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Narrative Review

Thrombosis of Mechanical Heart Valves: Current Evidence and Practical Considerations for Management

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Abstract

Introduction: Mechanical valve thrombosis (MVT) is a life-threatening complication of prosthetic heart valve implantation and remains a major cause of morbidity and mortality despite advances in prosthetic valve design and anticoagulation therapy. This review aims to summarize the current evidence on the pathophysiology, risk factors, clinical presentation, diagnosis, and contemporary management of MVT.

Methods: A structured narrative review of the literature was conducted using PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar. Relevant clinical practice guidelines, systematic reviews, randomized controlled trials, observational studies, and landmark publications addressing mechanical heart valve thrombosis were critically reviewed and synthesized.

Results: The available evidence indicates that thrombus formation is a multifactorial process involving prosthetic valve characteristics, altered hemodynamics, coagulation activation, and patient-related factors. Inadequate anticoagulation remains the most important modifiable risk factor for MVT. Contemporary multimodality imaging, including transthoracic echocardiography, transesophageal echocardiography, fluoroscopy, and cardiac computed tomography, has substantially improved diagnostic accuracy and facilitates differentiation between thrombus and pannus. Current treatment strategies include optimization of anticoagulation, thrombolytic therapy, or surgical intervention, depending on the patient's clinical condition, thrombus characteristics, and prosthetic valve function.

Conclusion: Mechanical heart valves continue to provide excellent long-term durability; however, valve thrombosis remains a significant clinical challenge. Early diagnosis, individualized anticoagulation management, and appropriate application of multimodality imaging are essential for improving clinical outcomes. Future prospective studies are warranted to optimize preventive strategies and establish evidence-based management algorithms for patients with mechanical valve thrombosis.

Keywords: Mechanical Heart Valve, Prosthetic Valve Thrombosis, Mechanical Valve Thrombosis, Anticoagulation, Echocardiography

Introduction

Cardiovascular diseases (CVDs) remain one of the leading causes of morbidity and mortality worldwide and represent a major public health challenge.[1-3] Among these disorders, heart valve diseases constitute a significant proportion of cardiovascular conditions requiring surgical intervention.[1] The global demand for heart valve replacement is expected to increase substantially, rising from approximately 290,000 procedures in 2003 to more than 850,000 annually by 2050.[1,3]

Valve thrombosis is a serious complication that may occur following prosthetic heart valve implantation, particularly in patients with mechanical heart valves, although it can also occur in surgically implanted or transcatheter bioprosthetic valves.[4]

Prosthetic valve thrombosis is associated with considerable morbidity and mortality and requires prompt diagnosis and appropriate management. According to Virchow's triad, thrombus formation results from the interaction of three major factors: blood stasis, endothelial injury, and hypercoagulability. Patients with hypercoagulable conditions, including pregnancy and antiphospholipid syndrome (e.g., lupus anticoagulant or anticardiolipin antibody positivity), are at particularly high risk of prosthetic valve thrombosis.[5] Appropriate anticoagulation therapy substantially reduces this risk; however, anticoagulant treatment is also associated with bleeding complications,

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and the balance between thromboembolic prevention and bleeding risk varies according to the anatomical position of the prosthetic valve. For example, anticoagulation-related hemorrhage is more common in patients with mechanical aortic valves, whereas thromboembolic events occur more frequently in those with mechanical mitral valves. Prosthetic valve thrombosis is particularly concerning in patients with tricuspid valve prostheses.[6] Therefore, it is required to manage and personalize the anticoagulation therapy based on different events in various patient.

Heart valve replacement remains the definitive treatment for many patients with advanced valvular heart disease, particularly those with severe aortic valve disease.[7] The incidence of valve-related complications varies according to the anatomical location of the prosthetic valve. Among the four cardiac valves, mechanical prostheses implanted in the tricuspid position are associated with the highest risk of thrombosis, whereas prostheses in the aortic position generally have the lowest risk of valve-related events.[6] In order to achieve the greatest outcomes in patients with valve replacement, it is suggested to apply an individualized management courses. Altogether, to provide the best patient follow-up strategy, the following key points should be taken into consideration: 1) antithrombotic prophylaxis and/or anti-platelet therapy in patients with mechanical valve prostheses require;[8,9] 2) chronic oral anticoagulation therapy in patients with aortic and mitral valve prostheses during the first 7 years of life;[10,11] 3) similar trend of thromboembolism (TE) in long lasting biological valves than mechanical;[10,11] 4) modern mechanical valves are associated;[11] 5)atrial fibrillation caused TE and anticoagulant related hemorrhage.

Materials and Methods

Study Design

This manuscript was conducted as a structured narrative review to summarize the current evidence regarding mechanical heart valve thrombosis (MVT), including its pathophysiology, risk factors, clinical presentation, diagnostic approaches, and contemporary management strategies. Although a systematic review methodology was not employed, the literature search and study selection were performed using a predefined and transparent approach to ensure comprehensive coverage of the available evidence.

Literature Search Strategy

A comprehensive literature search was performed using PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar to identify relevant publications. The search included articles published from January 2000 to March 2026, while landmark studies published before 2000 were included when considered essential for historical context or current clinical practice.

The following keywords and Medical Subject Headings (MeSH) were used individually and in combination using Boolean operators (AND/OR): mechanical heart valve, prosthetic valve thrombosis, mechanical valve thrombosis, prosthetic heart valve, anticoagulation, thrombolytic therapy, echocardiography, transesophageal echocardiography, cardiac computed tomography, fluoroscopy, pannus, and prosthetic valve dysfunction.

Eligibility Criteria

Eligible studies included clinical practice guidelines, systematic reviews, narrative reviews, randomized controlled trials, prospective and retrospective cohort studies, observational studies, registry-based investigations, and relevant case series involving adult patients with mechanical prosthetic heart valves.

Studies focusing exclusively on biological prosthetic valves, transcatheter valves, pediatric populations, experimental animal studies, conference abstracts without full-text availability, editorials, and non-English publications were excluded unless they provided essential background information directly relevant to the topic.

Data Synthesis

The retrieved literature was critically reviewed and synthesized according to five predefined themes: (1) mechanisms of thrombosis formation, (2) prosthetic valve characteristics and thrombogenicity, (3) clinical presentation, (4) diagnostic imaging and differentiation of thrombus from pannus, and (5) current therapeutic strategies and long-term management recommendations. Priority was given to the most recent international guidelines and high-quality evidence whenever available.

Mechanism of Thrombosis Formation

Prosthetic heart valves are inherently thrombogenic because their artificial surfaces activate the coagulation cascade and promote platelet adhesion and aggregation. It has been well established that the biomaterials used

in mechanical heart valves can activate the intrinsic coagulation pathway through factor XII activation, leading to thrombus formation.[4,12] Platelet deposition is a common complication that occurs on the valves after implantation within the first 24 hours. Platelet activation and thrombosis quickly promote due to the similarity between the mechanical prosthetic valves and blood flow patterns.[4,13] Lack of prosthetic material endothelialisation leads to thromboembolism in the first 3 months after implantation.[4,12] An increase in valve gradients and a reduction in valve area cause obstructive valve thrombosis via haemodynamic compromise.[14]

A number of cell types could be applied in heart valve construction including endothelial cells (EC), valve interstitial cells (VIC), fibroblasts, smooth muscle cells (SMC) and nerve cells, which some of them can create a non-thrombogenic surface layer and may help thrombosis prevention.[15]

Type of Heart Valves

Heart valves are composed of three layers: 1) ventricularis, 2) fibrosa, and 3) spongiosa.[16] Heart valves are divided into 4 types: aortic, pulmonary, mitraland tricuspid.[1] Valvuloplasty (native valves of patient) is the preferred conventional surgery which is applied in the case of mitral and tricuspid valve replacement of middle-age patients. In the cases of substantial regurgitation or endocarditis, the most surgical option is tricuspid and pulmonary valve replacement which are rare in older patients.[7] The replacement of four types of heart valves with prostheses has been reported in clinical cases.[7] Heart valve prostheses which is applied in patients divided into two basic groups of mechanical and biological prostheses. The main construction of mechanical prostheses is composed of pyrolytic carbon combined with metallic andpolymeric components. The major cause of risks such as thrombus formation, thromboembolic complications, and endocarditis in patients with heart valves is associated with surface of foreign materials of valves itself.[1]

Types of Mechanical Valves

Caged-ball valves, tilting-disk valves and bileaflet valves have been considered as three major types of mechanical valves. Patients who receive newer valves such as tilting-disk or bileaflet valves have lower risk of thrombosis compared with caged-ball valves.[13,17] The caged ball was the first artificial heart valve implanted in 1952.[18]

Biological versus Mechanical Heart Valves

Although the primary focus of this review is mechanical heart valve thrombosis, a brief comparison between mechanical and biological prosthetic valves is important because prosthesis selection directly influences the risk of thrombotic complications and long-term management. Mechanical valves provide excellent structural durability but require lifelong anticoagulation because of their higher thrombogenic potential. In contrast, biological valves generally exhibit lower thrombogenicity and usually do not require lifelong anticoagulation; however, they are associated with limited durability and an increased risk of structural valve degeneration over time. Therefore, understanding the advantages and limitations of each prosthesis type is essential for appropriate patient selection and individualized treatment planning.[19,20,22]

Clinical Presentation of Patients with Valve Thrombosis

The clinical presentation of mechanical valve thrombosis (MVT) is highly variable and depends on the location of the prosthetic valve, the size and mobility of the thrombus, the degree of valve obstruction, and the occurrence of systemic embolization. Clinical manifestations may range from asymptomatic incidental findings to life-threatening cardiogenic shock.

Patients with obstructive MVT typically present with progressive dyspnea, reduced exercise tolerance, orthopnea, pulmonary edema, or acute heart failure resulting from impaired prosthetic valve function. In severe cases, hypotension, cardiogenic shock, or sudden cardiac death may occur.

In contrast, non-obstructive MVT may remain clinically silent or present with systemic thrombo-embolic events, including ischemic stroke, transient ischemic attack, or peripheral arterial embolism. Some patients present only with inadequate anticoagulation or an incidental increase in transprosthetic pressure gradients detected during routine echocardiographic follow-up.

Clinical manifestations also differ according to prosthetic valve position. Mechanical mitral valve

thrombosis most commonly presents with pulmonary congestion and heart failure symptoms, whereas mechanical aortic valve thrombosis is more frequently associated with reduced cardiac output, syncope, or cardiogenic shock. Thrombosis of right-sided mechanical valves, particularly in the tricuspid position, may present with systemic venous congestion, hepatomegaly, peripheral edema, and elevated jugular venous pressure.

On physical examination, diminished or absent prosthetic valve closing sounds, a newly developed cardiac murmur, signs of heart failure, or evidence of systemic embolization should raise suspicion for prosthetic valve thrombosis. Because delayed diagnosis is associated with poor clinical outcomes, patients presenting with these findings require prompt multimodality imaging and appropriate therapeutic intervention.[19-22]

Differential Diagnosis of Pannus, Thrombus or Mismatch

The main structure of thrombous are non-nucleated red cells packed in a platelet or fibrin matrix.[23] Fibroblastic proliferation may arise arisen during the capillary formation and collagen may be found 5–10 days later. However, organized thrombi have lower fibrinogen content than pannus.[23,24]

Capillary formation and fibroblast proliferation can lead to clot contraction due to the high concentrations of hemoglobin and iron.[19]

Findings of studies on pannus formed in the explanted valves showed that it is composed of three different layers.

- Lumen layer consisting of endothelial cells.
- Internal medial layer of spirally oriented spindle cells as myofibroblasts and chronic inflammatory cells infiltrated in the inner surface.
- External medial layer of collagen and fibrous tissue.

Factors Influencing Prosthetic Valve Selection and Thrombogenicity

The selection of a prosthetic heart valve should be individualized and based on current clinical practice guidelines rather than theoretical characteristics of an "ideal" valve. Several factors influence prosthetic valve selection, including patient age, life expectancy, bleeding risk, the ability to maintain long-term anticoagulation, comorbidities, patient preference, and the anatomical position of the valve. Mechanical valves provide excellent long-term durability but require lifelong anticoagulation because of their higher thrombogenic potential. In contrast, biological valves are associated with lower thrombogenicity and reduced anticoagulation requirements but have limited durability due to structural valve degeneration.

From a thrombosis perspective, prosthetic valve thrombogenicity is influenced by multiple factors, including valve material, leaflet design, hinge mechanism, blood flow characteristics, and the degree of endothelialization. Recent advances in valve engineering have focused on improving hemodynamic performance and reducing regions of blood stasis and platelet activation to minimize thrombus formation. Current ESC/EACTS and ACC/AHA guidelines recommend that prosthetic valve selection should be individualized through shared decision-making, balancing the risks of thrombosis, bleeding, reoperation, and patient-specific clinical characteristics.[19,20,22]

Commercial Application of Heart Valve Prostheses

Several products are available for commercial use as follows:

- Transplanted human valves such as transplanted homograft pulmonary vales (Ross procedure) with limited availability nowadays.[25]
- Most surgically implanted valves include the mechanical (50% of implanted valves in the late 1990s) and bioprosthetic valves (minor effective opening space than the mechanical valves).[26,27]
- Tissue valves are applied in the commercial world today (more than 80% of implanted valves).[28,29]
- Tilting disc valves (annular rings inclosing two pyrolytic carbon blocks) applied currently with great stability but un-physiological haemodynamics and long-lasting anticoagulation therapy.[30,31]
- Bioprosthetic valves, also called animal-derived pericardium/chemically treated animal valves or leaflets exist as stented or un-stented, similar to natural flexible leaflet valves with improved haemodynamics whitout long-lasting anticoagulation therapy but with lower durability due to calcification and degeneration.[30-32]
- What are the reasons for the application of transcatheter valves?

Regardless of some deficiencies in different valves, they have manyadvantages.

But open-heart surgery is an expensive and invasive

procedure.[33-35].Therefore, trans-catheter valves are less invasive.[36] One target of trans-catheter valves is transcatheter Aortic Valve Replacement (TAVR) or Implantation (TAVI).[35,36] Contents of most clinically appliedtrans-catheter valves is collapsible/expandable metal stents containing soft leaflets as well as surgically implantable bio-prosthetic valves.[37,38]

Valve Related Events (Vre)

The main events of valve replacement are thrombo-embolism, hemorrhage and valve thrombosis, prosthetic endocarditis, para-valvular leak, and structural failure.[39]

Strategies for Treatment of Thrombosis

It is reported that different intensities of vitamin K antagonists are a good strategy for thrombosis prevention.[40,41] Because of the high rate of mortality, especially in early pregnancy, it is essential to apply a non-invasive method of thrombosis prevention. The first-line therapy of MVT in pregnancy is lytic therapy, which has shown 85% success rate, low complication rate of 18%, and mortality rate of 5.6%.[42] Streptokinase is applied as another targeted therapy in pregnant women with mechanical prosthetic heart valve thrombosis due to higher levels of coagulation factors and reduced endogenous fibrinolytic ability.[42] Different commercial thrombolytic agents such as streptokinase, urokinase, and recombinant tissue plasminogen activator are available as typical thrombolytic agents.[42] But lytic therapy should be continuously performed even in the presence of peripheral embolism until neurological complications appear.[43] It is recommended that anticoagulation such as Coumadin during the thrombolysis therapy of pregnant people not be applied. On the other hand, heparin should be established until the therapeutic effect of Coumadin appeared.[44] Aspirin is recommended as additional therapy along with other anticoagulants.[45]

VREsincluding TE, hemorrhage and somewhat valve thrombosis are related to thenon proper administration of anti-coagulation drugs and lead to 75% of all VREs.[48] TE in patients with mechanical heart valve prostheses could be controlled by the use of warfarin as a gold standard.[47]

Diagnosis of Mechanical Valve Thrombosis

Mechanical valve thrombosis (MVT) should be suspected in any patient with a prosthetic heart valve who presents with new or worsening heart failure symptoms, thromboembolic events, unexplained dyspnea, or evidence of prosthetic valve dysfunction. Prompt diagnosis is essential because delayed treatment is associated with increased morbidity and mortality.

Initial Clinical Evaluation

The diagnostic evaluation begins with a detailed medical history and physical examination. Particular attention should be paid to anticoagulation status, medication adherence, recent International Normalized Ratio (INR) values, previous thromboembolic events, and underlying hypercoagulable conditions. On physical examination, diminished or absent prosthetic valve closing sounds, a newly developed cardiac murmur, pulmonary congestion, systemic embolic manifestations, or signs of cardiogenic shock should raise suspicion for prosthetic valve thrombosis.

Echocardiography

Transthoracic echocardiography (TTE) is the recommended first-line imaging modality for evaluating suspected MVT. It provides an assessment of transprosthetic pressure gradients, leaflet motion, ventricular function, and the hemodynamic consequences of valve obstruction. However, acoustic shadowing from prosthetic material may limit thrombus visualization.

Transesophageal echocardiography (TEE) is the preferred imaging modality for confirming the diagnosis. TEE offers superior spatial resolution, allowing an accurate assessment of thrombus size, mobility, location, and the degree of prosthetic valve obstruction. It is particularly valuable for evaluating left-sided prosthetic valves and for guiding therapeutic decision-making.

Cine-Fluoroscopy

Cine-fluoroscopy provides a rapid assessment of mechanical leaflet mobility by measuring opening and closing angles of the prosthetic valve. Although it cannot directly visualize thrombus, abnormal leaflet motion strongly supports the diagnosis of prosthetic valve obstruction and complements echocardiographic findings.

Cardiac Computed Tomography

Cardiac computed tomography (CT) has become an

important complementary imaging modality, particularly when echocardiographic findings are inconclusive. CT allows detailed visualization of prosthetic valve structures and is especially useful for differentiating thrombus from pannus, which is critical because management strategies differ substantially. Thrombus typically appears as a low-attenuation, relatively soft mass that may respond to intensified anticoagulation or thrombolytic therapy, whereas pannus usually demonstrates higher attenuation, dense fibrous tissue characteristics, and generally requires surgical intervention.

Imaging Features for Differentiating Thrombus from Pannus

Differentiating thrombus from pannus is essential because the therapeutic approach differs substantially. Prosthetic valve thrombus may respond to intensified anticoagulation or thrombolytic therapy, whereas pannus formation generally requires surgical intervention.

Transesophageal echocardiography (TEE) provides valuable information regarding the size, mobility, and attachment of the obstructive mass. Thrombi typically appear as larger, soft, mobile masses with lower echogenicity, whereas pannus usually appears as a small, dense, immobile, highly echogenic lesion originating from the sewing ring of the prosthetic valve.

Cardiac computed tomography (CT) further improves diagnostic accuracy through tissue characterization. Thrombus generally demonstrates low attenuation (<90 Hounsfield units [HU]), reflecting its soft composition, whereas pannus exhibits higher attenuation (>145 HU) because of its dense fibroconnective tissue. Lesions with attenuation values between 90 and 145 HU may represent mixed thrombus and pannus and should be interpreted together with clinical findings and other imaging modalities.

Cine-fluoroscopy complements echocardiography by demonstrating restricted leaflet motion but cannot reliably distinguish thrombus from pannus. Therefore, current guidelines recommend integrating clinical assessment with multimodality imaging, including TTE, TEE, cine-fluoroscopy, and cardiac CT, to establish the correct diagnosis and guide appropriate treatment.

Multimodality Diagnostic Approach

Current international guidelines recommend a multimodality imaging strategy for patients with suspected MVT. The initial assessment should begin with TTE, followed by TEE when diagnostic uncertainty persists. Cine-fluoroscopy and cardiac CT provide complementary information regarding leaflet motion and tissue characterization, respectively. The integration of clinical findings, anticoagulation status, and multimodality imaging significantly improves diagnostic accuracy and facilitates appropriate therapeutic decision-making.

Diagnostic Framework

A practical diagnostic approach for suspected MVT consists of the following steps:

Clinical suspicion based on symptoms, physical examination, and anticoagulation history.

Initial evaluation with transthoracic echocardiography.

Confirmation using transesophageal echocardiography when necessary.

Assessment of leaflet mobility with cine-fluoroscopy.

Cardiac CT to differentiate thrombus from pannus in equivocal cases.

Selection of treatment (optimization of anticoagulation, thrombolytic therapy, or surgery) according to imaging findings, thrombus characteristics, valve function, and patient clinical status.[19-22]

Discussion

This review focuses on mechanical heart valve thrombosis (MVT) involving prosthetic valves implanted in the aortic, mitral, and tricuspid positions. Although several previous studies have evaluated mechanical prostheses in pulmonary valve replacement (PVR), the hemodynamic environment and thrombogenic profile of the pulmonary circulation differ substantially from those of the systemic circulation. Therefore, evidence derived from PVR should be regarded as supplementary rather than directly applicable to patients with left-sided mechanical heart valves. Recent international guidelines similarly emphasize that recommendations for mechanical valve thrombosis are primarily based on studies involving aortic and mitral prosthetic valves.[19-21]

Mechanical valve thrombosis remains one of the most serious complications following prosthetic valve implantation and is associated with significant morbidity and mortality. Despite major improvements in prosthetic valve design and anticoagulation strategies,

MVT continues to occur, particularly in patients with subtherapeutic anticoagulation. Current evidence indicates that inadequate vitamin K antagonist therapy remains the most important modifiable risk factor for prosthetic valve thrombosis. Furthermore, the incidence of thrombosis is generally higher in mitral and tricuspid mechanical prostheses than in aortic prostheses because of lower transvalvular blood flow velocities and less favorable hemodynamic conditions.[19,20,22]

The available evidence consistently demonstrates that mechanical heart valves provide superior structural durability compared with biological prostheses. However, this advantage is offset by the lifelong requirement for anticoagulation therapy and the associated risk of bleeding complications. Consequently, individualized anticoagulation management, regular INR monitoring, and careful patient selection remain essential to optimize long-term outcomes.[20-22,49]

Early diagnosis is fundamental to improving clinical outcomes in patients with suspected MVT. Contemporary guidelines recommend a multimodality imaging approach beginning with transthoracic echocardiography, followed by transesophageal echocardiography, cine-fluoroscopy, and cardiac computed tomography when necessary. In particular, cardiac CT has emerged as a valuable modality for differentiating thrombus from pannus, thereby facilitating appropriate therapeutic decision-making and avoiding unnecessary surgery or thrombolysis.[20-22,51,50]

Although several earlier reports investigated the performance of mechanical valves in the pulmonary position, these studies primarily evaluated prosthetic valve durability rather than the diagnosis or management of mechanical valve thrombosis. Therefore, they provide limited evidence for contemporary management recommendations and should be interpreted within the specific context of pulmonary valve replacement rather than generalized to all mechanical prosthetic valves.[49]

Overall, current evidence indicates that successful management of mechanical valve thrombosis requires early diagnosis, individualized anticoagulation therapy, appropriate use of multimodality imaging, and close long-term follow-up. Future prospective multicenter studies using standardized diagnostic criteria and contemporary imaging protocols are needed to optimize prevention strategies, refine therapeutic decision-making, and further improve long-term outcomes in patients with mechanical prosthetic heart valves.[20-22,49]

Authors' Contributions

MA: Study design and concept, Litrature review, writing the manuscript. AA: litrature review, wrting the first draft.

Ethics Approval

The study was done according to Helsinki proncipals of law.

Conflict of Interest

The authors declare no conflicts of interest.

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