MEDICINE AND MATERIALS

Volume 4, Issue 1, 2024: 43-50 | ISSN: 2784 – 1499 & e-ISSN: 2784 – 1537

DOI: 10.36868/MEDMATER.2024.04.01.043 | www.medicineandmaterials.com |

BIOMATERIALS USED IN HEART VALVE SUBSTITUTION

Iulia Alecsandra SALCIANU[1], Ana Magdalena BRATU[1]*,
Iulian Catalin BRATU[2], Simona PARVU[1]

[1] Carol Davila University of Medicine and Pharmacy, Bucuresti, Romania
[2] Ovidius University of Constanta, Constanta, Romania

Abstract

Heart valve replacement is a common surgical procedure in treating heart conditions such as stenosis or valvular insufficiency. The use of biomaterials in the manufacture of these valves is crucial for ensuring sustainable and compatible results with the patient's body. This article examines the different types of biomaterials used in heart valve manufacturing and their impact on their performance and durability. Among the biomaterials discussed are dentures, mechanical valves, and hybrid materials. Bioprostheses, made from treated biological tissues, offer advantages such as the absence of the need for long-term anticoagulants but may have a limited lifespan. Mechanical valves, made of synthetic materials, are durable but often require long-term anticoagulants. Hybrid materials, combining biological and synthetic components, are a promising innovation, offering durable functionality and improved compatibility with the human body. Choosing the right biomaterial in heart valve replacement is crucial and should be made taking into account factors such as the patient's age, and individual preferences, to ensure the success of the procedure and improve the patient's quality of life.

Keywords*:* biomaterials, heart valves, regenerative medicine, cardiac valve regeneration.

Introduction

Heart valves are fundamental elements for the normal functioning of the heart, ensuring the correct direction of blood flow within it. Malfunctions or impairments of these valves can have serious health consequences for patients, including heart failure, heart rhythm disturbances, and even death [1-3].

Heart valve replacement is a common and effective solution for treating these problems. In this context, choosing the right biomaterial to manufacture new heart valves becomes essential for the success and sustainability of the procedure. The biomaterials used must be compatible with the human body, provide long-term strength and functionality, and minimize the risk of post-operative complications [1-3].

In this article, we aim to explore the different types of biomaterials used in heart valve substitution and analyze their relevant characteristics. We will examine bioprosthetics, mechanical valves, and hybrid materials, highlighting the advantages and limitations of each type of biomaterial in the context of cardiac surgery. In addition, we will discuss the impact of the use of these biomaterials on the performance and durability of heart valves, hoping to provide comprehensive insight into this crucial aspect of modern medical practice [2-4].

Corresponding author: anaconstm@gmail.com, dr_bratuiulian@yahoo.com

The heart valves are essential components of the human cardiovascular system, responsible for directing blood flow through the heart. The heart has four main valves: tricuspid valve, pulmonary valve, mitral valve, and aortic valve [2-4].

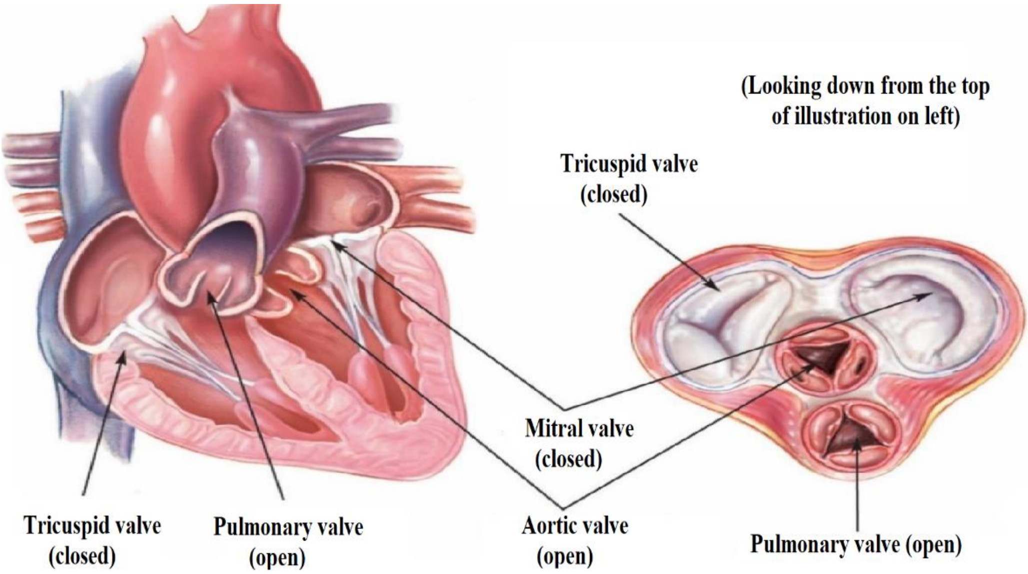

Fig. 1. A visual scheme of the heart valves. [3]

Cardiac bioprostheses

Heart bioprostheses are a way of replacing damaged or dysfunctional heart valves using biological materials. They are mainly made from biological tissues such as bovine or porcine pericardial tissue. The manufacturing process involves treating these materials to minimize immune reactions and improve their compatibility with the human body [3-6].

The advantages of using heart bioprostheses include the absence of the need for long-term anticoagulants and biomechanical functionality similar to natural valves [3-5].

Since bioprostheses are made from biological tissues, they are less susceptible to blood clots compared to mechanical valves. Therefore, patients receiving cardiac bioprostheses generally do not require long-term anticoagulants, which may reduce the risk of complications related to anticoagulant drugs [4-6].

Biodentures offer functionality similar to natural valves, which can improve blood circulation and heart function compared to mechanical valves. This is important for patients' quality of life and for avoiding bloodstream complications [4-6].

However, heart bioprostheses also present some limitations and challenges, such as limited lifespan and the need for re-surgery [4-6]

Although dentures offer advantages in terms of the absence of the need for long-term anticoagulants and biomechanical functionality similar to natural valves, they may have a limited lifespan. The biological materials used in the manufacture of bioprostheses can undergo degeneration over time, which can lead to malfunctions and the need to re-replace heart valves [6-8].

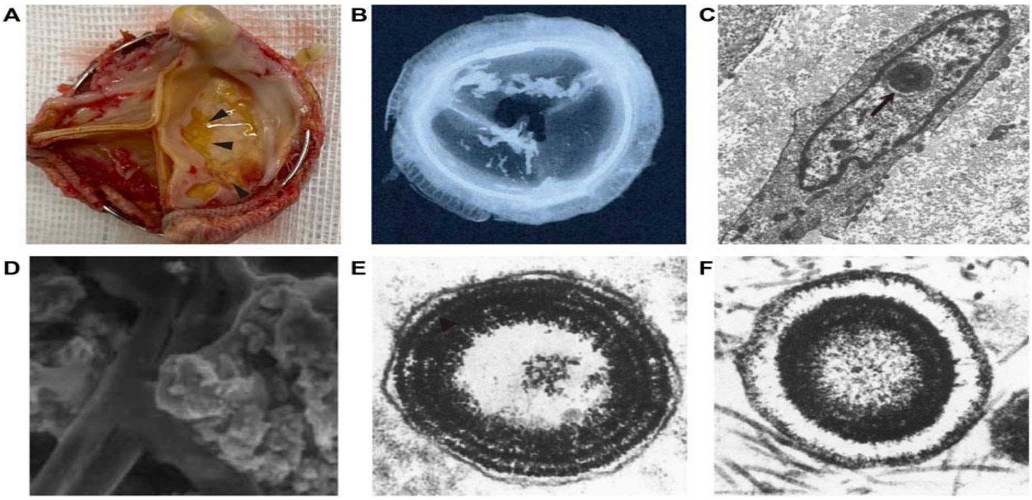

Fig. 2. A representation of calcification of a bioprosthetic heart valve. (A) Calcification of the bioprosthetic heart valve; (B) Low energy X-ray; (C) The arrow represents the ultrastructure of calcium deposits in cell nuclei; (D) A scanned electron microscopic image of calcification deposits on collagen and elastin fibers.; (E, F) Chalcospherules arranged in concentric rings, some having a central core and others without a central core [6].

Due to the degeneration of biological materials, cardiac bioprostheses may require re-surgery in the future to replace damaged or dysfunctional valves. These re-interventions may be required at variable intervals and may be associated with additional risks and costs [6-8].

Heart bioprostheses are an important option in heart valve replacement surgery, offering advantages such as no need for long-term anticoagulants and biomechanical functionality similar to natural valves. However, it is important to consider the limitations and risks associated with them, such as their limited lifespan and the potential need for re-surgery [5-8].

Mechanic Valve

Mechanical valves are devices used in heart valve substitution and are made of synthetic materials such as metal or plastic. They are designed to be durable and durable over time, providing an alternative to heart bioprosthetics [9-13].

The main characteristics of mechanical valves are durability, strength, the need for long-term anticoagulation, and longer service life [9-11].

Due to the synthetic materials used in manufacturing, mechanical valves are known for their durability and resistance to wear over time [9-11].

One of the main limitations of mechanical valves is that they pose an increased risk of blood clots forming on their surface. To prevent this, patients receiving mechanical valves must take long-term anticoagulants to thin the blood and prevent clots, thereby reducing the risk of strokes or other complications [10-13].

Compared to heart bioprosthetics, mechanical valves can have a longer lifespan, making them an appealing option for younger patients or those who want a long-term solution for heart valve replacement [10-13].

However, there are also certain negative aspects associated with mechanical valves, such as complications related to anticoagulants, and the need for additional monitoring and interventions [11-13].

Taking long-term anticoagulants may be associated with risks and complications, such as excessive bleeding or clot formation in other parts of the body [11-13].

Patients receiving mechanical valves should undergo regular monitoring and may require additional interventions to adjust doses of anticoagulants or to treat other complications associated with the use of these devices [12-14].

Mechanical valves are an important option in heart valve replacement surgery, providing durability and resistance over time. However, it is important to consider the risks and complications associated with the need for long-term anticoagulation and the need for additional monitoring and interventions. The choice between mechanical valves and heart bioprostheses should be made taking into account the individual needs and preferences of each patient [10-13].

Hybrid material

Hybrid materials are an innovation in the field of heart valve replacement surgery, being developed in an attempt to combine the advantages of bioprosthetics and mechanical valves. These materials are designed to provide durable functionality, eliminate the need for long-term anticoagulation, and improve compatibility with the human body [15-18].

The use of biological and synthetic components, durable functionality, and improved compatibility with the human body are the main characteristics of hybrid materials [15-18].

Hybrid materials are created by combining biological components, such as bovine or porcine pericardial tissues, with synthetic materials, such as metal or plastic. This combination allows us to obtain a structure that benefits from both types of materials [18-20].

By integrating biological and synthetic components, hybrid materials can provide durable functionality, similar to that of mechanical valves, but without the need for long-term anticoagulation. This can reduce the risk of complications associated with taking anticoagulants and improve patients' quality of life [16-18].

Hybrid materials are designed to be compatible with the human body and minimize immune and inflammatory reactions. They can reduce the risk of rejection and other complications associated with the use of foreign materials in heart surgery [16-18].

Although hybrid materials are a promising innovation in heart valve substitution, they can also present certain challenges and limitations, such as the manufacturing process and associated costs, which may be higher than with other types of heart valves. However, continued research and development in this area could lead to significant improvements and wider adoption of hybrid materials in clinical practice [17-19].

Hybrid materials are a promising alternative to heart valve substitution, offering advantages such as durable functionality and improved compatibility with the human body. However, further research is needed to fully evaluate the efficacy and safety of these materials in clinical practice [17-19].

Bioprosthetic valves

There are three main types of bioprosthetic valve replacements, each with specific characteristics and indications: stented bioprosthetic valves, stentless bioprosthetic valves, and percutaneous bioprosthetic valves [20-24]

Sttented bioprosthetic valves are bioprosthetic valves that are supported by a metal skeleton called a stent. The stent provides structural support and stabilizes the valves in the correct position inside the heart.

Stetented bioprosthetic valves are often used in open surgery to replace heart valves [20-22].

The advantages of these valves include stability and precise positioning but may be associated with a higher risk of thrombosis compared to bioprosthetic valves without a stent [20-22].

Stentless bioprosthetic valves are bioprosthetic valves that do not have a metal stent and are only made of biological material, such as bovine or porcine pericardial tissue. They can be surgically implanted into the heart and are fixed in place with the help of sutures [21-24].

Stent-free bioprosthetic valves may offer advantages such as a reduction in the risk of thrombosis and improved compatibility with heart structures but may be more difficult to position and stabilize compared to stented valves [21-24].

Percutaneous bioprosthetic valves are implanted into the heart through a percutaneous process, that is, without the need for open surgery, they are inserted into the body through a catheter that is guided to the heart, usually through a peripheral artery, such as the femoral artery [20-23].

This type of valve may be an option for patients who are not candidates for open surgery or who are at high risk associated with major surgery [20-23].

Although the percutaneous procedure may be less invasive than open surgery, percutaneous bioprosthetic valves may be associated with specific risks, such as valve dislocation or perforation during implantation [22-24].

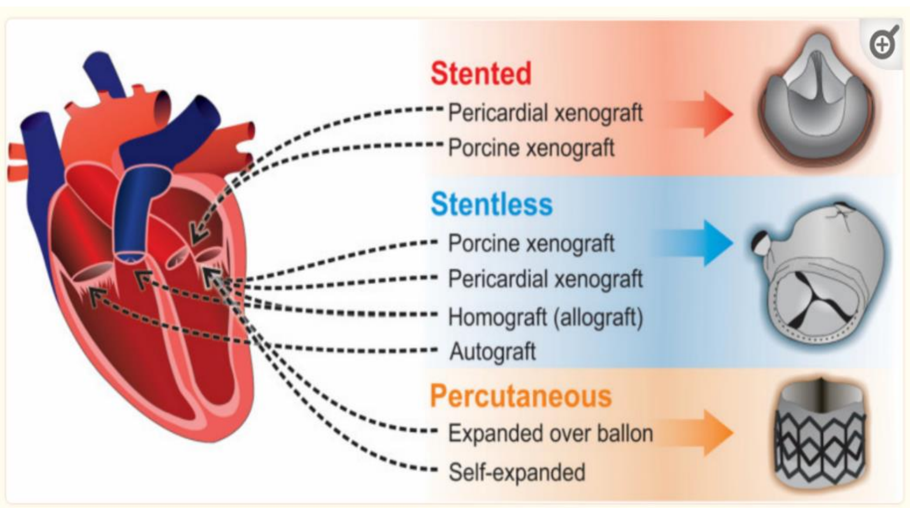

Fig. 3. Three main types of bioprosthetic valve replacements: stented bioprosthetic valves, stentless bioprosthetic valves, and percutaneous bioprosthetic valves [22].

Conclusion

Heart valve replacement is an essential procedure in the treatment of heart disease, and choosing the right biomaterial can have a significant impact on patients' outcomes and quality of life. Bioprosthetics, mechanical valves, and hybrid materials are all important options in heart valve replacement surgery, each with distinct advantages and limitations.

Heart dentures offer the absence of the need for long-term anticoagulants and a biomechanical functionality similar to natural valves, making them an attractive option for patients who want to avoid the risk of complications related to anticoagulants. However, they may have a limited lifespan and may require pre-surgery due to the degeneration of biological materials.

Mechanical valves offer a longer lifespan and resistance over time but require long-term anticoagulants to prevent blood clots. They may be an appropriate option for younger patients or those who require a long-term solution for heart valve replacement but have risks and complications associated with anticoagulation.

Hybrid materials are a promising innovation, combining the advantages of dentures and mechanical valves to provide durable functionality and improved compatibility with the human body. However, further research is needed to fully evaluate the efficacy and safety of these materials in clinical practice.

In choosing between these options, it is essential to consider factors such as the patient's age, their preferences, and the risks and benefits associated with each type of biomaterial. By carefully evaluating these factors, the most appropriate decision can be made for each patient, thus ensuring the best results and improving their quality of life.

References

1. Padala M. *Biomaterials for heart valve replacement: Conjectures and refutations*. ***J Thorac Cardiovasc Sur***g. 2016. doi 10.1016/j.jtcvs.2016.05.055.
2. Mihaljevic T, Koprivanac M, Kelava M, Smedira NG, Lytle BW, Blackstone EH. *Mitral valve replacement in patients with severely calcified mitral valve annulus: surgical technique*. ***J Thorac Cardiovasc Surg.*** 2013. doi 10.1016/j.jtcvs.2013.02.034.
3. Ciolacu DE, Nicu R, Ciolacu F. *Natural Polymers in Heart Valve Tissue Engineering: Strategies, Advances and Challenges*. ***Biomedicines***. 2022. doi: 10.3390/biomedicines10051095.
4. Bui HT, Khair N, Yeats B, Gooden S, James SP, Dasi LP. *Transcatheter Heart Valves: A Biomaterials Perspective*. ***Adv Healthc Mater***. 2021. doi: 10.1002/adhm.202100115.
5. Fioretta ES, Dijkman PE, Emmert MY, Hoerstrup SP. *The future of heart valve replacement: recent developments and translational challenges for heart valve tissue engineering*. ***J Tissue Eng Regen Med***. 2018. doi: 10.1002/term.2326.
6. Shuyu Wen,Ying Zhou,Ying Zhou,Wai Yen Yim,Shijie Wang,Li Xu, Jiawei Shi,Weihua Qiao,Nianguo Dong. *Mechanisms and Drug Therapies of Bioprosthetic Heart Valve Calcification*. ***Front. Pharmacol***. 2022. https://doi.org/10.3389/fphar.2022.909801

7. Di Franco S, Amarelli C, Montalto A, Loforte A, Musumeci F. *Biomaterials and heart recovery: cardiac repair, regeneration and healing in the MCS era: a state of the "heart".* ***J Thorac Dis***. 2018. doi: 10.21037/jtd.2018.01.85.
8. Aazami M, Schäfers HJ. *Advances in heart valve surgery*. ***J Interv Cardiol***. 2003. doi: 10.1046/j.1540-8183.2003.01053.x.
9. Sapirstein JS, Smith PK. *The "ideal" replacement heart valve*. ***Am Heart J***. 2001. doi: 10.1067/mhj.2001.114979.
10. Deverall PB, Campalani G, *Anderson DR. Heart valve replacement*. ***Arch Dis Child***. 1985. doi: 10.1136/adc.60.12.1111.
11. Ghobrial J, Aboulhosn J. *Transcatheter valve replacement in congenital heart disease: the present and the future.* ***Heart***. 2018. doi: 10.1136/heartjnl-2016-310898.
12. Huh J, Bakaeen F. *Heart valve replacement: which valve for which patient?* ***Curr Cardiol Rep.*** 2006. doi: 10.1007/s11886-006-0021-2.
13. Israel DH, Sharma SK, Fuster V. *Antithrombotic therapy in prosthetic heart valve replacement*. ***Am Heart J***. 1994. doi: 10.1016/0002-8703(94)90131-7.
14. Rabkin-Aikawa E, Mayer JE Jr, Schoen FJ. *Heart valve regeneration.* ***Adv Biochem Eng Biotechnol***. 2005. doi: 10.1007/b100003.
15. Sewell-Loftin MK, Chun YW, Khademhosseini A, Merryman WD. *EMT-inducing biomaterials for heart valve engineering: taking cues from developmental biology*. ***J Cardiovasc Transl Res***. 2011. doi: 10.1007/s12265-011-9300-4.
16. Dijkman PE, Fioretta ES, Frese L, *Pasqualini FS, Hoerstrup SP. Heart Valve Replacements with Regenerative Capacity*. ***Transfus Med Hemother***. 2016. doi: 10.1159/000448181.
17. Usprech J, Chen WL, Simmons CA. *Heart valve regeneration: the need for systems approaches*. ***Wiley Interdiscip Rev Syst Biol Med***. 2016. doi: 10.1002/wsbm.1329.
18. Schoen FJ. Morphology, *Clinicopathologic Correlations, and Mechanisms in Heart Valve Health and Disease*. ***Cardiovasc Eng Technol***. 2018. doi: 10.1007/s13239-016-0277-7.
19. Sun M, Elkhodiry M, Shi L, Xue Y, Abyaneh MH, Kossar AP, Giuglaris C, Carter SL, Li RL, Bacha E, Ferrari G, Kysar J, Myers K, Kalfa D. *A biomimetic multilayered polymeric material designed for heart valve repair and replacement*. ***Biomaterials***. 2022. doi: 10.1016/j.biomaterials.2022.121756.
20. Simmons CA, Jo H. *Editorial: Special Issue on Heart Valve Mechanobiology: New Insights into Mechanical Regulation of Valve Disease and Regeneration*. ***Cardiovasc Eng Technol***. 2018. doi: 10.1007/s13239-018-0360-3.
21. Toma M, Singh-Gryzbon S, Frankini E, Wei ZA, Yoganathan AP. *Clinical Impact of Computational Heart Valve Models*. ***Materials (Basel).*** 2022. doi: 10.3390/ma15093302.
22. Taghizadeh B, Ghavami L, Derakhshankhah H, Zangene E, Razmi M, Jaymand M, Zarrintaj P, Zarghami N, Jaafari MR, Moallem Shahri M, Moghaddasian A, Tayebi L, Izadi Z. *Biomaterials in Valvular Heart Disease*s. ***Front Bioeng Biotechnol***. 2020. doi: 10.3389/fbioe.2020.529244.
23. Velho TR, Pereira RM, Fernandes F, Guerra NC, Ferreira R, Nobre Â. *Bioprosthetic Aortic Valve Degeneration: a Review from a Basic Science Perspective*. ***Braz J Cardiovasc Surg***. 2022. doi: 10.21470/1678-9741-2020-0635.

24. Edmunds LH Jr. *Evolution of prosthetic heart valves*. ***Am Heart J***. 2001. doi: 10.1067/mhj.2001.114978.

Received: October 20, 2023
Accepted: February 15, 2024