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Three-Dimensional Printing of Cardiovascular Structures: A Literature Review

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Abstract: The human hearts limited regenerative potential, due to the absence of endogenous stem cells and terminal differentiation of cardiomyocytes, poses a challenge for conventional tissue engineering. Three-dimensional (3D) printing and bio-printing have emerged as transformative technologies in cardiovascular medicine, enabling the development of patient=specific anatomical models and bioengineered implants for therapeutic applications. This review examines over many studies, highlighting the innovations in 3D cardiovascular modelling, tissue engineering, and the integration of stem cell-derived bio-inks. High resolution imaging modalities like CT, MRI and echocardiography facilitate precise anatomical reconstruction, while bio-printing advances the fabrication of functional myocardial tissues, vascular grafts, and autologous heart valves. These developments address key limitations of conventional prosthetics, including immune rejection, poor biocompatibility, and the need for long term anticoagulation. However, challenge persist in replicating complex cardiac vascularisation and ensuring long term viability of bio printed constructs. Overall, 3D bio-printing holds substantial promise for personalised cardiovascular interventions, with ongoing advancements in cellular integrating, material science, and imaging poised to enhance its clinical translation.

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I. BACKGROUND

Due to the lack of endogenous stem cells and the terminally differentiated nature of cardiomyocytes, the human heart exhibits limited regenerative capacity, making conventional tissue engineering strategies largely ineffective, such as the use of adult cardiomyocytes or de-cellularized scaffolds. Three-dimensional (3D) printing has emerged as a transformative technology in cardiovascular medicine, enabling the creation of patient-specific anatomical models for education, pre-surgical planning, device testing, and therapeutic applications. The integration of bio-printing further advances possibilities in regenerative therapies and the development of biomimetic cardiovascular implants. This review explores current technologies and applications of 3d printing in cardiology, focusing on functional modeling, tissue engineering in implants, and incorporating living cells to address challenges associated with conventional prosthetics, such as immune rejection and durability.

II. METHODS

15+ Papers published between January 2020 and February 2025 were analyzed across databases such as Google Scholar and PubMed using Keywords such as 3D printing, bio-printing, cardiovascular implants, heart valves, and myocardial regeneration.

III. RESULTS

High-resolution imaging modalities such as CT, MRI, and echocardiography enable accurate anatomical segmentation essential for 3D modeling in cardiovascular applications. Bio-printing integrates stem cell–based bio-inks to fabricate viable myocardial tissues, heart valves, and vascular grafts, with constructs seeded with bone marrow–derived cells demonstrating enhanced biocompatibility and reduced risk of transplant rejection. In myocardial infarction and heart failure, bio-printing of contractile tissue using stem cell-derived cardiomyocytes offers promising regenerative potential for damaged myocardium. For coronary artery

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disease, 3D-printed arterial models assist in optimizing stent placement and analyzing hemodynamic parameters such as wall shear stress. Functional bio-printed aortic valve models have successfully replicated in vivo dynamics, while autologous cell-seeded valves reduce the need for long-term anticoagulation. Furthermore, 3D vascular models support pre-surgical planning and risk assessment for vascular diseases such as aneurysms or post-operative complications. These advancements demonstrate the capacity of 3D printing to personalize and enhance cardiovascular interventions across a spectrum of clinical conditions. One major limitation of 3D printing in cardiovascular applications is the challenge of replicating the complex vascularisation and mechanical properties of native cardiac tissues. Additionally, long-term viability with cells undergoing apoptosis and integrating bioprinted implants in human patients remains under active investigation.

IV. CONCLUSIONS

3D printing, particularly with stem cell technologies, offers a promising future for personalised cardiovascular interventions. Bio-printed constructs using autologous cells may eliminate the need for lifelong anticoagulation and improve implant longevity, addressing the limitations of mechanical and biological prostheses. Continued integration of cellular engineering, imaging, and advanced materials will enhance the clinical impact of 3D printing in cardiovascular care.

POTENTIAL FIGURES

- *TITLE- Bio-Printing Technique Integration and Myocardial Tissue Engineering Using Stem Cell Derived Bio Inks*

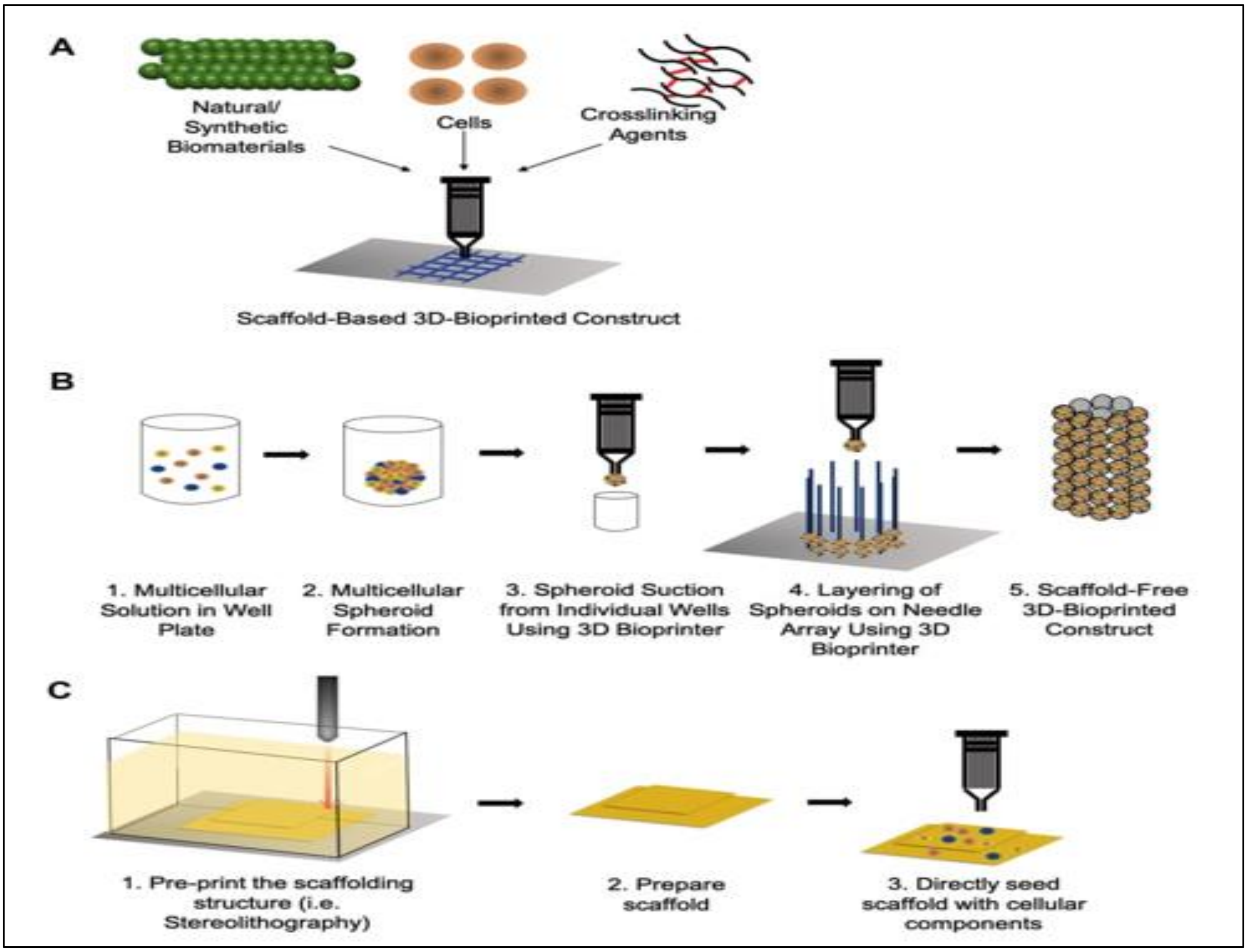

Fig 1 Bio-Printing Technique Integration and Myocardial Tissue Engineering using Stem Cell Derived Bio Inks
Reference of picture: Kevin sung, Nisha R patel, nureddin ashammakhi, Kim-lien Nguyen .3 dimensional bioprinting of cardiovascular tissues. 2021, may 24; 6(5):467-482. Doi: 10.106/j.jacbts.2020.12.006

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- *TITLE – Recent Application of 3D Printing – A AND B – AORTIC VALVE CONSTRUCTS C, D AND E – MYOCARDIAL CELL AND TISSUE*

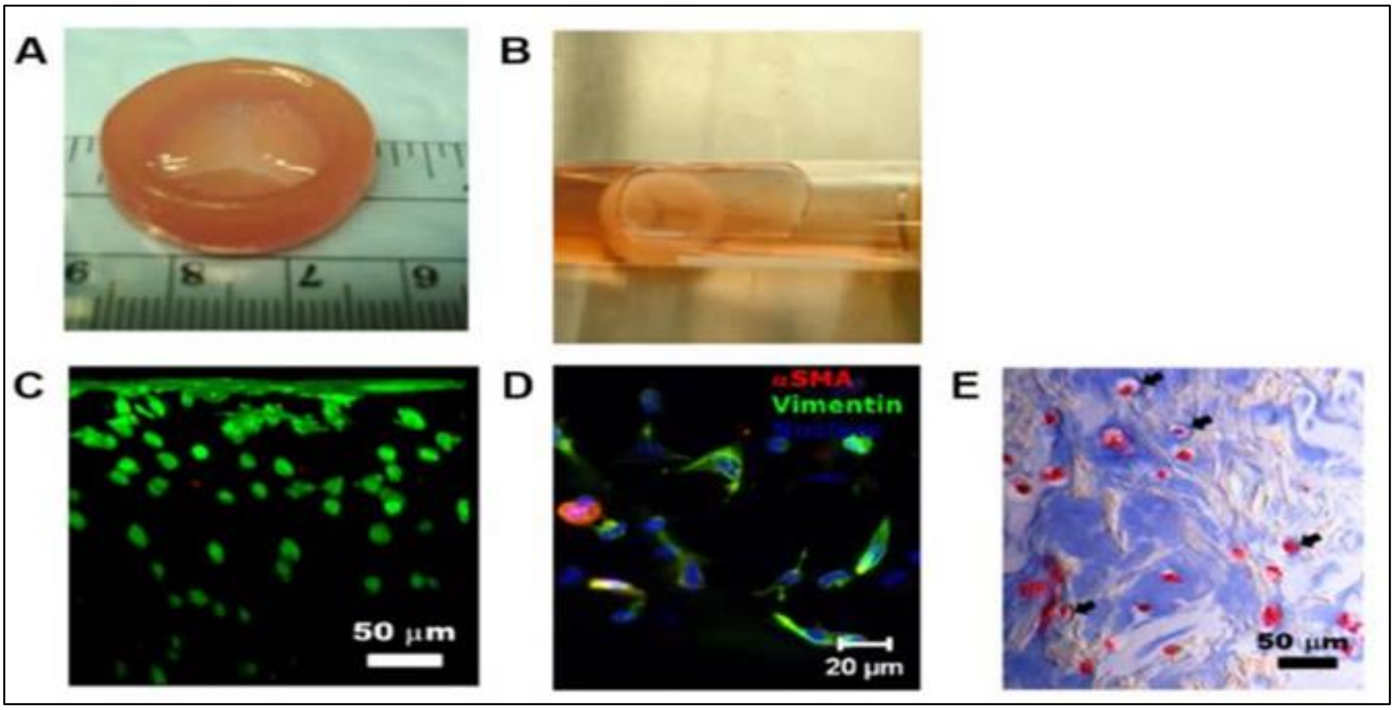

Fig 2 Recent Application of 3D Printing – A AND B – AORTIC VALVE CONSTRUCTS C, D AND E – MYOCARDIAL CELL AND TISSUE

Reference of this picture: Chiara gardin, Letizia Ferroni, Christian latremouille, Juan carlos chachques, Dinko mitrecic, Barbara zavan. Recent applications of three-dimensional printing in cardiovascular medicine, 2020, March 17 ;9(3):743. doi: 10.3390/cells9030742

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