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Simple Summary

In this study, we evaluated the effect of transcatheter edge-to-edge repair (TEER), which is a minimally invasive modality for mitral regurgitation (MR) in dogs with myxomatous mitral valve disease (MMVD). Ten dogs with moderate-to-severe MR received TEER under imaging guidance. The intervention effectively decreased MR severity in the majority of dogs and maximized myocardial work efficiency with greater constructive cardiac work and decreased amount of wasted energy. These findings suggest that TEER can improve cardiac function in dogs with MMVD. However, longer-term studies are required to assess its benefit relative to its absence and its impact on residual MR.

Abstract

Transcatheter edge-to-edge repair (TEER) is a recent minimally invasive method of managing mitral regurgitation (MR) in dogs with myxomatous mitral valve disease (MMVD). The goal of interventions is to minimize MR severity. The objective of this study was to determine the association between reduced MR and changes in myocardial work indices after TEER in dogs. Client-owned dogs with moderate-to-severe MR were enrolled in the study. TEER performance was completed with multimodal imaging guidance in all 10 dogs. Before and after the procedure, myocardial work was analyzed. MR severity, transmitral pressure gradients, left atrial and ventricular measurements, and index of myocardial work (GWI, GCW, GWW, and GWE) were calculated. TEER significantly reduced MR severity in the majority of dogs. MR decrease was associated with a greater efficiency of myocardial work, more constructive work, and less wasted energy. No significant negative associations of moderate post-procedure gradients with short-term clinical outcomes emerged. TEER-mediated reduction of MR improves myocardial function in dogs. However, long-term studies are also needed to examine the effects of residual MR and transmitral gradients on cardiac function and clinical outcome.

Keywords: MMVD; mitral regurgitation; myocardial work; speckle-tracking echocardiography; TEER

1. Introduction

Myxomatous mitral valve disease (MMVD) is a known and prevalent cause of mitral regurgitation (MR) in dogs and an important cause of morbidity and mortality in small animal cardiology [1–3]. Gradual degeneration of the valve leads to chronic volume overload, enlargement of the left atrium, and finally, congestive heart failure [4–6]. While medication itself is the cornerstone of management, it does not directly resolve the structural defects in the mitral valve. In the field of veterinary medicine, Transcatheter edge-to-edge repair (TEER), a less invasive method for mitral valve repair than open-heart surgery, has recently been developed. TEER is applied to the mitral valve leaflets to decrease regurgitant flow and avoid the need for cardiopulmonary bypass [7–10].

The TEER procedure has the trade-off of decreasing the effective mitral valve orifice area and increasing transmitral pressure gradients. Optimizing these conflicting effects will be key to the success of the procedure [11–13]. In addition to conventional echocardiographic parameters, myocardial work analysis based on strain echocardiography has been identified as a new tool for evaluating cardiac function [14–18]. Unlike conventional indices, myocardial work combines myocardial deformation and afterload, offering a more complete indication of ventricular function in conditions such as MR, in which there are changes in the work loading. The relative extent of MR reduction to changes in myocardial work in dogs receiving TEER is poorly defined. Moreover, the clinical relevance of post-procedural transmitral gradients has been limitedly established in veterinary practice, particularly in those with residual MR. The knowledge gained from examining the interaction of these processes may enhance patient selection, intervention planning, and outcome prediction.

The objective of this study was to determine whether reductions in MR and myocardial work indices after TEER in dogs with MMVD were associated with hemodynamic and functional consequences of residual MR and post-procedural transmitral gradients.

2. Materials and Methods

2.1. Study Design and Ethical Approval

This study represents a prospective observational study involving client-owned dogs diagnosed with myxomatous mitral valve disease (MMVD) and moderate-to-severe mitral regurgitation (MR). Dogs were recruited from Kasetsart University Veterinary Teaching Hospital, Kamphaeng Saen campus, cardiology service. Inclusion criteria included (1) echocardiographic evidence of MMVD, with at least moderate MR; (2) body weight and anterior-posterior mitral valve leaflet diameter (AP) access compatible with TEER intervention; and (3) clinical signs and risk for TEER procedure. Dogs with AP diameter less than 12 millimeters, severe systolic dysfunction unrelated to volume overload, or clinically relevant mitral stenosis were excluded. The general characteristics of dogs in this study are presented in Table 1. All procedures were performed with the owners' informed consent. The study protocol was approved in accordance with the Kasetsart University animal care and use committee (ACKU68-VET-086).

Table 1. Baseline characteristics of the study population (n = 10 dogs).

Variable	Value
Number of dogs	10
Breed distribution: Pomeranian (n = 3), Beagle (n = 2), Maltese (n = 2), Shih Tzu (n = 1), Poodle (n=1), Chihuahua (n = 1)	Small breeds (n = 8), Middle breed (n = 2)
Age (years)	10.7 ± 2.32
Sex:	Male (n = 5), Female (n = 5)
Body weight (kg)	8.1 ± 5.16
ACVIM stage	B2 (n = 3), C (n = 6), D (n = 1)
Heart rate (beats/min)	128 ± 18
LA/Ao ratio	1.9 ± 0.3
LVIDd (normalized)	1.85 ± 0.25
Baseline MR severity	Moderate (n = 3), Severe (n = 7)

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Medication	Number of dogs (%)
Pimobendan	10 (100%)
Furosemide	8 (80%)
Spironolactone	8 (80%)
ACE inhibitors	3 (30%)
Sildenafil	4 (40%)

2.2. Pre-Procedural Assessment

All dogs underwent a standardized physical examination, thoracic radiography, electrocardiography, and full transthoracic (TTE) and transesophageal (TEE) echocardiography prior to intervention, as previously described [19,20]. Echocardiographic studies were performed using an ultrasound system with phased-array transducers. The left atrial-to-aortic root ratio (LA/Ao), left ventricular internal dimensions in diastole and systole (LVIDd, LVIDs), fractional shortening, and Doppler assessment of MR severity were measured. MR severity was determined semi-quantitatively by color Doppler jet area and other supportive indices, e.g., vena contracta width and regurgitation volume. The transmitral pressure gradients at baseline were determined by continuous-wave Doppler. Dogs with evidence of elevated baseline gradients suggestive of functional mitral stenosis were excluded from the study.

2.3. Transcatheter Edge-to-Edge Repair

All procedures were performed under general anesthesia with constant hemodynamic and electrocardiographic monitoring. A transapical puncture was performed to access the left atrium with transesophageal echocardiographic guidance after an introducer sheath was placed. A delivery system was deployed into the left atrium, and the mitral valve was visualized by TEE, as in a previous study [21,22]. Device orientation and positioning were optimized to best fit with the regurgitant jet. The grasp of the leaflets was performed by moving the delivery system across the mitral valve into the left ventricle and subsequently retraction of the clip from both anterior and posterior mitral leaflets.

The appropriate leaflet insertion and reduction of MR were confirmed in real time by TEE imaging. Procedural success was defined as successful implantation of the device with a reduced MR severity of at least one grade (≥ 1) with no major intraoperative complications. Patients were monitored after treatments for hemodynamic stability and arrhythmias during post-procedure recovery. Post-procedural echocardiography was performed 24-48 hours after the procedure, with a focus on assessing MR severity, transmitral gradients, and device placement. Conducted follow-up evaluations at every month intervals, which comprised clinical assessment and echocardiographic inspection. Based on the clinical status, the attending clinician decided to adjust the medical therapy.

2.4. Echocardiographic and Hemodynamic Analysis

The examinations were performed using a Vivid E95 ultrasound system (GE Healthcare, Norway) equipped with a 4-6 MHz phased-array transducer and 9VT-D, 3D TEE. Standard echocardiographic findings were performed as previously described in published veterinary practice guidelines [23,24]. MR severity was re-assessed after the procedure, following its course, in the same way as at baseline, to maintain comparability. Transmitral pressure gradients were determined with continuous-wave Doppler from the apical view, and the mean gradients were computed using multiple cardiac cycles. Concentrated on detecting high gradients that can signal functional mitral stenosis after TEER.

2.5. Severity Assessment of Mitral Regurgitation

The severity of mitral regurgitation was determined using semi-quantitative echocardiographic scores optimized for canine cases, adapted from a previous study [25]. Assessment was performed

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using transthoracic echocardiography with simultaneous two-dimensional and color Doppler imaging. All examinations were performed by an experienced veterinary cardiologist with standardized imaging planes. The MR grading system included two echocardiographic variables: (1) vena contracta (VC) width and (2) mitral valve regurgitant volume (MRV). Measurements were performed on optimized left apical views during systole for at least 3 consecutive cardiac cycles, and the average value was used for analysis. The vena contracta was defined as the narrowest part of the regurgitant jet immediately distal to the mitral valve orifice. VC width was measured in millimeters using color Doppler zoom imaging with Nyquist limits adjusted to minimize aliasing artifacts.

Mitral regurgitant volume was calculated by Doppler-derived volumetric assessment and presented in milliliters per beat. Quantification is performed using standard echocardiographic methodology, with forward stroke volume and total left ventricular stroke volume calculated. The scores for each parameter were given different ranges from 1 to 10 (Table 2). Total MR severity was classified using the combined score from VC width and mitral regurgitant volume. MR severity categories were defined as follows: mild MR (total score <6), moderate MR (total score 6 to <12), and severe MR (total score ≥12). This scoring system was applied before and after TEER to evaluate procedural effectiveness and residual MR severity.

Table 2. Mitral regurgitation severity scoring system.

Parameter	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6	Score 7	Score 8	Score 9	Score 10
VC (mm)	<1	1- <2	2- <3	3- <4	4- <5	5- <6	6- <7	7- <8	8- <10	≥10
MRV (mL/beat)	<1	1- <2	2- <3	3- <4	4- <5	5- <6	6- <8	8- <10	10-<12	≥12

2.6. Myocardial Work Analysis

Myocardial work indices were calculated using two-dimensional speckle-tracking echocardiography with vendor-specific software, as previously described [26]. Standard apical views (four-chamber, two-chamber, and long-axis) were acquired at high frame rates (usually >60 frames per second) and retained for offline analysis. Global longitudinal strain (GLS) was calculated as the total myocardial strain during the entire cardiac cycle. Non-invasive left ventricular pressure curves were estimated by combining non-invasive systolic blood pressure measurements with the timing of valvular events obtained through echocardiography-based time frames. Pressure-strain loops were built per cardiac cycle, which allowed estimation of myocardial work parameters, including: GWI: the total myocardial work during systole, GCW: work contributing to LV ejection, GWW: ineffective work that contributes to no forward displacement, GWE: ratio of constructive work to total work. All measurements were taken on 3 or more consecutive cardiac cycles. Analyses were executed by an observer blind to clinical responses.

2.7. Outcome Measurement

The main outcome of interest was the association between a decrease in MR severity and the change in myocardial work indices post-TEER. Concomitant secondary outcomes were alterations in cardiac dimensions, transmitral pressure gradients, and short-term clinical status. Dogs were further stratified by MR and post-procedural transmitral gradients to determine their associations with myocardial work and clinical response (Table 3).

Table 3. Echocardiographic and myocardial work parameters before and after transcatheter edge-to-edge repair (TEER) in dogs with MMVD (n = 10).

Parameter	Pre-TEER	Immediate Post-TEER	p-value
Mitral regurgitation severity score	12.2 ± 4.4	7.1 ± 3.8	<0.0005

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Vena contracta (mm)	5.9 ± 1.5	3.8 ± 1.6	<0.0001
Mitral regurgitant volume (mL/beat)	8.4 ± 6.4	3.3 ± 4.1	0.0058
LA/Ao ratio	2.2 ± 0.6	1.9 ± 0.3	0.012
LVIDdN	1.9 ± 0.3	1.76 ± 0.3	0.039
Fractional shortening (%)	34.7 ± 8.6	33.3 ± 11.9	0.5855
Transmitral gradient (mmHg)	3.03 ± 0.65	1.01 ± 0.48	<0.005
Global longitudinal strain (%)	−22.1 ± 4.8	−27.8 ± 2.9	0.005
Global work index (mmHg%)	921.7 ± 168	1149.3 ± 174	0.0847
Global constructive work (mmHg%)	2238 ± 560	2311 ± 314	0.1955
Global wasted work (mmHg%)	338.3 ± 188	179 ± 64.7	<0.05
Global work efficiency (%)	84.9 ± 3.6	92.7 ± 2.6	<0.05

*LA/Ao = left atrial-to-aortic root ratio; LVIDdN = normalized left ventricular internal diameter in diastole; LVIDsN = normalized left ventricular internal diameter in systole; GLS = global longitudinal strain.

2.8. Statistical Analysis

The continuous variables were examined for normality using the Shapiro–Wilk test. Data are shown as mean ± standard deviation. Pre- and post-procedural values were compared by paired t-test. Correlation coefficients were calculated between MR reduction and myocardial work parameters using Pearson or Spearman. Group comparisons were made using independent t-tests or, where appropriate, Mann-Whitney U tests. A p-value < 0.05 was considered statistically significant. Statistical analyses were conducted using commercially available software.

2.9. Use of Artificial Intelligence (AI) Tools

During preparation of the manuscript, the authors used the artificial intelligence–based language model ChatGPT to assist with language editing, grammatical revision, sentence restructuring, and reference formatting. The AI tool was used only to improve the readability and organization of the manuscript text and was not involved in study design, data acquisition, echocardiographic analysis, statistical analysis, interpretation of results, or generation of scientific conclusions. All AI-assisted outputs were carefully reviewed, revised, and verified by the authors. The authors take full responsibility for the accuracy, integrity, and final content of the manuscript.

3. Results

3.1. Procedures and Mitral Regurgitation Amelioration

Pre- and post-TEER visualization of the mitral valve anatomy was achieved by three-dimensional echocardiography (Figure 1). Pre-procedural imaging revealed mitral valve coaptation in the form of a large central regurgitant orifice and severe mitral regurgitation (MR). Real-time 3-D guidance allowed precise adjustment and grasp of mitral valve leaflets during clip application. Insertion of the device resulted in a notable decrease in the regurgitant orifice area and improvement in leaflet coaptation. Color Doppler echocardiography demonstrated a significant reduction in MR severity immediately after TEER, and the majority of dogs showed only mild residual regurgitant flow.

In continuous-wave Doppler, the transmitral inflow shows a mild increase in transmitral pressure gradient following TEER implantation (Figure 1F-G). Prior to TEER, Doppler recording showed the typical mitral inflow due to severe mitral regurgitation and unrestricted transmitral flow (Figure 1F). After TEER, the profile of the transmitral flow with a slight increase in the diastolic inflow velocity and mean transmitral pressure gradient exhibited higher values compared to the control test data and reflected a reduction of the effective mitral valve orifice area after leaflet approximation (Figure 1G). Despite a greater transmitral gradient, no dogs had echocardiographic evidence of clinically significant mitral stenosis during the follow-up. Mean post-procedural transmitral

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gradients remained within clinically accepted limits, with no evidence of progressive pulmonary edema, severe left atrial hypertension, or clinical deterioration suggestive of increased transmitral flow resistance. Results suggest that TEER effectively decreased MR and maintained sufficient transmitral diastolic flow. The increase in transmitral pressure gradient after TEER was accompanied by a substantial decrease in mitral regurgitation severity and an improvement in measures of myocardial work indices.

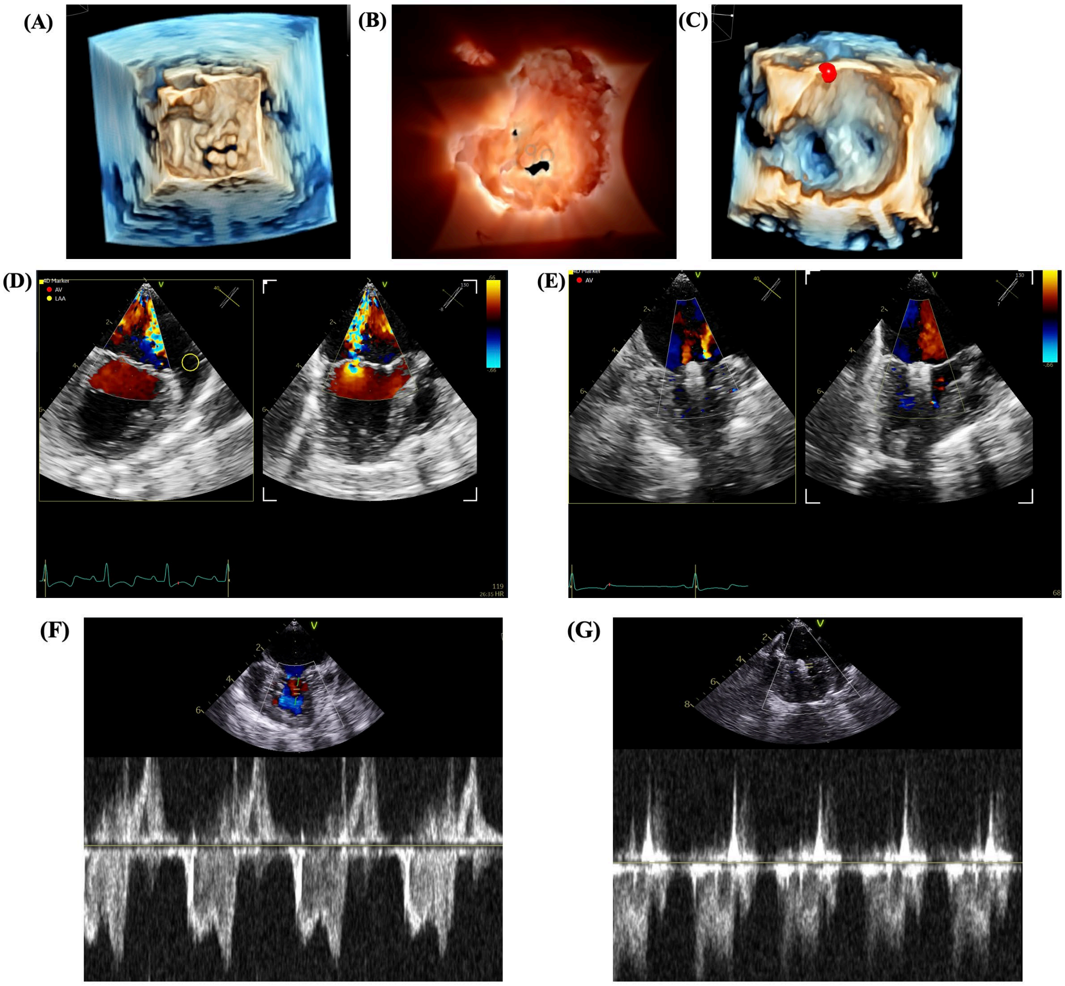

Figure 1. Three-dimensional echocardiographic and Doppler assessment before and after transcatheter edge-to-edge repair (TEER) in dogs with MMVD. (A) Three-dimensional transesophageal echocardiographic (3D-TEE) of the mitral valve before TEER demonstrating severe leaflet prolapse and incomplete coaptation. (B) Intraoperative surgical view of the mitral valve during TEER device implantation. (C) Three-dimensional echocardiographic image after TEER showing successful leaflet approximation and improved coaptation. (D) Color Doppler echocardiography before TEER demonstrates severe mitral regurgitation with a large eccentric regurgitant jet. (E) Color Doppler echocardiography immediately after TEER showed a marked reduction in regurgitant jet area. (F) Continuous-wave Doppler assessment of transmitral inflow before TEER demonstrates a low baseline transmitral pressure gradient. (G) The assessment after TEER.

TEER decreased multiple echocardiographic parameters (including MR severity) (Table 3). Mitral regurgitation severity score, vena contracta width, and regurgitant volume decreased significantly immediately after intervention and remained improved at 2-month follow-up. Significant reductions of left atrial and left ventricular dimensions were also observed at follow-up. After TEER, myocardial work analysis showed significant improvement. Global work index, global constructive work, and global work efficiency improved significantly after intervention, while global wasted work decreased. Although global longitudinal strain became less negative after TEER,

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myocardial work indices still indicated improved mechanical efficiency in the ventricles following reduction in chronic volume overload. Transmitral pressure gradients were elevated slightly after clip implantation but remained within the clinically acceptable range in the majority of dogs.

3.2. Changes in Myocardial Strain and Myocardial Work Following TEER

Figure 2 represents myocardial strain and myocardial work analyses. Prior to TEER (Figure 2A), dogs with severe MR exhibited impaired myocardial work performance, with reduced global work index (GWI) and global work efficiency (GWE), even though global longitudinal strain (GLS) was preserved or accentuated. Heterogeneous regional work distribution of the myocardial region by pressure–strain loop analysis, with areas of inefficient contraction of the myocardium, especially in the puncture site on the apical area. After TEER (Figure 2B), myocardial work parameters demonstrated significant improvement. GWI was elevated (383 mmHg% prior to intervention to 927 mmHg% immediately postprocedure), and GWE improved from 82% to 90%. Despite a marginal decrease in absolute magnitude (-32% to -29%) observed in the GLS, myocardial working efficiency increased, confirming that there was improvement in ventricular mechanical function after the decrease in volume overload. (Figure 2C) At a 2-month follow-up assessment, myocardial work parameters improved relative to baseline. GWI rose to 1003 mmHg%, whilst GWE remained unchanged at 89%. At -20%, this reduction in GLS signifies the normalization of loading parameters following a successful MR reduction rather than deterioration of systolic function. We observed a significant flattening of the regional myocardial work distribution at follow-up, suggesting improved ventricular mechanical coordination after TEER.

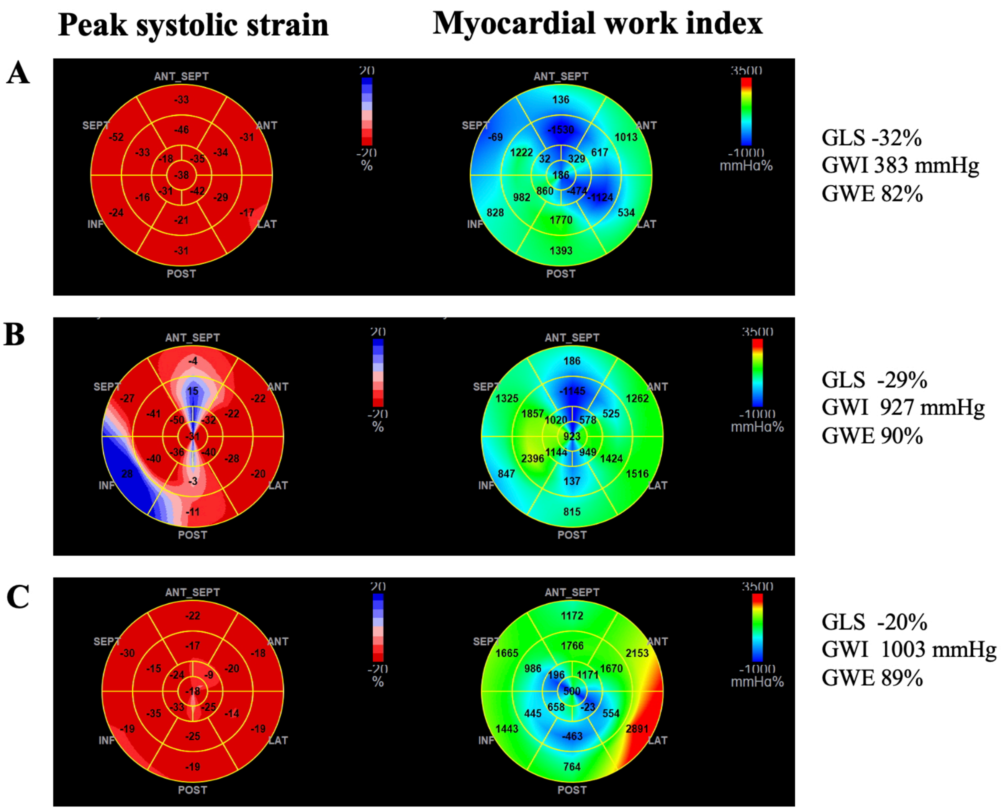

Figure 2. Left ventricular strain and myocardial work after TEER in dogs with MMVD. The bull's-eye maps of peak systolic strain and myocardial work index before and after TEER. (A) Pre-TEER examination of global longitudinal strain (GLS), global work index (GWI), and global work efficiency (GWE). (B) Immediate post-TEER examination. And (C) two-month follow-up examination.

3.3. Correlation Analysis

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Figure 3 shows correlation analysis with MR reduction, echocardiographic remodeling variables, and myocardial work indices. GLS was positively associated with GWE, with a correlation of (r = 0.81), implying that myocardial deformation had an effect on ventricular work efficiency following TEER. Moderate positive correlations (r = 0.53) were observed between GWI and GWE, suggesting that better myocardial work performance was accompanied by improvements in ventricular efficiency. Weak correlations between MR reduction and myocardial work indices such as the GWI (r = -0.04) and GWE (r = -0.33) were also found. The left atrial size (LA/Ao) and normalized left ventricular internal diameter in diastole (LVIDdN) had weak-to-moderate opposite correlations with the two indices of GWI and GWE. Therefore, they may represent functional ventricular adaptation beyond typical structural remodeling indices after TEER in myocardial work parameters. Results of myocardial work analysis suggested substantial improvement of ventricular performance after clinical success after MR reduction, and would be useful when evaluating functional recovery after TEER in dogs.

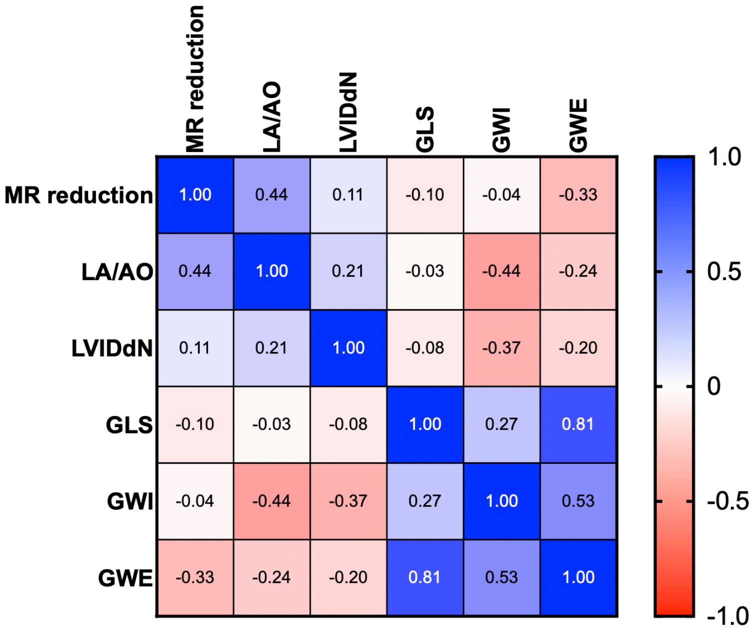

Figure 3. Correlation matrix between mitral regurgitation reduction, echocardiographic remodeling, and myocardial work indices after TEER. Heatmap demonstrating correlation coefficients among mitral regurgitation (MR) reduction, left atrial-to-aortic ratio (LA/Ao), normalized left ventricular internal diameter in diastole (LVIDdN), global longitudinal strain (GLS), global work index (GWI), and global work efficiency (GWE). Positive correlations are represented by blue coloration and negative correlations by red coloration.

4. Discussion

This study aims to evaluate the effect of myocardial work following transcatheter edge-to-edge repair (TEER) in dogs with MMVD and significant MR. The major finding was that TEER decreased MR severity in the majority of dogs and improved the global work index (GWI) and global work efficiency (GWE). These observations indicate that an analysis of myocardial work might be useful in informing ventricular function following mitral valve procedures in veterinary populations. Reduction of MR by TEER is the primary therapeutic goal because chronic regurgitation leads to progressive volume overload of the left atrium and left ventricle [27,28].

In the current study, three-dimensional echocardiography provided fine detail of valve morphology and improved device positioning during leaflet grasping. Procedural imaging after the procedure showed improved leaflet coaptation and decreased regurgitant flow, consistent with the expected hemodynamic effect of the operation. Other similar observations have been established in both human and veterinary interventional cardiology, where residual MR severity following TEER

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is consistently linked to clinical outcome [9,21,28]. The improvement in myocardial work parameters, including those measured by global longitudinal strain (GLS), is notable. Prior to TEER, some dogs showed significantly low GLS values and myocardial work efficiency. In chronic MR, increased preload might exaggerate myocardial deformation, leading to an apparent preservation or supranormal strain despite inefficient ventricular work. Pre-TEER GLS values became less negative, but GWI and GWE increased. This pattern is more consistent with modified loading following a decrease in regurgitant volume than with impaired systolic performance. Myocardial work assessment combines strain with afterload, which is therefore more likely to offer accurate representations of real ventricular mechanics in MR-treated dogs. Pressure-strain loop analysis showed even more homogeneous regional myocardial work distribution post-intervention.

Some myocardial sections showed less constructive work and more wasted work before TEER, indicating mechanical inefficiency due to chronic volume overload. The improvement in regional work distribution after MR reduction can reflect partial normalization of the ventricular contraction pattern. While myocardial work analysis has been evaluated more frequently in human cardiology, its availability in veterinary medicine is limited. The current results are consistent with its potential use as an adjunct assessment of functional status in dogs undergoing mitral valve treatment. Correlation analysis revealed a close positive relationship between GLS and GWE and a moderate correlation between GWI and GWE. Direct correlations between MR reduction and myocardial work were weak. This may be the consequence of the multiple processes underlying ventricular adaptation after TEER, including myocardial remodeling, loading conditions, heart rate, and intrinsic myocardial function, all of which contribute to postoperative cardiac outcomes.

A secondary clinical significance of TEER also lies in its potential in predicting prognostic risk and circulating cardiac biomarkers in dogs with MMVD. Long-term MR has a role in continuous cardiac remodeling, increased neurohormonal activation, progressive heart failure, and prognosis with worsening heart failure state [29–31]. We did not further quantify biomarkers in this study; however, if MR severity decreased and myocardial work indices improved after TEER, hemodynamic adaptation would be a significant predictor of prognosis. Previous studies showed that cardiac enlargement variables (LA/Ao ratio, LV size) and pulmonary hypertension were associated with the disease prognosis in animals with MMVD and survival [32]. Reduction in MR severity and stabilization of transmitral gradients by this study may result in attenuation of persistent volume overload and ventricular remodelling. N-terminal pro-B-type natriuretic peptide (NT-proBNP), among the existing biomarkers, has been extensively employed in dogs with MMVD in the assessment of myocardial wall stress and disease severity [33]. Elevated NT-proBNP levels have been linked to congestive heart failure and pulmonary hypertension and reduced survival from disease in dogs with MMVD [32,33]. After the successful TEER, decreased regurgitant volume and left atrial pressure, as previously described, might theoretically reduce myocardial stretch and reduce the circulating NT-proBNP levels. The results suggest that following mitral valve repair of mitral valve dysfunction in MR patients, the results are similar to decreased concentrations of natriuretic peptides [34]. Enhanced myocardial work efficiency seen following TEER could potentially alleviate chronic myocardial stress and oxygen demand and decrease the chances of persistent injury to the myocardium after TEER.

Nevertheless, the association of TEER with further longitudinal change in cTnI concentrations in veterinary medicine is unknown and is still under investigation. Myocardial work indices analyzed in the current study may indicate a prognostic effect. Moreover, improvements in GWI and GWE following TEER might reflect enhanced ventricular mechanics and increased myocardial energy utilization. In human cardiology, alterations in myocardial work parameters have been correlated with adverse cardiovascular outcomes and impairments in recovery following valvular therapy. Thus, myocardial work analysis could be a promising non-invasive tool to assess dogs with chronic ventricular dysfunction and a success-aided procedure. However, this study provides preliminary clinical insight into myocardial functional adaptation following TEER in dogs with MMVD and may serve as a basis for future interventional research in veterinary cardiology.

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The results of this study confirm that, with a sufficient selection of cases and protocols, it is possible to achieve successful MR reduction while maintaining satisfactory transmitral flow. However, the long-term influence of increasing gradients in dogs after TEER remains to be determined. The number of dogs was small and needed long-term follow-up. Hemodynamic evaluation was performed mostly on an echocardiographic basis without invasive pressure measurements. Furthermore, myocardial work analysis adapted in this study is based on the same methods developed in human cardiology, which have not been validated in dogs. In addition, the variations among breeds and anesthesia-associated effects may further affect myocardial work measurements. Moreover, further studies on optimal transmitral gradients, residual MR thresholds, and procedural methods may help to enhance the survival and outcomes for the TEER procedure in dogs.

The limitations in this study include a small sample size, which likely reduced statistical power and the ability to detect associations. It was noted that 10 dogs underwent TEER in the initial assessment, whereas only 6 dogs completed the echocardiographic and myocardial work after follow-up evaluations. Four dogs died during the follow-up period, which greatly decreased the sample size for serial assessment and may have affected the statistical power of the study. Therefore, the relationships among MR reduction, myocardial work indices, and cardiac remodeling should be interpreted with caution.

Survivor bias was also likely due to the mortality of four dogs in follow-up. Dogs that made it to the follow-up probably included those with either better hemodynamic adaptation. However, dogs with more advanced disease progression or postoperative problems may have been underrepresented in subsequent investigations. The Predictors of survival or adverse outcome were therefore limited in the present study. Long-term follow-up studies should be performed as a major design to ascertain the prognosis for improvement of myocardial work changes and postprocedural hemodynamics in dogs undergoing a TEER intervention.

The progression of mitral valve disease and chronic ventricular remodeling can persist for months to years after treatment, and the long-term viability of TEER in dogs can be unknown. Moreover, myocardial work analysis performed in this study was an adaptation of human cardiology software and is not yet fully standardized or validated across dog breeds and body size. Different loading requirements, heart rate, anesthesia, and image quality could have influenced strain and myocardial work parameters.

Although there are several limitations in the current study, this study provides preliminary evidence of a working myocardial response to TEER in myocardial function in veterinary patients. Further study should focus on longer follow-up periods, larger sample sizes, and relationships with survival, quality of life, or progression of heart failure.

5. Conclusions

Transcatheter edge-to-edge repair significantly reduced mitral regurgitation in MMVD-treated dogs and improved myocardial work indices during the intervention. Global longitudinal strain decreased after TEER, whereas global work index and myocardial work efficiency improved, indicating that volume overload correction improved ventricular mechanics. Three-dimensional echocardiography complemented analysis with 3D myocardial work data for procedural assessment and postoperative evaluation. The results affirm the feasibility of TEER in dogs. The treatment of the mitral valve and myocardial work analysis may serve a supplementary role in monitoring cardiac functional recovery after mitral valve intervention.

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Informed Consent Statement: Written informed consent was obtained from all owners involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

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

Abbreviations

The following abbreviations are used in this manuscript:

MMVD	Myxomatous Mitral Valve deneration
MRV	Mitral valve regurgitant volume
GLS	Global longitudinal strain
GWI	Total myocardial work index during systole
GCW	Myocardial work contributing to LV ejection
GWW	Myocardial ineffective work that contributes to no forward displacement
GWE	Ratio of constructive work to total work
TEER	Transcatheter edge-to-edge repair
VC	vena contracta

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