Chordae Tendineae Repair Techniques: A Literature Review

Dayakshin Arumugam[1], Brandon Li[2]
1. Emerald High School, Dublin, CA, 2. Harvard Medical School, Boston, MA
**Corresponding Author Email: dayakshin.arumugam@gmail.com*

Abstract

Advancements in cardiac surgery have significantly transformed the management of mitral valve (MV) disease, with chordae tendineae repair techniques emerging as crucial for restoring heart function and preventing heart failure. Among these, the neochord procedure has gained increasing popularity as a primary repair approach. Many studies longitudinally followed patients who received neochord procedures to see their overall, long-term outcomes. Across countless sources, neochord generally demonstrated positive outcomes, some results including 98.2 ± 1.8% five-year survival and 97.2 ± 2.8% freedom from grade 1+ regurgitation in one series, as well as 4.2% reoperation with death and after 20 years 14.1% in a long-term cohort had moderate-to-severe mitral regurgitation (Chiappini et al., 2006; David et al., 2020). Pediatric studies also showed durable outcomes, with a 90.4% freedom from reoperation at 10 years (Oda et al., 2013). In general, these studies found long-term outcomes to be positive, including low rates of disease recurrence and reoperation. Studies continue to demonstrate that the neochord procedure is effective at mitigating MV regurgitation while also improving overall heart function. Complications have been found to be rare for this procedure. These findings position the neochord procedure as a safe, effective, and increasingly preferred surgical option for appropriately selected patients. While current evidence strongly supports the safety and efficacy of the neochord procedure, future research should focus on large-scale, randomized controlled trials comparing neochord to other minimally invasive and conventional mitral valve repair techniques. Additionally, further studies are needed to evaluate the long-term durability of neochord implants beyond the current follow-up periods, explore patient selection criteria, and optimize procedural techniques to enhance outcomes.

Introduction

Progress in cardiac surgery has transformed the treatment of mitral valve (MV) disease, with chordae tendinae repair techniques playing a vital role in restoring heart function and preventing heart failure. Neochord is a primary repair technique that has grown in popularity. As a minimally invasive procedure, it replaces damaged chordae tendinae in MV repair. Techniques like neochord help prevent MV regurgitation (MR). MR occurs when the MV, between the left atrium and ventricle, does not close tightly. In this case, improper sealing can cause blood to flow back into the atrium, causing the heart to work harder. MR is caused by myocardial infarction, rheumatic heart disease, and MV prolapse. With its growing popularity for patients with severe MV disease, it is important to understand the overall outcomes, risks, and benefits of the neochord procedure. In this review, we investigate the current literature pertaining to the outcomes of the neochord procedure, as well as other similar valve repair surgical techniques that may have advantages and/or disadvantages compared to the neochord procedure.

Additionally, long-term outcomes show why neochord has been growing popular as a chordae tendinae repair method. In a large cohort study of 746 patients undergoing chordal replacement with expanded polytetrafluoroethylene sutures, reoperation with death only occurred in 4.2% of the patients at 20 years, although moderate-to-severe MR still developed in 14.1%, adding nuance to the durability of this rising method. Similarly, Chiappini et al. (2006) reported a 98.2 ± 1.8% survival at 5 years, and 97.2 ± 2.8% freedom from grade mild regurgitation after surgery, and in a long-term study on pediatric patients, Oda et al. (2013) reported a 90.4% freedom from reoperation at 10 years. These results show that Neochord is significant because it preserves valve shape, but it is heavily shown to be durable in the case of controlling regurgitation long-term in many patient populations.

Materials and Methods

This study consists of a systematic review that addresses the question: *In patients with mitral valve regurgitation, how do clinical outcomes, complication rates, and long-term stability of the neochord procedure compare to other conventional mitral valve repair techniques?* An encompassing search of existing systematic reviews and randomized control trials (RCT) involving databases such as PubMed was conducted. Data from the randomized controlled trials were selected including the study's design plan, participant demographics, outcomes, and reasoning for findings. Using all of the results of the trials and the information gathered, this literature search allowed for a comprehensive outlook on the advantages and disadvantages of neochord.

Search strategies

To identify studies on NeoChord, Harpoon, chordae transposition, and MitralStitch, I conducted a structured search of search engines like PubMed and Google Scholar and the reference lists of related articles. The search terms I used included "NeoChord," "mitral valve," "mitral regurgitation," "Harpoon," "chordae transposition," and "MitralStitch." The literature used includes human clinical, pediatric, and animal studies. case reports and computational research, which had contributed to surgical outcomes, repair mechanics, fit, and complications. Studies also included at least one related outcome, like survival, MR grade, reoperation, hemodynamic performance, force distribution, and complications in surgery. Editorials, duplicate reports, studies without related outcome data, and articles not associated with mitral chodae repair were not included in the review.

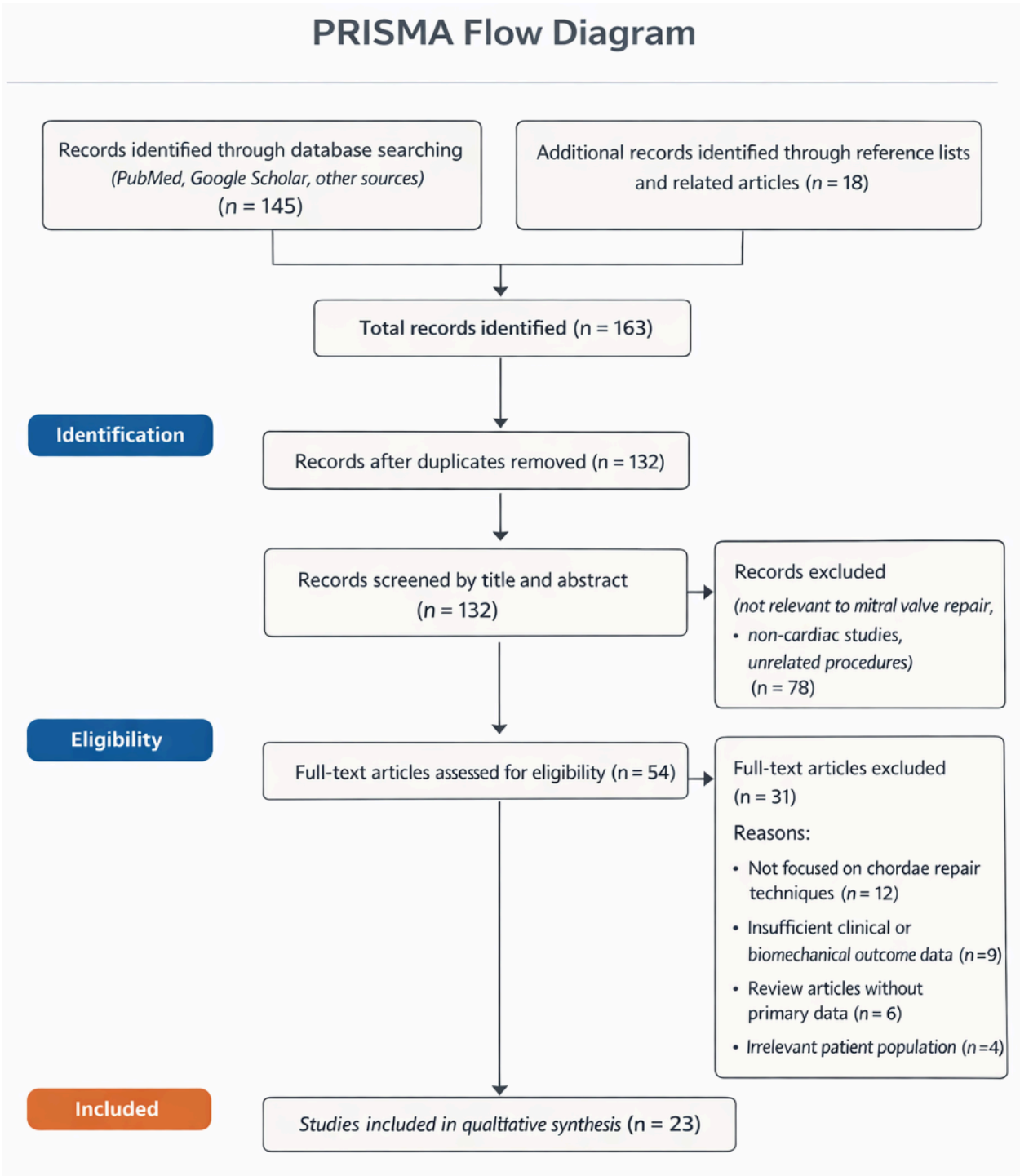

Figure 1. PRISMA flow diagram illustrating the study selection process for the literature review

Discussion

Neochord

Outcomes

Chordae tendinae help maintain one-way flow in the heart and can be damaged by stresses like myocardial infarction. Neochord is a chordae tendinae repair technique that prevents MR. Several studies investigating a variety of outcome measures after the neochord procedure suggest it is a safe and effective procedure. Many studies longitudinally followed patients who received neochord procedures to see their overall, long-term outcomes. In general, these studies found long-term outcomes to be positive, including low rates of disease recurrence and reoperation. In a 2020 observational study with 746 patients, the rate of reoperation with death was 4.2% at 20 years. Moderate to severe MR occurrence was 14.1% after 20 years. (David et al., 2020) Another study involving 29 patients found that patients classified as New York Heart Association (NYHA) functional class 3 or 4 before the neochord procedure ended up in classes 1-2, 23.7 ± 12.8 months after the surgery. (Cimen et al., 2006) Another study involving 111 patients found the five-year success rate of the neochord procedure, defined by survival, was 98.2 ± 1.8%, and freedom from grade 1+ regurgitation rate was 97.2 ± 2.8%. (Chiappini et al., 2006) These studies demonstrate that the neochord procedure effectively accomplishes high rates of success, low rates of reoperation, and effective management of MR. More long-term research outcomes looking at mortality and morbidity would help to better characterize the ultimate impact of neochord procedures on patient-centered outcomes.

Few studies also looked at other surrogate outcomes after neochord surgery. One observational study investigated the hemodynamic profile at rest and at peak exercise of 24 patients who had undergone neochord surgery by measuring pressure gradients in the heart via echocardiography. This study found that patients had good hemodynamic profiles and also good exercise capacity. (Ragnarsson et al., 2017) Another observational study with 66 patients assessed the outcomes of patients after neochord surgery by measuring left ventricular geometry and found that the LV end-diastolic volume had a 14% reduction, showing improved cardiac efficiency and a decrease in volume overload. (Colli et al., 2018) Other studies also measured and found reduced chordae tension after neochord, indicating a positive outcome. In one of these studies involving seven patients, chordae tendinae tensions were measured with transesophageal echocardiography (TEE) before and after neochord. Before neochord, chordae tendinae tensions ranged from 0.7-0.9N and decreased on average by 12% after neochord. (Grinberg et al., 2019) Another study measuring these chordae tendinae tensions, but in sheep hearts, found that the neochord procedures could reduce tension on the chordae to the baseline value of 0.21 ± 0.14 N for those sheep. (Zhu et al., 2024) Overall, these measurements show that neochords reduce overall tension in the valve and the chordae, allowing for better efficiency and durability in the procedure and for long-term outcomes. These studies continue to demonstrate that the neochord procedure is effective at mitigating MV regurgitation while also improving overall heart function.

Complications of Neochord

Gathered altogether, reported complications show that harmful events after Neochord repair can not be explained by a single mechanism. Some complications arise more often due to the

difficulty of procedures and when surgeons are learning new techniques. For example, leaflet-free edge tear and loss of neochord tension during the implantation likely stem from challenges in the surgery itself from the correct positioning of the Neochord device and the adjusting of chord tension, meaning that with improved positional planning, surgical experience, and better technique can decrease the likelihood of these issues over time (D'Onofrio et al., 2022; Di Micco et al., 2022). On the other hand, some complications reflect issues caused by a less-than-ideal repair geometry or incorrect patient selection. Recurrent MR caused by postoperative valve remodeling shows that a difficult structure may be less durable after nonresectional artificial chordal repair, while severe hemolytic anemia and renal failure caused by a regurgitant jet striking the annuloplasty ring display the physical risks associated with abnormal flow dynamics after surgery (Moore et al., 2020; Li & Duan, 2021). Therefore, current research shows many explanations for complications: lack of experience and difficult procedures, valves, and leaflets.

Animal studies

Many promising results have been seen not only in humans but in animals and computational models as well. These tests can prove that neochord can balance stress and improve overall valve function. A 2019 intervention study used porcine MVs in a 3D-printed heart simulator to test out polyvinyl alcohol nanofiber (PVAN) neochords, which are known to prevent MR caused by a posterior leaflet prolapse. This study found that PVAN neochords allowed the forces on the chordae tendineae to return to baseline levels, suggesting that PVAN neochords are effective, minimally invasive, and put less stress on chordae tendinae. (Paulsen et al., 2020) A different study used 8 porcine MVs to evaluate the importance of leaflet preservation in different surgical strategies to fix MV prolapse for chordal rupture. Neochordoplasty led to a significant decrease in regurgitant volumes, as well as returned coaptation length to baseline levels. (Padala et al., 2009) Also, a recent 2024 study used sheep hearts to evaluate different MV repair techniques, including neochord, non-sectional leaflet remodeling, and triangular resection. Among these methods, neochord procedures have done the best at reducing peak chordal forces, bringing them closer to baseline values. (Zhu et al., 2024) In summary, the evidence of successful neochord procedures is reinforced in the animal studies we present, and future studies should take advantage of studying novel techniques and methods in animal hearts to find ways to improve MV surgical management in humans.

Pediatrics

Studies suggest the neochord procedure is effective for pediatric patients, with favorable outcomes in short and long-term settings. An observational study following 21 children to evaluate the outcomes of pediatric atrioventricular valve repair with artificial chordae found that there was no deaths or valve restrictions, the only complications to be moderate tricuspid insufficiency and moderate mitral insufficiency experienced by 2 patients each at the last follow-up which was around 28 ± 18 months, two patients had to go under reoperation(for mitral ring dehiscence recurring MV insufficiency). (Boon et al., 2007) Another observational study with 78 pediatric patients examined the long-term results of neochord MV repair with ePTFE. Of the 78, there was one in-hospital death due to left ventricular dysfunction, severe aortic regurgitation, and moderate MR, and three experienced moderate regurgitation. Despite this, there was an overall high rate of freedom of reoperation, which was 90.4% at 10 years.

Additionally, echocardiography confirmed good heart and valve function at the 1-15 year mark. (Oda et al., 2013) A different observational study followed 15 infants to find the long-term effects of MV repair, focusing on durability with ePTFE sutures in infants with severe MR. There were no operative or hospital deaths, and there was a 10-year survival rate of 89%. (Murashita et al., 2012) Overall, the short-term and long-term outcomes of severe MR repair in infants with the neochord procedure are satisfactory. The procedure is also durable and safe, and the elevated risk of long-term adverse effects is low.

Harpoon

Another technique that has not been widely used but may gain popularity in the future is the Harpoon technique, which is similar to neochord with the exception that it is placed with automated, catheter-based deployment. Studies have shown that Harpoon is a reasonable option for minimally invasive techniques, offering specific advantages. Neochord, using a posterior access site, had lower leaflet stress and improved coaptation during systole, which made it effective for Barlow's disease, a form of MV prolapse that requires precise and durable support to properly close valves during systole. On the other hand, the Harpoon technique utilizes anterior access, which allows it to perform better in some cases, but studies found greater variability in chordae tension forces, making it unstable. Moreover, anterior access methods increase the risk of suture-leaflet contact, so incision sites must be precise. (Di Micco et al., 2022) Another observational study was conducted to assess the effectiveness of the Harpoon system for minimally invasive MV repair in patients with severe MR secondary to posterior leaflet prolapse. Similar to neochord, the Harpoon method helps avoid cardiopulmonary bypass and cardioplegia. Even though the stabilization of the device was hard due to the extensive leaflet flail, the result was successful as it yielded MV competence after attaching the implanted chordae. (Gerosa et al., 2018) Overall, Harpoon has the potential for minimally invasive techniques for MV repairs, but specific care in the variability in tension and stabilization will be needed in order to ensure positive outcomes.

Chordae Transposition

Overall, studies have shown that chordae transposition, a strategy that takes chordae from places of less need to greater need, can have some promising results and be an effective strategy. The procedure of chordae transposition is used to include isolated mitral insufficiency, mitral stenosis, tricuspid valve repair, and ruptures in MV chordae transposition. In an interventional study featured, 29 patients, 21 with isolated mitral insufficiency and 8 with both mitral insufficiency and stenosis. Before the surgery, 12 patients were in the NYHA Functional Class II, 16 were in Class III, and one child was in Class IV. After the surgery, a follow-up showed that 24 out of 26 patients were in Class I, which shows improvement. Additionally, 17 patients had no heart murmurs, 5 had mild, and 4 had moderate murmurs. However, two in-hospital deaths occurred due to severe arrhythmia and respiratory failure. (Lessana et al., 1988) A case report for a 48-year-old male reports that one month after the procedure, echocardiography showed only mild tricuspid regurgitation with no transvalvular gradient, cardiomegaly improved, with a reduced cardiothoracic ratio of 55%; and after a year, the patient remained well with a strong valve. (Takamatsu et al., 2018) Finally, an interventional study that used computational modeling found that after the repair, the stress was reduced from 0.61 MPa to 0.37 MPa, showing ideal results, and leaflet coaptation was restored (with a coaptation length of 6.37 mm). Additionally,

the anterior leaflet coaptation angle decreased to 4.0° post-repair(8.8° is normal), while the posterior leaflet angle increased to 43.3°(31.5° is normal), which helped improve leaflet coaptation and valve function and could restore normal geometry. Stabilizing the posterior leaflet more than the anterior leaflet can help maintain coaptation and support chordae tendinae. Even though the angles differ from normal leaflet angles, they are still acceptable as they restore normal MV function and redistribute stress. (Jeong et al., 2023)Overall, these studies show that chordae transposition is a good repair strategy; it is durable, and it can also avoid some cases of valve replacement entirely.

MitralStitch

The novel method known as MitralStitch could have probable benefits in the future in regards to safety. MitralStitch is a method like neochord, but it uses sutures rather than artificial chords. In these procedures, MitralStitch was used to fix MR. Also, testing safety, effectiveness, and outcomes. A 2022 case report with 10 participants found that one year after the procedure, the results were mixed, with 4 out of 10 patients having some MR. (Saccocci & Colli, 2022) A case report in the same year using 10 patients found that after Mitralstitch, 5 patients had little to no MR, and 5 patients had mild MR; after a 1-month follow-up, all patients were safe, and an efficacy endpoint was completed. (Wang et al., 2022) Another case report involving just 1 patient showed that after the surgery was complete, a TEE showed that the 78-year-old man had no MR, the MV had neocoaptation length, and positioning was good. (Wang et al., 2018) Overall, the surgery had mixed short-term results and was easily reproducible, but further studies should test more long-term effects, efficiency, and refinement could be needed for better outcomes and in order to allow it to be used widely.

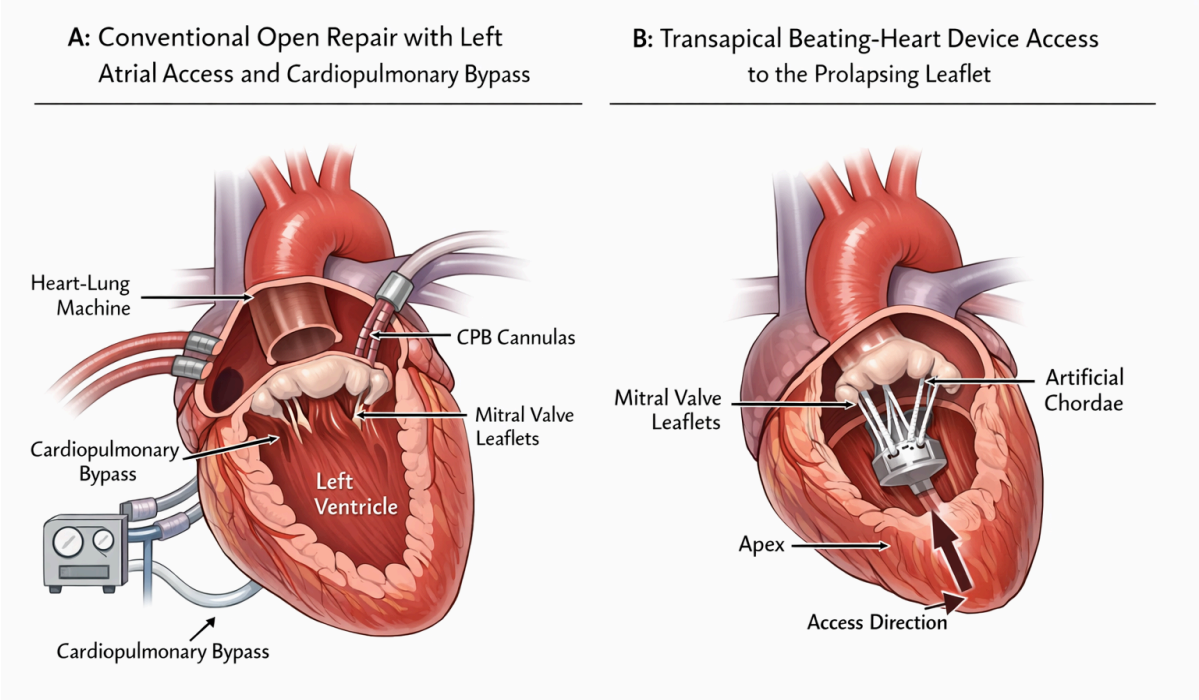

Figure 2. Comparison of conventional open mitral valve repair and transapical beating-heart neochordal repair.

Comparative Synthesis

Viewed together, these studies suggest that the key distinction among chordal repair strategies is not simply the device used, but the interaction between access geometry, target leaflet pathology, and procedural reproducibility. NeoChord, which has been associated with posterior access and favorable leaflet stress distribution, appears particularly suited to anatomies requiring stable coaptation and controlled force transfer, whereas Harpoon's anterior access may expand technical reach but has been associated with greater variability in chordal tension and a higher risk of suture-leaflet contact, making access-site precision especially important (Di Micco et al., 2022). Chordae transposition remains a valuable strategy when native tissue can be repurposed during conventional repair, but it is less directly comparable to off-pump beating-heart systems because it reflects a fundamentally different operative setting and philosophy of repair (Lessana et al., 1988; Jeong et al., 2023). MitralStitch appears promising as an early device-based alternative, but the currently reviewed evidence is limited to small early feasibility experiences with mixed short-term MR outcomes, so it should still be regarded as investigational rather than equivalent to more established approaches (Wang et al., 2018; Wang et al., 2022; Saccocci & Colli, 2022). Overall, the literature suggests that procedural success depends heavily on matching valve anatomy and repair geometry to the strengths of each technique rather than assuming that one minimally invasive system is universally superior.

Technique	Access / procedural approach	Cardiopulmonary bypass	Main strengths	Main limitations	Representative outcomes from reviewed studies

NeoChord	Transapical, beating-heart, device-assisted neochord implantation; posterior-access biomechanics favored in modeling studies	Avoids bypass/cardioplegia in transapical off-pump use	Minimally invasive; good long-term durability; improved coaptation and force redistribution	Residual MR, remodeling-related recurrence, leaflet tear, access-related technical sensitivity	98.2 ± 1.8% 5-year survival; 97.2 ± 2.8% freedom from grade 1+ MR; 4.2% reoperation with death at 20 years; 14.1% moderate-to-severe MR at 20 years (Chiappini et al., 2006; David et al., 2020)
Harpoon	Transapical beating-heart repair with anterior access/device deployment	Avoids bypass/cardioplegia	Minimally invasive; promising early feasibility	Greater tension variability; higher risk of suture-leaflet contact; technically sensitive stabilization	Early successful MV competence reported, but limited comparative durability data in current review (Gerosa et al., 2018; Di Micco et al., 2022)
Chordae transposition	Conventional surgical transfer of native chordae	Usually part of conventional/open repair	Uses native tissue; can restore coaptation and reduce stress	Less directly comparable to off-pump device-based approaches; older evidence base	Functional improvement and acceptable durability reported; 24/26 patients improved to NYHA class I in one study (Lessana et al., 1988;

					Jeong et al., 2023)
MitralStitch	Early transapical beating-heart device-based repair system	Avoids bypass in reported early transapical cases	Reproducible device concept; minimally invasive potential	Very limited evidence base; mixed short-term MR outcomes; investigational	Mixed early results: residual MR in some patients, small feasibility cohorts only (Wang et al., 2018; Wang et al., 2022; Saccocci & Colli, 2022)

Table 1. Comparison of repair strategies

Limitations of the Review

This review has several limitations. First, the evidence is from many different types of studies, combining long-term observational studies, case reports, pediatric series, animal studies, and computational models, which limits fair comparison among techniques. Second, many of the newer tools, such as Harpoon and MitralStitch, lack long-term evidence, with much of the current literature reporting small sample sizes and short follow-ups. Third, the studies' measures of success were not standardized, with some focusing on survival and reoperation rate, while others focused on MR grade, thermodynamics, and biomechanical force profiles. Finally, due to most available evidence being nonrandomized and using only one method, this review cannot prove the superiority of one repair technique over another; instead, it should be viewed as a synthesis of patterns and trends in efficacy, candidacy, and complications.

Future Trends

The next major trend in the field will likely move away from using the same techniques on different people, but more patient-specific and image-guided. Recent modeling and translational studies have shown that access sites have a major influence on outcomes like leaflet stress, coaptation, and chordal force distribution, suggesting that procedures in the future will be made to shape the patients' valve anatomy and prolapse pattern (Di Micco et al., 2022; Paulsen et al., 2020). Therefore, the long-term trend of this field will likely focus on specific patient selection, optimization of access sites, and refining devices with comparative studies to test durability and patient candidacy.

Conclusion

In this review, we investigated the current literature on the outcomes of the neochord procedure and also looked at complications, alternative surgical methods, the evidence in animal studies, and use in pediatric populations. The neochord is safe and effective in both adult and pediatric populations; it will continue to be a first-line surgical management option for patients with the

appropriate indications. In the future, more research can focus on optimizing neochord strategies, developing further patient-specific usages, and studying further long-term outcomes to advance neochord and patient care.

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