslow et al. (2011)[40]	USA	Patients with MR, pathologies not disclosed.	Case series, prospective observational study	25	Comparative
Riegel et al. (2011)[43]	USA, Germany	Patients with degenerative, functional and rheumatic MV disease.	Case series, retrospective study	552	Non-comparative
Vernick et al. (2013)[42]	USA	Patients with degenerative and functional MV disease.	Case series, prospective observational study	20	Comparative
Mabrouk-Zerguini et al. (2008)[53]	UK, France	Patients with degenerative, functional, and unknown MV disease.	Case series, prospective observational study	25	Comparative
Manabe et al. (2012)[32]	Japan	Patients with degenerative MV disease.	Case series, retrospective study	179	Comparative
Rosendal et al. (2012)[33]	Germany	Patients with no MV disease, degenerative and functional MR.	Cohort, retrospective study	50	Comparative
Vergnat et al. (2011)[29]	USA	Patients with degenerative MV disease.	Cohort, prospective observational study	16	Comparative
Vergnat et al. (2012)[28]	USA	Patients with functional MV disease	Case series, prospective observational study	21	Comparative
Wei et al. (2017)[51]	China	Patients with degenerative MV disease.	Case series, retrospective study	20	Non-comparative

is an isolated study and further trials are necessary to delineate the role of speckle tracking and determine the metrics of strain associated with quality or duration of the repair.

Iatrogenic mitral stenosis

A restrictive annuloplasty or extensive resection of leaflet tissue may decrease the effective Mitral Valve Area (MVA) during diastole, in turn leading to Mitral Stenosis (MS) following repair.[42] The influence of CPB on ventricular compliance immediately after surgery may be an important factor that limits the usefulness of Pressure-Half-Time (PHT) to assess MV patency post-repair,[43] and currently there is a call for guidelines to assess MS in a repaired MV, once there is conflicting data regarding which method should be used to determine the MVA immediately following repair (PHT, 2-dimension planimetry 2D-PLAN or 3-dimension planimetry 3D-PLAN).[44]

Our review found 5 studies on this specific topic. Vernick et al. showed that Doppler-derived trans-mitral gradients provide a simple, safe, and reliable measure of the true physiologic trans-mitral valve gradient.[45] Although a mean gradient of less than 5 mmHg across the valve is characteristic of an adequate repair,[19] Riegel et al. pointed out that higher mean gradients up to 7 mmHg immediately post-CPB might be present in situations of increased Left Atrial Pressure (LAP), namely high cardiac output, tachycardia and Atrial Fibrillation (AFib), and this may not cause clinical postoperative MS that needs to be addressed surgicaly.[46] Three observational studies attempted to compare different methods, and none of them showed strong evidence of a superior method[42,47,48] (Table 1).

Coaptation surface

A key objective of surgical valve repair is to restore the largest possible leaflet coaptation surface.[49-52] There is an association of CH > 8 mm post-repair with better outcomes although the normal Coaptation Height (CH) in a native MV ranges from 3 to 6 mm.[53] Wei et al. demonstrated that a taller coaptation height post-repair is associated with less residual MR in 12 months post-repair,[54] and Guo et al. showed that both 2D and 3D-TEE can be used to assess leaflet coaptation post-repair, with 2D been found to be a simpler and faster method.[55]

Left ventricular assessment

Predicting the risk of LV dysfunction post-MV repair is challenging because of the overestimation of LV ejection fraction in patients with severe MR. Mabrouk-Zerguini et al. showed that the Myocardial Performance Index (Tei-index) is not affected by MV repair. This index could be used to predict post-repair Fractional Area Change (FAC) and, consequently, predict patients at risk of post-CPB LV dysfunction.[56]

New LV lateral wall regional motion abnormality following repair should raise suspicion of injury to the circumflex artery.[6,15-18] Ender et al. proposed and validated a method to interrogate the circumflex artery with Color Flow Doppler (CFD) and Pulse Wave Doppler (PWD) at its proximal,

Table 2 Summary of study design and echocardiographic findings.

Study	Study objectives	Study design	Results	Author's conclusion
Bartels et al. (2014)[24]	Hypothesized that quantitative 3D analysis would reveal distinct differences among diseased, repaired, and normal MV.	Case-control observational clinical study. Retrospectively analyzed 80 patients who underwent intraoperative TEE: 20 patients with degenerative MR were evaluated before and after mitral valve repair, 20 patients had functional MR and 20 patients had no MV disease.	Annulus area was enlarged in degenerative and functional MR. Annular displacement distance was decreased in functional MR and repaired valves. Annular displacement velocity was decreased in functional MR. Annular area fraction was decreased in functional MR and repaired valves.	Normal, functional regurgitant, degenerative, and repaired MV have distinctly different dynamic signatures of anatomy and function as reliably determined by perioperative echocardiographic tracking.
Ben Zekry et al. (2016)[30]	The investigation was aimed at deriving novel intrinsic parameters of regional and global MA shape and function, namely, curvature and torsion.	Prospective observational study. Indices were evaluated in a group of 15 patients with normal MV and in a group of 15 patients with organic MR, prior to and after MV repair. Novel parameters of MA curvature and torsion were derived from 3D TEE.	Patients with organic MR presented the smallest global curvature and torsion; this decrease in curvature and torsion reflects a loss of tonicity of the MA tissue. These changes were largely corrected with MV repair surgery, to higher values, compared with normal individuals. The regional analysis revealed similar trends. The maximal MA curvature was found to be at the MA 'anterior horn', whereas the MA 'posterior horn' had the lowest curvature values.	Novel MA parameters of curvature and torsion can be computed from 3D echocardiography and provide quantitative characteristics of dynamic regional MA geometry. In patients with organic MR, the reduced regional and global curvatures improve following surgical MV repair. These quantitative parameters may help further refine the quantitative description of MA geometry in various mitral valve pathologies and after MV repairs.
Grewal et al. (2010)[25]	Investigated and compare mitral annular size, shape, and motion over the cardiac cycle using RT 3D-TEE in patients with myxomatous MV disease before and after repair, in normal control subjects and in patients with ischemic MR.	Prospective observational study. RT 3D-TEE of the mitral valve was acquired in 32 patients with MVD before and after repair, 15 normal control subjects, and 10 patients with IMR of identical body surface area.	RT 3D-TEE provides insights into normal, dynamic MA function with early-systolic area contraction and saddle-shape deepening contributing to mitral competency. MVD annulus is also dynamic but considerably different with loss of early-systolic area contraction and saddle-shape deepening despite similar magnitude of ventricular contraction, suggestive of ventricular-annular decoupling. Subsequent area enlargement may contribute to mitral incompetence. After mitral repair, MVD annulus remains dynamic without systolic saddle-shape accentuation.	RT 3D-TEE provides new insights that allow the refining of mitral pathophysiology concepts and repair strategies

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
Ma et al. (2008)[20]	Investigated the feasibility, imaging quality and accuracy of live 3D-TEE for assessing MV morphology to determine if live 3D-TEE has important value in MV surgery.	Prospective observational study. Twenty-four patients with MV disease underwent live 3D-TEE and 2D-TEE before and after MV surgery. Sensitivity, specificity, and total consistency rates of live 3D-TEE for diagnosing ruptured chordae were calculated and compared to surgeon's findings. We also compared the diagnostic accuracy of MV disease between live-3D-TEE and 2D TEE.	Live-3D-TEE allowed visualization of the anatomic structures of the heart online and clearly identified the valvular apparatus and their defects. Sensitivity and specificity for the detection of ruptured chordae by live 3D-TEE were 87.5% and 100% respectively, and the total consistency rate was 95.8%. Additional defects not diagnosed by 2D TEE were found in three cases (12.5%) preoperatively by live 3D-TEE. Live 3D-TEE could evaluate the function of prosthetic or native valves immediately after operation. One case was re-repaired (4.2%) using guidance by live 3D-TEE.	Live 3D-TEE enabled evaluation of MV function and provided adequate valuable information before and after MV surgery. We conclude that live 3D-TEE can play an important role in MV surgery.
Ma et al. (2018)[34]	Investigated the impact of full annuloplasty rings versus C-shape bands on mitral annular geometry in the presence of FED assessed by intraoperative 3D-TEE.	Retrospective study. 65 patients who underwent MV repair for severe MR caused by FED using full rings (the Ring group, n = 30) and C-shape bands (the Band group, n = 35). 71 controls without valvular heart disease were also included. Thorough 3D-TEE inspections were performed for the entire cohort to measure morphological parameters of MA before and after surgery. Mid-term repair durability and left atrial diameter were followed up.	The preoperative 3D-TEE parameters, including annular diameters, area, height and aorto—mitral angle, were significantly larger in the FED groups than normal, and were comparable between two groups using different annuloplasty devices. After repair, the anterior—posterior diameter, annulus circumference and area were significantly larger in the Band group than in the Ring group. The aorto—mitral angle became comparable with normal value in the Ring group, but not in the Band group. Follow-up echocardiographic data showed a significant correlation between postoperative aorto—mitral angle and reduced left atrial diameter at 50.3 months after surgery.	Compared with C-shape bands, full rings may impose less narrowing on aorto—mitral angle, which correlates well with mid-term left atrial reverse remodeling
Maffessanti et al. (2011)[21]	Quantified the effects induced by prolapse on MV anatomy in the presence of FED or Barlow's disease, assess the effect of surgery on the MV apparatus, and investigate the potential	Prospective observational study. 56 patients (29 with FED, 27 with Barlow's disease) undergoing MV repair and annuloplasty were studied immediately before and after surgery. Also, 18 age-matched	MV prolapse and regurgitation were associated with a markedly enlarged annulus and leaflets compared with controls, while annular height and the mitral aortic angle were similar. Patients with Barlow's disease showed	Intraoperative 3D-TEE allows quantitative evaluation of the MV apparatus in the presence of FED or Barlow's disease and could be useful for immediate

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
	role of 3D-TEE in surgical planning.	patients with normal MV anatomy, undergoing coronary artery bypass, were included as a control group. 3D-TEE data sets were acquired and analyzed to quantify several MV annulus and leaflet parameters using dedicated software.	greater values than those with FED. MV repair and annuloplasty led to a significant undersizing of leaflet and annular areas, diameters, and height compared with controls. CL remained in the normal range. Differences between Barlow's disease and FED were reduced but still present after surgery.	assessment of the surgical procedure.
Mahmood et al. (2010)[36]	Investigated if when compared to flat rings, saddle-shaped rings would decrease the NPA after MV repair for both ischemic and myxomatous MV disease.	Prospective observational study. Geometric analysis on 38 patients undergoing MV repair for myxomatous and ischemic MR with full flat rings (n = 18) and saddle rings (n = 18) were performed. The acquired 3D volumetric data were analyzed and the degree of change in the NPA was calculated and compared before and after repair for both types of rings.	Both types of annuloplasty rings resulted in significant changes in the geometric structure of the MV after repair. However, saddle rings lead to a decrease in the NPA, whereas flat rings increased the NPA.	Implantation of saddle-shaped rings during MV repair surgery is associated with augmentation of the nonplanar shape of the MA. This favorable change in the mitral annular geometry could possibly confer a structural advantage to MV repairs with the saddle rings.
Mahmood et al. (2008)[26]	Studied the feasibility of using 3D-TEE in the operating room for MV repair or replacement surgery. To perform geometric analysis of the mitral valve before and after repair.	Prospective observational study. Intraoperative reconstruction of 3D images of the mitral valve in 102 consecutive patients scheduled for MV surgery.	Successful image reconstruction was performed in 94 patients – 8 patients had arrhythmias or a dilated MV annulus resulting in significant artifacts. Time from acquisition to reconstruction and analysis was less than 5 minutes. Surgeon identification of MV anatomy was 100% accurate.	The study confirms the feasibility of performing intraoperative 3D reconstruction of the MV. The incorporation of CFD into these 3D images helps in identification of the commissural or perivalvular location of regurgitant orifice.
Mahmood et al. (2009)[35]	3D intraoperative TEE evaluation of the MV annulus before and immediately after repair	Prospective observational study. 3D geometric analysis on 75 patients undergoing MV repair during coronary artery bypass graft surgery for MR or myxomatous MV disease. Geometric analysis of the MV was performed before and immediately after valve repair with full rings and annuloplasty bands.	Complete echocardiographic assessment of the MV was feasible in 69 of 75 patients (92%) within 2 to 3 minutes of acquisition. Placement of full rings resulted in an increase in the NPA or a less saddle shape of the native MA. By contrast, the NPA did not change significantly after placement of partial rings.	Mitral annular nonplanarity can be assessed in the operating room. Application of full annuloplasty rings resulted in the MA becoming more planar. Partial annuloplasty bands did not significantly change the nonplanarity angle. Neither of the two types of rings restored the native annular planarity
Maslow et al. (2014)[27]	Examined the geometric changes of the MV after repair	Prospective observational study. 50 consecutive patients scheduled for elective repair of the MV for	Good correlations and agreement were seen between the MVA measured with 3D-Plan and PHT and were better	3D imaging provides caregivers with a unique ability to assess

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
	using conventional and 3D echocardiography.	regurgitant disease. Intraoperative TEE assessments of MVA were performed using 2D-PLAN, PHT, and 3D-PLAN. In addition, the direction of ventricular inflow was assessed from the 3D imaging.	than either one compared to 2D-Plan. MVAs were smaller after repair of functional disease repaired with an annuloplasty ring. After repair, ventricular inflow was directed toward the lateral ventricular wall. Subgroup analysis showed that the change in inflow angle was not different after repair of functional disease as compared to those presenting with degenerative disease.	changes in valve function after MV repair.
Nishi et al. (2016)[37]	Assessed the effects of different types of prosthetic rings on mitral annular dynamics using RT 3D-TEE.	Prospective observational study. 44 patients, including patients undergoing mitral annuloplasty using the Cosgrove—Edwards flexible band (Group A, n = 10), the semi-rigid Sorin Memo 3D ring (Group B, n = 17), the semi-rigid Edwards Physio II ring (Group C, n = 7) and ten control subjects. Various annular diameters were measured throughout the cardiac cycle.	Flexible anterior annulus motion in all of the groups except Group C. A flexible posterior annulus was only observed in Group B and the Control group. The MAA changed during the cardiac cycle by 8.4 ± 3.2, 6.3 ± 2.0, 3.2 ± 1.3, and 11.6 ± 5.0 % in Group A, Group B, Group C, and the Control group, respectively. The dynamic diastolic to systolic change in mitral annular diameters was lost in Group C, while it was maintained in Group A, and to a good degree in Group B. In comparison to the Control group, the MA shape was more ellipsoid in Group B and Group C, and more circular in Group A.	Although MR was well controlled by all of the types of rings that were utilized in the present study, we demonstrated that the annulus motion and annulus shape differed according to the type of prosthetic ring that was used, which might provide important information for the selection of an appropriate prosthetic ring.
Owais et al. (2014)[38]	Selectively flexible rings are used for annuloplasty during MV repair to facilitate dynamic annular motion while preventing annular dilation. This study assessed the extent and nature of the flexibility of 2 rings in vivo.	Prospective observational study. 3D-TEE was used intraoperatively to acquire data regarding dynamic motion of mitral annuli and annuloplasty rings in 33 patients undergoing mitral repair and in 15 control patients. Data were analyzed to assess the dynamic changes in annular geometry after implantation of selectively flexible rings.	After annuloplasty, there was an immediate and significant decrease in annular displacement and annular displacement velocity. Dynamic change in multiple variables including anteroposterior diameter and annular area was also significantly depressed. In comparison with normal MV, partially flexible rings allowed limited dynamic motion: percentage changes in anteroposterior diameter, AL diameter, PM diameter, and total circumference were significantly lower. Compared	Mitral annular dynamics were uniformly depressed after implantation of these rings. Selective flexibility could not be demonstrated in vivo using echocardiographic data.

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
			with each other, the two rings resulted in similar changes in anterior annulus length, posterior annular length, and annular area.	
Pan et al. (2008)[22]	Investigated the value of RT-3D-TEE in MV repair.	Prospective observational study. RT-3D-TEE was performed in 6 patients with MV prolapse. Preoperative RT-3D-TEE studies were compared with surgical findings in patients undergoing surgical MV repair, and quantitative evaluation was performed before and after surgical MV repair.	RT-3DTEE could display dynamic morphology of MV, the location of prolapse, and spatial relation to the surrounding tissue. It could provide surgical views of the valves and the valvular apparatus. These results were consistent with surgical findings. The quantitative evaluation before and after surgical MV repair indicated that AL to PM diameter of annulus, anterior to posterior diameter of annulus, perimeter of annulus, and area of annulus in projection plane were significantly smaller after operation compared with those before operation. The length of posterior leaflet, the area of anterior and posterior leaflet, the maximal prolapse height, the volume of leaflet prolapse and the length of coaptation in projection plane were significantly reduced after operation.	RT-3DTEE is a unique new modality for rapid and accurate evaluation of MV prolapse and MV repair.
Tautz et al. (2020)[23]	Provided a new 4D segmentation method to enable a quantitative assessment of valve geometry and pathological properties in all heart phases, as well as the changes achieved through surgery.	Prospective observational study. Tracking-based approach combining GVF and PBD. An open-state surface model of the valve is propagated through time to the closed state, attracted by the GVF field of the leaflet area. The PBD method ensures topological consistency during deformation. For evaluation, one expert in cardiac surgery annotated the closed-state leaflets in 10 TEE sequences of patients with normal and abnormal MV and defined the corresponding open-state models.	The average point-to-surface distance between the manual annotations and the final tracked model was 1.00± 1.08 mm. Qualitatively, four cases were satisfactory, five passable and one unsatisfactory. Each sequence could be segmented in 2−6 min.	Our approach enables to segment the mitral valve in 4D-TEE image data with normal and pathological valve closing behavior. With this method, in addition to the quantification of the remaining orifice area, shape and dimensions of the coaptation zone can be analyzed and considered for planning and surgical result assessment.

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
Veronesi et al. (2012)[31]	Characterized MAC in 3D space before and after MV repair and to identify the untoward effects of annuloplasty rings on MAC compared with normal valvular function.	Prospective observational study. RT-3D-TEE was performed on 28 consecutive patients with degenerative MV disease and severe MR before and after MV repair and in 25 age-matched control subjects. Custom software was used to semi-automatically identify the mitral and aortic annuli throughout the cardiac cycle and to measure parameters describing valvular dynamics.	Patients with MR before MV repair were characterized by altered morphology and function of the MV but preserved MAC because of the maintained ability of the MA to change size and position. MV repair together with annuloplasty ring implantation forced the MA to be smaller and less pulsatile, with decreased displacement ability compared with normal mitral annuli. Because of this alteration in MAC, the "unaffected" aortic annulus became less pulsatile and less mobile.	This study shows unwanted and unexpected changes in aortic annular function secondary to MV repair with an annuloplasty ring due to altered MAC mechanisms. These changes may alter the dynamic mechanism of the aortic root that facilitates blood ejection, so MAC should be considered and evaluated from diagnosis to treatment in MV disease.
Wang et al. (2011)[13]	Delineated the utility of intraoperative TEE in robotic MV repair.	Prospective observational study. Intraoperative TEE was performed in 22 consecutive patients undergoing robotic MV repair for severe degenerative MR over a period of 2 years. Before CPB, TEE was used to define the lesions of degenerative MR and the localization of the prolapsed leaflets, and to evaluate the severity of MR. During establishment of peripheral CPB, TEE was used to guide placement of the cannula in the IVC, SVC, and AAO. After weaning from CPB, TEE was used to assess immediately the competency of the surgical repair.	Agreement between TEE and surgical findings was 92.3% for the lesions of degenerative MR, and 98.5% for the localization of the prolapsed leaflets. Under TEE guidance, all the cannulas in the SVC, IVC, and AAO were placed correctly. TEE demonstrated all the patients had successful robotic MV repairs.	Intraoperative TEE is a valuable adjunct in the assessment of robotic MV repair.
Ender et al. (2010)[54]	Evaluated an echocardiographic method to visualize the course and flow of the circumflex artery, to detect iatrogenic injury to this structure intraoperatively, as well as to predict the coronary dominance pattern in MV surgery patients.	Prospective study. 110 patients undergoing minimal invasive MV repair. Intraoperative TEE was used to visualize the circumflex artery using a combination of B-mode imaging and color Doppler with different Nyquist limits. The course of the circumflex artery and the coronary sinus and their corresponding diameters were documented at the proximal and distal ends of both vessels.	The course of the circumflex artery could be detected proximally in 109 patients (99%), to the point of intersection with the coronary sinus in 99 patients (90%), and distal to this intersection in 95 patients (86%). Three patients had evidence of iatrogenic aliasing (circumflex stenosis) or "no flow" (circumflex occlusion) on TEE examination after repair and therefore underwent surgical or percutaneous correction.	The early recognition of iatrogenic injury of the circumflex artery is feasible with intraoperative TEE examination and may lead to treatment before extensive myocardial infarction occurs.

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
		Preoperative angiographic data were used to determine the coronary dominance type.		
Grapsa et al. (2015)[39]	Assessed the papillary muscle strain as a contributor to recurrent MR after MV repair for FED.	Prospective study. 64 patients with isolated posterior MV prolapse and severe MR referred for surgery. 2D, 3D-TEE and speckle tracking were performed in all patients. The longitudinal strain of the AL and PM papillary muscles were individually calculated as well as the global longitudinal strain of both papillary muscles was measured before and after mitral repair and normalized to left ventricle end-diastolic volume.	Eight patients (12.5%) had at least moderate MR 6 months after mitral repair. The longitudinal strain of the AL and the PM papillary muscles as well as the global strain of both papillary muscles were all reduced after surgical repair. The longitudinal strain of the PM papillary muscle was the strongest predictor of recurrent MR. The global preoperative papillary muscle strain was also a determinant of recurrent MR when the global strain was greater than 29.05.	Patients with isolated posterior mitral leaflet prolapse are less likely having any residual MR post repair when the global papillary muscle strain of both papillary muscles is close or equal to zero. Strain of the papillary muscles may be an important determinant in predicting residual MR in patients who undergo mitral valve repair.
Guo et al. (2018)[52]	Evaluated the utility of 2D and 3D-TEE to assess MV coaptation before and after MV repair.	Prospective study. 48 patients undergoing MV repair for MR were studied. Assessed the utility of 2D and 3D-TEE to assess MV coaptation before and after MV repair. Complete conventional 2D and 3D-TEE studies were performed, and the degree of the MV coaptation defect before and after surgery was assessed by measuring the MV CL and CLI with 2D TEE, and the CA and CAI with 3D-TEE.	Compared with preoperatively, postoperative CL, CLI, CA, and CAI were significantly increased. Correlation analysis revealed that the CLI and CAI had a significant negative correlation with the degree of MR. Furthermore, correlation analysis revealed that the CLI was significantly correlated with the CAI both preoperatively and postoperatively.	The coaptation variables increased significantly in patients undergoing MV repair. The CLI and CAI significantly correlated with MR severity. The CL and CLI determined with 2D TEE are more feasible than the CA and CAI determined with 3D-TEE. Both 2D and 3D variables may complement each other for aiding MV repair. 2D CLI is an alternative to 3D CAI due to its simplicity.
Kang et al. (2013)[44]	Hypothesized that MVA with echocardiography, using 3D-PLAN technique (measured at one point at maximal opening of MV) versus PHT (measured during entire diastolic phase) in MV repair surgery would be different.	Retrospective study. 26 patients who had undergone MV repair were retrospectively reviewed, and two different observers measured the MVAs using PHT and 3D-PLAN technique. The MVAs derived from recorded medical data, using PHT and 3D-PLAN technique were abbreviated to MVA-PHT1 and MVA-3D1, and data from the PHT and 3D-PLAN	Intraclass correlation coefficients were 0.90 for the intra-operative PHT technique and 0.78 for the intra-operative 3D-PLAN technique. MVA-3D1, MVA-3D2 and MVA-3D3 were significantly larger than MVA-TTE, but intra-operative MVAs-PHT were not.	MVA measured by 3D-PLAN technique with TEE at the intra-operative post-MV repair period was seemed to be larger than that measured by the PHT technique with TTE at the post-operative period. However, it did not mean that the 3D-PLAN technique was inaccurate but needs cautions at

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
		techniques by observer A and observer B were determined as MVA-PHT2 and MVA-3D2, and MVA-PHT3 and MVA-3D3, respectively. The MVA derived by post-operative TTE using the PHT technique was determined as MVA-TTE.		determination of MVA using different techniques.
Karamnov et al. (2020)[45]	Compared repaired MVAs obtained with commonly used 2D and 3D echocardiographic methods to a 3DOA, which is a novel echocardiographic measurement and independent of geometric assumptions	Retrospective study. Intraoperative 2D and 3D TEE images from 20 patients who underwent MV repair for MR obtained immediately after repair were retrospectively reviewed. MVAs obtained by PHT, 2D-PLAN, and 3D-PLAN were compared to those derived by 3DOA.	MVAs obtained by the 3DOA method were significantly smaller compared to those obtained by PHT, 2DP, and 3DP. In addition, MVA defined as an area $\leq$1.5 cm^2 was identified by 3DOA in 2 patients and by 3DP in 1 patient.	Post-MV repair, MVAs obtained using the novel 3DOA method were significantly smaller than those obtained by conventional echocardiographic methods and may be consistent with a higher incidence of MVA reduction when compared to 2D techniques.
Maslow et al. (2011)[40]	3 different methods to measure MVA after MV repair were studied. Data obtained immediately after repair were compared with postoperative data. The objective was to determine the feasibility and correlation between intraoperative and postoperative MVA data.	Prospective study. 25 patients scheduled for MV repair surgery. Echocardiographic data included MVAs obtained using the PHT, 2D-PLAN, and the CE. These data were obtained immediately after CPB and were compared with data obtained before hospital discharge (transthoracic echocardiogram 1) and 6 to 12-months after surgery (transthoracic echocardiogram 2). Intraoperative care was guided by hemodynamic goals designed to optimize cardiac function.	The data show good agreement and correlation between MVA obtained with PHT and 2D-PLAN within and between each time period. MVA data obtained with the CE in the postoperative period were lower than and did not correlate or agree as well with other MVA data.	The MVA recorded immediately after valve repair, using PHT, correlated and agreed with MVA data obtained in the postoperative period.
Riegel et al. (2011)[43]	Hypothesized that intraoperative echocardiography can be utilized to diagnose iatrogenic MS immediately after MV repair.	Retrospective study. Data of 552 consecutive patients undergoing MV repair at a single institution were reviewed. Post-CPB peak and mean TMPG, and PHT were obtained from intraoperative TEE examinations in each patient.	Nine patients received a reoperation for primary MS, prior to hospital discharge. All of these patients already showed intraoperative post-CPB mean and peak TMPGs that were significantly higher compared to values for those who did not However, PHT varied considerably within the entire population, and only weakly predicted the requirement for reoperation	Intraoperative TEE diagnosis of a peak TMPG 17 mmHg or mean TMPG 7 mmHg immediately following CPB are suggestive of clinically relevant MS after MV repair.

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
			Receiver operating characteristic curves showed strong discriminating ability for mean gradients and peak gradients, but poor performance for PHT. A value of 7 mmHg for mean, and 17 mmHg for peak TMPG, best separated patients who required reoperation for MS from those who did not.	
Vernick et al. (2013)[42]	Evaluated the accuracy of Doppler-derived transmitral valve gradients immediately after MV repair by comparing them with near simultaneously obtained direct catheter gradients.	Prospective study. 20 patients presenting for MV repair surgery. After completion of the MV repair and subsequent cardiac de-airing, the patient was weaned from CPB. Immediately after separation, near simultaneous transmitral Doppler gradients were obtained with directly measured catheter gradients via the vent catheter.	While the mean peak gradient difference of 1.1 mmHg was small, the correlation between Doppler and catheter gradient measurements only approached statistical significance due to the large variance associated with the small sample size. In all patients with a peak gradient greater than 10 mmHg (4 of the 20 patients), overestimation of catheter gradients by Doppler occurred, with two showing a 62% to 73% discrepancy. In these two cases, there was also evidence for elevated LVEDP along with high transmitral blood flow velocities.	Doppler-derived transmitral gradients provide a simple, safe, and reliable measure of the true physiologic transmitral valve gradient. At the same time, it is important to recognize that significant Doppler over-estimation of catheter gradients may occur in patients with elevated Doppler transmitral velocities.
Mabrouk-Zerguini et al. (2008)[53]	Tested the hypothesis where the Tei-index could be useful in assessing the perioperative cardiac function in patients undergoing MV repair.	Prospective study. 25 patients were enrolled. TEE was performed perioperatively before and after the correction of MR. We compared the impact of the MV repair on the left ventricular FAC and the Tei-index. FAC was calculated from the transgastric short-axis view and Tei-index was determined from the four chambers and deep transgastric views.	FAC significantly decreased after MVR from 53% to 42%, while Tei index was unaffected. A significant relationship was found between the preoperative Tei index and the postoperative FAC. Moreover, a significant and clinically relevant relationship was determined between the predicted (using preoperative Tei-index) and the measured postoperative FAC.	FAC but not the Tei index is influenced by MVR. The preoperative determination of the Tei index allows predicting postoperative FAC and offers the opportunity to identify patients in whom a severe unsuspected systolic dysfunction could render difficult the weaning from CPB.
Manabe et al. (2012)[32]	Investigated SAM of the MV mechanism by analysing the change in MV morphology associated with operative procedures.	Retrospective study. Components of MV were measured before and after operative procedures by TEE in 179 patients who underwent MV repair. Comparisons were made between 15 patients with SAM (SAM group) and 164	Operative procedures shifted the coaptation point towards the LVOT by 6.9 mm and increased the extra portion of anterior leaflet that extended beyond the coaptation point by 5.4 mm. These changes were enhanced in the SAM group.	The results of this study show that operative procedures might modify the morphology of MV susceptible to developing SAM. Postoperative smaller annular diameter and anterior shift of coaptation point were

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
		patients without SAM (non-SAM group).	Intergroup comparison revealed that there were no differences in the preoperative MV morphologies between the two groups. After operative procedures, however, the SAM group showed smaller annular diameter and smaller coapted anterior/posterior length ratio compared with the non-SAM group.	considered to contribute to the development of SAM.
Rosendal et al. (2012)[33]	RT-3D-TEE permits excellent visualization of the LVOT and might improve standard 2D measurements. In this study, LVOT area and shape were assessed before and after MV surgery.	Retrospective study. 35 patients undergoing MV repair or replacement were compared with 15 patients undergoing coronary artery bypass grafting. LVOT area was measured by planimetry. Maximum possible methodologic errors by assuming a circular LVOT and an eccentricity index were calculated. LVOT diameter in a midesophageal long-axis view served to calculate the error for the circular LVOT determined in common intraoperative practice.	Common intraoperative 2D measurements underestimated actual LVOT area by 21%. MV surgery led to a significant reduction of LVOT area by 7%. Although LVOT height remained unchanged, width decreased, resulting in a more circular shape of the LVOT. This effect was more pronounced the smaller the size of the implanted annuloplasty ring or prosthesis. Coronary artery bypass grafting did not affect the LVOT. LVEF was significantly correlated with LVOT eccentricity. Impaired ventricular function and higher end-systolic volumes were associated with a rounder shape.	The eccentric LVOT shape leads to a distinct underestimation of its area with 2D measurements. LVOT eccentricity is less distinct in patients with low ejection fractions and higher end-systolic volumes. LVOT width is decreased through annuloplasty rings and prostheses, and the smaller the implanted device, the more profound the reduction.
Vergnat et al. (2011)[29]	Hypothesized that saddle-shaped annuloplasty would improve leaflet coaptation in cases of MV repair for flail posterior leaflet segments.	Prospective study. 16 with flail posterior segment and severe MR had MV repair using standard techniques. 8 patients received saddle-shaped annuloplasty and 8 patients received flat annuloplasty. RT-3D-TEE was performed before and after repair. Images were analyzed using custom software to calculate MAA, SLD, CW, TLA, and LCA.	Post-repair MAA and TLA were similar in both groups. Post-repair LCA was significantly greater in the saddle group than in the flat group.	When compared with flat annuloplasty, saddle-shaped annuloplasty improves LCA after MV repair for severe MR secondary to flail posterior leaflet segment. Use of saddle-shaped annuloplasty devices may increase repair durability.
Vergnat et al. (2012)[28]	Used RT-3D-TEE to assess the influence of the ring shape on leaflet curvature in patients with IMR.	Prospective study. RT-3D-TEE was performed in 21 patients with IMR after placement of either a flat or saddle shaped annuloplasty ring. A combination	Independently of the shape of the annuloplasty ring, all patients were subject to the same degree of annular undersizing. Patients who received saddle-shaped annuloplasty rings had	Saddle-shaped annuloplasty rings increase leaflet curvature compared with flat rings in patients with IMR. As a result, saddle-shaped annuloplasty

Table 2 (*Continued*)

Study	Study objectives	Study design	Results	Author's conclusion
		of commercially available and customized software was used to measure multiple leaflet curvature parameters across all regions of the MV.	greater leaflet curvature in all six MV leaflet regions compared with patients who received flat annuloplasty rings. These differences were statistically significant in all regions except the P1 region.	may decrease leaflet stress and potentially increases the durability of the repair in patients with IMR.
Wei et al. (2017)[51]	Investigated the association between the CH of MV and MR after MV repair.	Retrospective study with prospective follow-up. 20 patients that underwent MV valvuloplasty for MR were included. Ring annuloplasty was performed in all cases. MVd, CH, LVEF were measured by TEE before the operation in operation room and 3 months and 12 months after the operation by the TEE. A degree from 0 to 4 was used to measure the degree of MR.	There were 14 patients with 0, 3 patients with 1, 3 patients with 2 of MR 12 months after the operation. CH increased significantly at 3 months and 12 months after operation. MVd and LVEF were not significantly changed after MV repair. Furthermore, CH after resuscitation have a statistically significant negative correlation with the degree of MR 12 months after operation.	The MV repair with MV ring induces the morphologic change of the MV structure. The increase of CH after MV repair may be one of the main factors in regulation of MR.

2D, Two-Dimensional; 3D, Three-Dimensional; MV, Mitral Valves; TEE, Transesophageal Echocardiography; MR, Mitral Regurgitation; MA, Mitral Annulus; MVA, Mitral Valve Area; MVD, Myxomatous Valve Disease; FED, Fibroelastic Deficiency; NPA, Non-Planarity Angle; CFD, Color-Flow Doppler; 2D-PLAN, 2D Planimetry; PHT, Pressure Half-Time; 3D-PLAN, 3D Planimetry; RT, Real-Time; 4D, 4-Dimensional; GVF, Gradient Vector Flow; PBD, Position-Based Dynamics; MAC, Mitral-Aortic Coupling; CPB, Cardiopulmonary Bypass; IVC, Inferior Vena Cava; SVC, Superior Vena Cava; AAO, Ascending Aorta; AL, Anterolateral; PM, Posteromedial; CL, Coaptation Length; CLI, Coaptation Length Index; CA, Coaptation Area; CAI, Coaptation Area Index; 3DOA, 3D Orifice Area; CE, Continuity Equation; MS, Mitral Stenosis; TMPG, Transmitral Pressure Gradients; FAC, Fractional Area Change; LVEDP, Left Ventricular End-Diastolic Pressure; SAM, Systolic Anterior Motion; LVOT, Left Ventricular Outflow Tract; MAA, Mitral Annular Area; SLD, Septolateral Dimension; CW, Intercommissural Width; TLA, Total Leaflet Area; LCA, Leaflet Coaptation Area; IMR, Ischemic Mitral Regurgitation; MVd, MV short-axis dimension; CH, Coaptation Height; LVEF Left Ventricular Ejection Fraction; TTE, Transthoracic Echocardiography.

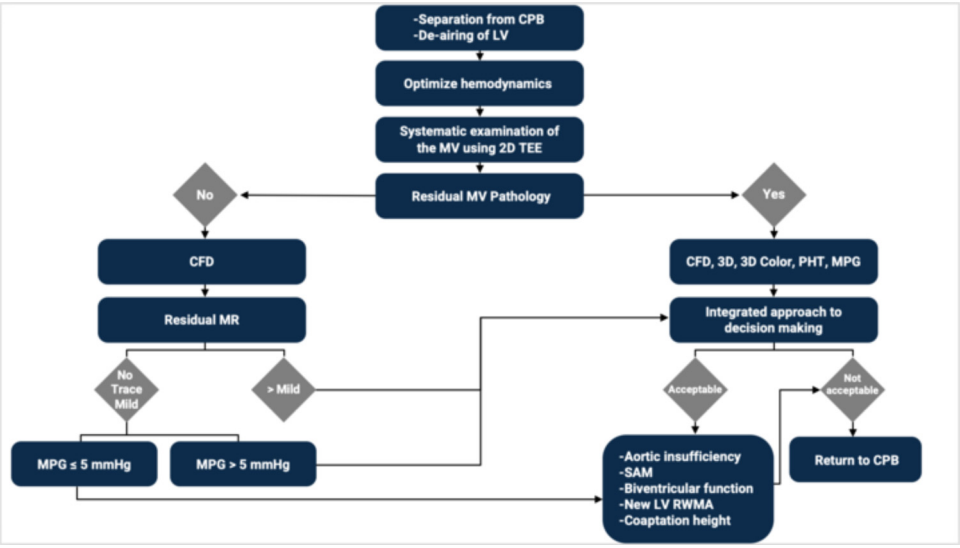

Figure 2 Flowchart representing an intraoperative stepwise approach to assess the Mitral Valve (MV) immediately after repair. Transesophageal Echocardiography (TEE) is used to guide the separation from Cardiopulmonary Bypass (CPB) and assure that the heart has no residual air; after hemodynamic optimization, a systematic examination of the MV using 2D TEE is used to identify if there is any residual mechanism of Mitral Valve Regurgitation (MR), and if this is not present, Color Flow Doppler (CFD) will confirm if there is residual MR. Any MR less or equal to mild is acceptable and further interrogation with Continuous Wave Doppler (CWD) calculating the Mean Pressure Gradient (MPG) will exclude significant Mitral Valve Stenosis (MS) post-repair. Residual MV pathology, any residual MR greater than mild and high MPG should undergo an integrated approach by the surgeon to decide if the repair is acceptable or not. If not acceptable, CPB is resumed, and further repair or replacement is performed. Once the outcome is acceptable, a comprehensive TEE examination is performed, including assessment of biventricular function, new Left Ventricle (LV) Regional Wall Motion Abnormalities (RWMA), new or worsening Aortic Valve Insufficiency, Systolic Anterior Motion of the MV and measurement of the MV Coaptation Height (CH).

intermediate, and distal segments, helpful to diagnose decreasedfloworocclusion.[57]

Limitations

Certain limitations can be appreciated in this study. Firstly, in chronological terms, our appraisal is limited to studies published from January 2008 until January 2021. However, most of the advanced technologies related to ultrasound and 3D-TEE were introduced to practice after 2008. Secondly, we did not find comparable studies and no data analysis was performed. A narrative description of the main findings was used as a feasible option. Thirdly, all studies included are observational in nature and ideally, adequately prospective randomized controlled trials are best suited to study outcomes with greater power of evidence. Finally, none of the studies included aimed to investigate the impact on the long-term outcomes, and no impact on duration of the repair or on patient's survival could be demonstrated.

Conclusion

This systematic review appraised the recent literature on intraoperative TEE for MV repair performed immediately after CPB. Although technological advances have allowed the objective assessment of geometric and dynamic alterations of the MV, the impact of the use of these technologies on short- or long-term outcomes has not been studied yet, and further prospective randomized trials are necessary to address this point. Moreover, we found uncertainty and conflicting evidence on the ideal method and metrics to evaluate MV patency post-repair, and few isolated studies validating methods to assess coaptation surface and LV function post-repair.

Conflicts of interest

The authors declare no conflicts of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjane.2022.03.002.

References

1. Carroll, D., Weerakkody, Y. Carpentier classification of mitral valve regurgitation. Reference article, Radiopaedia.org. https://doi.org/10.53347/rID-63316.
2. Enriquez-Sarano M, Akins CW, Vahanian A. Mitral regurgitation. Lancet. 2009;373:1382—94.
3. Prakash R, Horsfall M, Markwick A, et al. Prognostic impact of moderate or severe mitral regurgitation (MR) irrespective of concomitant comorbidities: a retrospective matched cohort study. BMJ Open. 2014;4:e004984.
4. Gammie JS, Sheng S, Griffith BP, et al. Trends in mitral valve surgery in the United States: results from the Society of Thoracic Surgeons Adult Cardiac Surgery Database. Ann Thorac Surg. 2009;87:1431—7. discussion 7-9.
5. Shernan SK. Perioperative transesophageal echocardiographic evaluation of the native mitral valve. Crit Care Med. 2007;35(8 Suppl):S372—83.
6. Sidebotham DA, Allen SJ, Gerber IL, et al. Intraoperative transesophageal echocardiography for surgical repair of mitral regurgitation. J Am Soc Echocardiogr. 2014;27:345—66.
7. David TE, Ivanov J, Armstrong S, et al. A comparison of outcomes of mitral valve repair for degenerative disease with posterior, anterior, and bileaflet prolapse. J Thorac Cardiovasc Surg. 2005;130:1242—9.
8. Lorusso R, De Bonis M, De Cicco G, et al. Mitral insufficiency and its different aetiologies: old and new insights for appropriate surgical indications and treatment. J Cardiovasc Med (Hagerstown). 2007;8:108—13.
9. Suri RM, Schaff HV, Dearani JA, et al. Survival advantage and improved durability of mitral repair for leaflet prolapse subsets in the current era. Ann Thorac Surg. 2006;82:819—26.
10. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. Open Med. 2009;3:e123—30.
11. Higgins JPT, Thomas J, Chandler J, et al. Cochrane Handbook for Systematic Reviews of Interventions. 2nd ed. Chichester (UK): John Wiley & Sons; 2019.
12. Lancellotti P, Moura L, Pierard LA, et al. European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 2: mitral and tricuspid regurgitation (native valve disease). Eur J Echocardiogr. 2010;11:307—32.
13. Nishimura RA, Otto CM, Bonow RO, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol. 2014;63:2438—88.
14. Wang Y, Gao CQ, Wang JL, et al. The role of intraoperative transesophageal echocardiography in robotic mitral valve repair. Echocardiography. 2011;28:85—91.
15. Grewal J, Mankad S, Freeman WK, et al. Real-time three-dimensional transesophageal echocardiography in the intraoperative assessment of mitral valve disease. J Am Soc Echocardiogr. 2009;22:34—41.
16. Mahmood F, Matyal R. A quantitative approach to the intraoperative echocardiographic assessment of the mitral valve for repair. Anesth Analg. 2015;121:34—58.
17. Iglesias I. Intraoperative TEE assessment during mitral valve repair for degenerative and ischemic mitral valve regurgitation. Semin Cardiothorac Vasc Anesth. 2007;11:301—5.
18. Banakal SC. Intraoperative transesophageal echocardiographic assessment of the mitral valve repair. Ann Card Anaesth. 2010;13:79—84.
19. Maslow A. Mitral valve repair: an echocardiographic review: Part 2. J Cardiothorac Vasc Anesth. 2015;29:439—71.
20. Ender J, Sgouropoulou S. Value of transesophageal echocardiography (TEE) guidance in minimally invasive mitral valve surgery. Ann Cardiothorac Surg. 2013;2:796—802.
21. Reshmi JL, Gopan G, Varma PK, et al. Transesophageal Echocardiographic Assessment of the Repaired Mitral Valve: A Proposed Decision Pathway. In: Seminars in Cardiothoracic and Vascular Anesthesia; 2021. September.
22. Ma N, Li ZA, Meng X, et al. Live three-dimensional transesophageal echocardiography in mitral valve surgery. Chin Med J. 2008;121:2037—41.
23. Maffessanti F, Marsan NA, Tamborini G, et al. Quantitative analysis of mitral valve apparatus in mitral valve prolapse before and after annuloplasty: a three-dimensional intraoperative transesophageal study. J Am Soc Echocardiogr. 2011;24:405—13.
24. Pan C, Shu XH, Cao Q, et al. Role of real-time three-dimensional transesophageal echocardiography in mitral valve repair. J Geriatr Cardiol. 2008;5:137—41.
25. Tautz L, Walczak L, Georgii J, et al. Combining position-based dynamics and gradient vector flow for 4D mitral valve segmentation in TEE sequences. Int J Comput Assist Radiol Surg. 2020;15:119—28.
26. Bartels K, Thiele RH, Phillips-Bute B, et al. Dynamic indices of mitral valve function using perioperative three-dimensional transesophageal echocardiography. J Cardiothorac Vasc Anesth. 2014;28:18—24.
27. Grewal J, Suri R, Mankad S, et al. Mitral annular dynamics in myxomatous valve disease: new insights with real-time 3-dimensional echocardiography. Circulation. 2010;121:1423—31.
28. Mahmood F, Karthik S, Subramaniam B, et al. Intraoperative application of geometric three-dimensional mitral valve assessment package: a feasibility study. J Cardiothorac Vasc Anesth. 2008;22:292—8.
29. Maslow A, Mahmood F, Poppas A, et al. Three-dimensional echocardiographic assessment of the repaired mitral valve. J Cardiothorac Vasc Anesth. 2014;28:11—7.
30. Vergnat M, Levack MM, Jassar AS, et al. The influence of saddle-shaped annuloplasty on leaflet curvature in patients with ischaemic mitral regurgitation. Eur J Cardiothorac Surg. 2012;42:493—9.
31. Vergnat M, Jackson BM, Cheung AT, et al. Saddle-shape annuloplasty increases mitral leaflet coaptation after repair for flail posterior leaflet. Ann Thorac Surg. 2011;92:797—803.
32. Ben Zekry S, Jain S, Alexander SK, et al. Novel parameters of global and regional mitral annulus geometry in man: comparison between normals and organic mitral regurgitation, before and after mitral valve repair. Eur Heart J Cardiovasc Imaging. 2016;17:447—57.
33. Veronesi F, Caiani EG, Sugeng L, et al. Effect of mitral valve repair on mitral-aortic coupling: a real-time three-dimensional transesophageal echocardiography study. J Am Soc Echocardiogr. 2012;25:524—31.
34. Manabe S, Kasegawa H, Fukui T, et al. Morphological analysis of systolic anterior motion after mitral valve repair. Interact Cardiovasc Thorac Surg. 2012;15:235—9.
35. Rosendal C, Hien MD, Bruckner T, et al. Left ventricular outflow tract: intraoperative measurement and changes caused by mitral valve surgery. J Am Soc Echocardiogr. 2012;25:166—72.
36. Ma W, Ye W, Zhang J, et al. Impact of different annuloplasty rings on geometry of the mitral annulus with fibroelastic deficiency: the significance of aorto-mitral angle. Int J Cardiovasc Imaging. 2018;34:1707—13.
37. Mahmood F, Subramaniam B, Gorman 3rd JH, et al. Three-dimensional echocardiographic assessment of changes in mitral valve geometry after valve repair. Ann Thorac Surg. 2009;88:1838—44.
38. Mahmood F, Gorman 3rd JH, Subramaniam B, et al. Changes in mitral valve annular geometry after repair: saddle-shaped versus flat annuloplasty rings. Ann Thorac Surg. 2010;90:1212—20.
39. Nishi H, Toda K, Miyagawa S, et al. Annular dynamics after mitral valve repair with different prosthetic rings: a real-time

three-dimensional transesophageal echocardiography study. Surg Today. 2016;46:1083—90.
40. Owais K, Kim H, Khabbaz KR, et al. In-vivo analysis of selectively flexible mitral annuloplasty rings using three-dimensional echocardiography. Ann Thorac Surg. 2014;97:2005—10.
41. Grapsa J, Zimbarra Cabrita I, Jakaj G, et al. Strain balance of papillary muscles as a prerequisite for successful mitral valve repair in patients with mitral valve prolapse due to fibroelastic deficiency. Eur Heart J Cardiovasc Imaging. 2015;16:53—61.
42. Maslow A, Gemignani A, Singh A, et al. Intraoperative assessment of mitral valve area after mitral valve repair: comparison of different methods. J Cardiothorac Vasc Anesth. 2011;25:221—8.
43. Nicoara A, Skubas N, Ad N, Finley A, Hahn RT, Mahmood F, et al. Guidelines for the use of transesophageal echocardiography to assist with surgical decision-making in the operating room: a surgery-based approach: from the american society of echocardiography in collaboration with the Society of Cardiovascular Anesthesiologists and the Society of Thoracic Surgeons. J Am Soc Echocardiogr. 2020;33:692—734.
44. Essandoh M. Intraoperative echocardiographic assessment of mitral valve area after degenerative mitral valve repair: a call for guidelines or recommendations. J Cardiothorac Vasc Anesth. 2016;30:1364—8.
45. Vernick WJ, Ochroch EA, Horak J, et al. Validation study of Doppler-derived transmitral valve gradients compared to near simultaneously obtained directly measured catheter gradients immediately after mitral valve repair surgery. J Card Surg. 2013;28:329—35.
46. Riegel AK, Busch R, Segal S, et al. Evaluation of transmitral pressure gradients in the intraoperative echocardiographic diagnosis of mitral stenosis after mitral valve repair. PLoS ONE. 2011;6(11):e26559.. [Electronic Resource].
47. Kang WS, Choi JW, Kang JE, et al. Determination of mitral valve area with echocardiography, using intra-operative 3-dimensional versus intra- & post-operative pressure half-time technique in mitral valve repair surgery. J Cardiothorac Surg. 2013;8:98.
48. Karamnov S, Burbano-Vera N, Shook DC, et al. A novel 3-dimensional approach for the echocardiographic evaluation of mitral valve area after repair for degenerative disease. Anesth Analg. 2020;130:300—6.
49. Padala M, Powell SN, Croft LR, et al. Mitral valve hemodynamics after repair of acute posterior leaflet prolapse: quadrangular resection versus triangular resection versus neochordoplasty. J Thorac Cardiovasc Surg. 2009;138:309—15.
50. Gillinov AM, Cosgrove DM, Blackstone EH, et al. Durability of mitral valve repair for degenerative disease. J Thorac Cardiovasc Surg. 1998;116:734—43.
51. Greenhouse DG, Dellis SL, Schwartz CF, et al. Regional changes in coaptation geometry after reduction annuloplasty for functional mitral regurgitation. Ann Thorac Surg. 2012;93:1876—80.
52. Bax JJ, Braun J, Somer ST, et al. Restrictive annuloplasty and coronary revascularization in ischemic mitral regurgitation results in reverse left ventricular remodeling. Circulation. 2004;110(11 Suppl 1). II103-8.
53. Adams DH, Rosenhek R, Falk V. Degenerative mitral valve regurgitation: best practice revolution. Eur Heart J. 2010;31:1958—66.
54. Wei D, Han J, Zhang H, et al. The correlation between the coaptation height of mitral valve and mitral regurgitation after mitral valve repair. J Cardiothorac Surg. 2017;12:120.
55. Guo Y, He Y, Zhang Y, et al. Assessment of the mitral valve coaptation zone with 2D and 3D transesophageal echocardiography before and after mitral valve repair. J Thorac Dis. 2018;10:283—90.
56. Mabrouk-Zerguini N, Leger P, Aubert S, et al. Tei index to assess perioperative left ventricular systolic function in patients undergoing mitral valve repair. Br J Anaesth. 2008;101:479—85.
57. Ender J, Selbach M, Borger MA, et al. Echocardiographic identification of iatrogenic injury of the circumflex artery during minimally invasive mitral valve repair. Ann Thorac Surg. 2010;89:1866—72.