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Metal-Organic Frameworks as Next-Generation Platforms for Cardiac Regeneration: Advancing Plasma-Enabled Biofunctionalization

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ABSTRACT

Introduction: Cardiovascular diseases remain the leading global cause of mortality, with the adult human heart exhibiting minimal regenerative capacity after myocardial infarction (MI). Metal-organic frameworks (MOFs) have emerged as highly promising multifunctional platforms in cardiac tissue engineering due to their ultra-high surface area, tunable porosity, and capabilities as scaffolds, coatings, and controlled-release carriers. This study comprehensively reviews the potential of MOFs in cardiac regeneration, with particular emphasis on their readiness for next-generation surface modification techniques.

Materials and Methods: We conducted a systematic literature review (2010–2024) across databases such as PubMed, Scopus, and Web of Science. Keywords included “metal-organic frameworks”, “MOFs”, “cardiac regeneration”, “myocardial infarction”, and “drug delivery”. The review concentrated on Zr-, Zn-, and Fe-based MOFs (UiO-66, ZIF-8, MIL-series, PCN-333), their synthesis routes, surface functionalization strategies, biocompatibility assays, and preclinical cardiac models (rodent MI, zebrafish). Special attention was given to MOF systems that can undergo post-synthesis modification, including plasma-based surface activation.

Results: MOFs demonstrated excellent cytocompatibility (>92% cardiomyocyte viability), sustained release of growth factors/miRNAs, enhanced angiogenesis, reduced fibrosis, and up to 68% infarct size reduction in rodent models. The abundant surface functional groups and thermal/chemical stability of MOFs render them ideal substrates for cold-plasma treatment, plasma polymerization, and plasma-induced grafting techniques, which have been proven to improve protein adsorption, cell adhesion, and anti-thrombogenic properties.

Conclusion: MOFs are a versatile, clinically translatable platform for cardiac repair. Their inherent structural advantages, combined with their readiness for plasma-mediated surface biofunctionalization, position them as next-generation materials capable of addressing proliferation, vascularization, and immunological barriers in post-MI regeneration.

Keywords: Cardiac regeneration, Controlled drug delivery, Myocardial infarction, Metal-organic frameworks, Plasma surface modification

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