Acta Cardiologica

ISSN: 0001-5385 (Print) 0373-7934 (Online) Journal homepage: www.tandfonline.com/journals/tacd20

Recent advances in cardiovascular medicine: from molecular mechanisms to precision care

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To cite this article: Patrizio Lancellotti & Cécile Oury (2025) Recent advances in cardiovascular medicine: from molecular mechanisms to precision care, Acta Cardiologica, 80:9, 949-953, DOI: 10.1080/00015385.2025.2579430

To link to this article: https://doi.org/10.1080/00015385.2025.2579430

Published online: 05 Nov 2025.

ACTA CARDIOLOGICA
2025, VOL. 80, NO. 9, 949–953
https://doi.org/10.1080/00015385.2025.2579430

EDITORIAL

Recent advances in cardiovascular medicine: from molecular mechanisms to precision care

Recent cardiovascular research illustrates a remarkable convergence between molecular discovery, technological innovation, and clinical translation. Investigators are redefining the understanding of vascular biology, myocardial mechanics, and systemic inflammation while integrating artificial intelligence, digital health tools, and neurostimulation into clinical practice [1–3]. These advances span the entire spectrum of cardiovascular medicine, from fundamental mechanisms of endothelial dysfunction to individualised digital models of care, offering new strategies for prevention, diagnosis, and treatment. The studies summarised below highlight emerging themes shaping the future of cardiology: precision risk assessment, early disease detection, minimally invasive monitoring, and targeted intervention.

In-stent neoatherosclerosis (ISNA) represents a major cause of late restenosis after drug-eluting stent (DES) implantation, yet its molecular mechanisms remain incompletely understood [4,5]. In endothelial cells exposed to everolimus, RNA sequencing revealed a significant upregulation of circular RNA circPTK2. Functional experiments showed that silencing circPTK2 restored cell proliferation and migration, reduced apoptosis, and improved endothelial barrier integrity, whereas its overexpression aggravated endothelial dysfunction. Mechanistic analyses demonstrated that circPTK2 acts as a molecular sponge for miR-1-5p, resulting in derepression of its downstream targets ACVR2B and StarD13. Inhibition of these targets mitigated the harmful effects of miR-1-5p suppression, confirming their involvement in the circPTK2-mediated pathway. Inflammatory stimuli further modulated the expression of circPTK2, miR-1-5p, and ACVR2B/StarD13, suggesting an interplay between inflammation and mTOR signalling. Overall, circPTK2 emerges as a key regulator of everolimus-induced endothelial injury, offering a potential therapeutic target to prevent late in-stent restenosis (Figure 1) [6].

Inflammation has emerged as a critical factor in the development of contrast-induced acute kidney injury (CI-AKI) [7]. In a retrospective analysis of 166 patients undergoing coronary angiography or intervention, indices such as neutrophil-to-lymphocyte ratio, systemic immune-inflammation index, and aggregate index of systemic inflammation (AISI) were evaluated. AISI showed the strongest predictive value for CI-AKI occurrence, demonstrating a linear relationship between increasing AISI and renal injury risk. Compared with other inflammatory indices, AISI provided superior predictive accuracy, supporting its use as a simple and cost-effective biomarker for risk stratification before coronary procedures [8].

Atherosclerosis, characterised by lipid accumulation and inflammation within the arterial wall, remains a central mechanism driving coronary artery disease and cardiovascular events [9,10]. Omega-3 fatty acid therapy continues to attract attention for its cardiovascular effects. A network meta-analysis comparing statin monotherapy with statin combined with either purified eicosapentaenoic acid (EPA) or mixed EPA/docosahexaenoic acid (DHA) demonstrated significant reductions in both total and lipid coronary plaque volumes with purified EPA. In contrast, EPA/DHA mixtures showed inconsistent effects. These results confirm that purified EPA exerts a more potent anti-atherosclerotic action, supporting its distinct biological and clinical properties compared with combined omega-3 formulations [11].

Hypertension remains one of the most prevalent and modifiable risk factors for cardiovascular morbidity and mortality worldwide, driving continuous exploration of complementary strategies beyond pharmacologic therapy [12–14]. Transcranial direct current stimulation (tDCS) has emerged as a potential nonpharmacologic intervention for hypertension. A meta-analysis of four clinical trials reported short-term improvements in blood pressure and autonomic modulation following a single tDCS session, though long-term effects after repeated sessions were limited. The most favourable responses were observed with anodic stimulation over the primary motor cortex, suggesting a role for central nervous system modulation in cardiovascular control [15].

Obstructive sleep apnoea syndrome (OSAS) is increasingly recognised as an independent cardiovascular risk factor, contributing to hypertension, arrhythmias, and structural cardiac remodelling through intermittent hypoxia and sympathetic overactivation [16,17]. In patients with OSAS, advanced echocardiographic analysis revealed subtle myocardial dysfunction despite preserved ejection fraction. Layer-specific strain measurements demonstrated reductions across endocardial, mid-myocardial, and epicardial layers, while severe OSAS was associated with increased systolic dyssynchrony. These findings indicate early, layer-dependent left ventricular impairment, emphasising the importance of timely detection to prevent progression to overt cardiomyopathy [18].

Artificial intelligence is rapidly transforming cardiovascular imaging, enabling faster, more accessible, and operator-independent assessments across clinical settings [19]. Artificial intelligence–enabled handheld ultrasound has shown high accuracy for left ventricular ejection fraction estimation at the point of care or home. In a cohort of 100 patients, the AI system achieved 91% sensitivity, 95% specificity, and 98% accuracy compared with expert hospital-based echocardiography. Serial assessments in heart failure patients

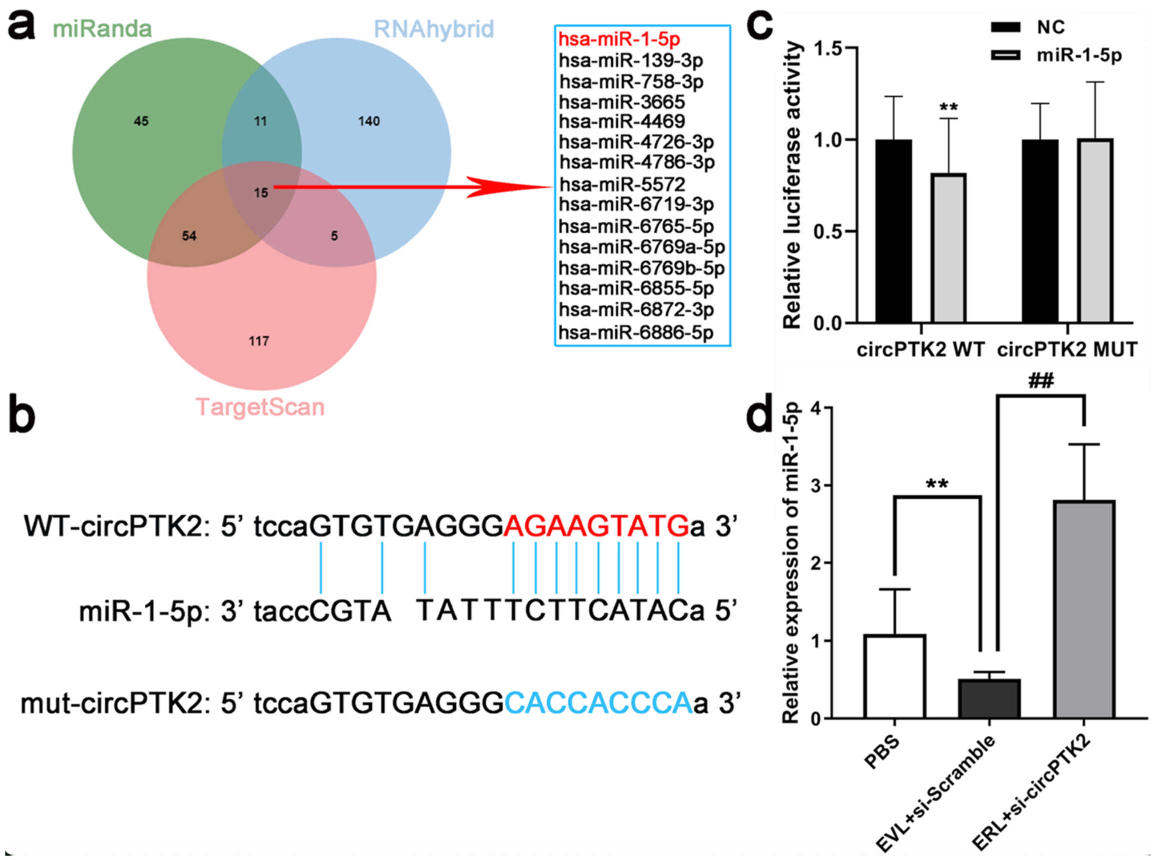

Figure 1. MiR-1-5p is a target of circPTK2. (a) Venn diagram showing the overlapping of the sponged miRNAs of circPTK2 predicted by miRanda, RNAhybrid, and TargetScan. (b) Binding sites between circPTK2 and miR-1-5p predicted by the miRanda database. (c) Dual-luciferase reporter assay confirming the interaction between circPTK2 and miR-1-5p ($n = 3$). $^{**}p < 0.01$ vs. circPTK2 MUT. (d) RT-qPCR detecting miR-1-5p expression in HUVECs transfected with EVL or EVL+si-circPTK2 ($n = 3$). $^{**}p < 0.01$ vs. PBS, $^{\#\#}p < 0.01$ vs. EVL+si-Scramble. Each experiment was performed in triplicates. One-way ANOVA was used in (c) and (d) (From reference 6).

confirmed over 96% accuracy, highlighting its potential for reliable, decentralised cardiac monitoring and home-based follow-up [20].

Digital twin technology is redefining cardiovascular medicine by creating virtual replicas of individual patients that integrate clinical, imaging, and molecular data. These models can simulate disease progression and therapeutic response, enabling personalised risk prediction, treatment optimisation, and remote monitoring. Despite challenges such as data integration, privacy, and model validation, digital twins represent a major step towards precision cardiology and sustainable, patient-specific care (Figure 2) [21].

The role of intra-aortic balloon pump (IABP) support in cardiogenic shock (SCAI) varies across stages of hemodynamic compromise [22]. Mortality reduction appears confined to intermediate shock (SCAI stage C), where circulatory instability remains reversible. No survival advantage is observed in early or advanced stages, suggesting that timing and stage-specific application are key to optimising outcomes with mechanical support (Figure 3) [23].

Assessment of left ventricular myocardial deformation in patients receiving maintenance haemodialysis provides valuable insight into subclinical cardiac dysfunction within this high-risk population [24,25]. Speckle-tracking echocardiography enables detection of early abnormalities in longitudinal, circumferential, and radial strain, often preceding measurable declines in ejection fraction [26–28]. Such findings emphasise the utility of advanced imaging for early cardiovascular risk stratification in chronic kidney disease. However, evaluation limited to patients with end-stage renal disease narrows the generalisability of the results across the full chronic kidney disease spectrum [25]. The absence of longitudinal outcome data and potential confounding effects of hypertension, diabetes, and dialysis-related volume shifts should also be considered. Future studies encompassing different chronic kidney disease stages, serial imaging throughout the dialysis cycle, and outcome correlations would strengthen understanding of myocardial remodelling and its prognostic significance in this population.

Cardiac resynchronisation therapy (CRT) has become an established treatment for pacing-induced or dyssynchronous heart failure, aiming to restore coordinated ventricular contraction and reverse adverse remodelling [29–31]. Epicardial pacing remains vital in paediatric patients but carries the risk of pacing-induced cardiomyopathy when leads are placed suboptimally. In resynchronised children, cardiac function improved markedly with increased ejection fraction, shortened QRS duration, and reduced BNP levels. These results

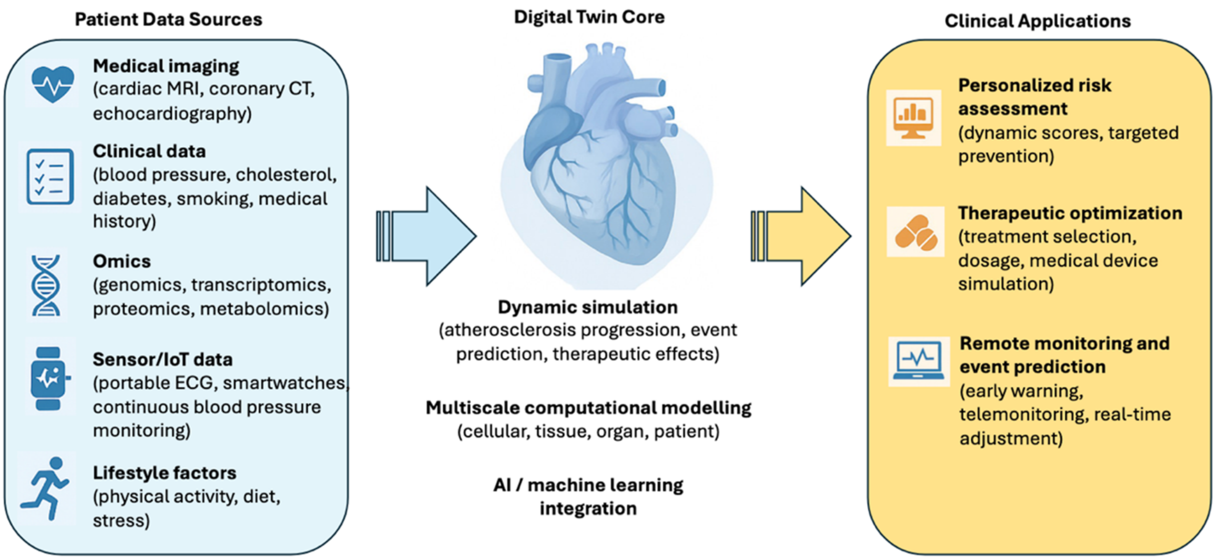

Figure 2. Multimodal patient data, including clinical parameters, imaging, lifestyle factors, omics, and wearable sensors, are integrated into a computational "digital twin" model. This model dynamically simulates cardiovascular physiology and disease progression through advanced machine learning and mechanistic modelling. Clinical applications include individualised risk stratification, optimised treatment planning, and real-time remote monitoring. Key challenges for implementation involve data interoperability, computational infrastructure, regulatory frameworks, and ethical considerations (From Reference 21].

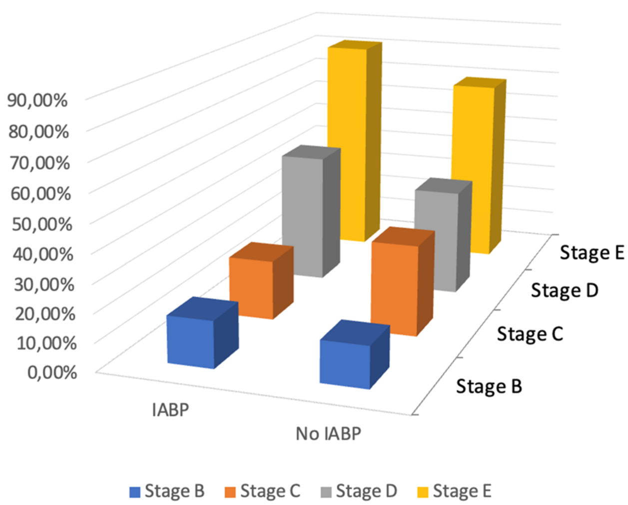

Figure 3. In-hospital mortality for different SCAI stage patients who did and did not receive an IABP during hospital (From reference 23].

confirm the reversibility of pacing-induced dysfunction and highlight the need to avoid anterior right ventricular lead placement to prevent long-term remodelling [32,33].

In this issue of Acta Cardiologica, some focus images highlighting interesting cases have also been reported [34–41].

Disclosure statement

No potential conflict of interest was reported by the author(s).

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