

AI-Enabled Medical Imaging for a Changing Cardiovascular Disease Landscape

How AI-integrated imaging can redefine cardiovascular disease assessment through continuous phenotyping and personalized models

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Cardiovascular disease (CVD) remains the leading cause of mortality worldwide, yet its underlying risk profile is undergoing a profound transformation. Historically dominated by hospitalizations for acute symptomatic events like myocardial infarction, stroke, arrhythmias or decompensated heart failure, contemporary cardiovascular disease is increasingly driven by chronic, lifestyle-related exposures—obesity, sedentary behavior, metabolic dysfunction, and psychosocial stress. These risks accumulate gradually, interact nonlinearly, and manifest clinically over decades. Consequently, the central challenge in modern cardiovascular care is no longer limited to diagnosis, but extends to the continuous identification, visualization, and modification of risk across the lifespan.

Traditional paradigms of cardiovascular assessment are poorly

aligned with this evolving landscape. Clinical evaluation relies heavily on episodic measurements and threshold-based classifications, often detecting disease only after structural or functional impairment has occurred. Medical imaging, while central to cardiovascular care, has largely mirrored this approach—focusing on discrete parameters such as ejection fraction or valvular gradients. These representations, although clinically useful, fail to capture the dynamic and multidimensional nature of cardiovascular physiology.

AI Integration in Cardiovascular Imaging

Artificial intelligence (AI), particularly when integrated with

imaging, offers an opportunity to fundamentally redefine this paradigm. Over the past decade, AI has enabled automation and predictive analytics across imaging modalities, improving efficiency and reducing variability in tasks such as segmentation, quantification, and disease detection.¹ Across modalities such as echocardiography, cardiac CT, and cardiac MRI, deep learning—particularly convolutional neural networks and emerging transformer-based architectures—now enables automated chamber quantification, myocardial strain analysis, valve assessment, and plaque characterization with accuracy approaching expert readers. A major shift is toward integrated, multimodal AI, combining imaging with ECG, clinical variables, and even omics data

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“Cardiovascular risk builds continuously from lifestyle exposures, but episodic measurements detect disease too late, overlooking the dynamic and multidimensional nature of cardiovascular health.”

Figure 1. AI-Enabled Cardiovascular Phenotyping Framework

Multimodal AI integrates diverse data to extract patterns and enable superior phenotyping and risk prediction.



to improve phenotyping and risk prediction. In echocardiography, AI is moving beyond static measurements to time-resolved waveform and video analysis, capturing cardiac mechanics (e.g., deformation, relaxation, and flow dynamics) and enabling detection of subclinical disease such as early diastolic dysfunction. In cardiac CT and MRI, AI enhances tissue characterization (e.g., fibrosis, inflammation, and plaque vulnerability) and enables rapid, reproducible quantification.

However, the clinical impact of these advances has been incremental rather than transformative, with limited evidence of improved patient outcomes or cost-effectiveness. A key limitation lies in the prevail-

ing approach which is that AI has primarily been used to optimize existing measurements rather than to rethink how cardiovascular disease is represented.

From Parameter-Based Assessment to Continuous Phenotyping

A more transformative opportunity lies in shifting from parameter-based assessment to continuous, data-driven phenotyping.² Cardiovascular function is inherently dynamic, governed by complex interactions between myocardial mechanics, hemodynamics, and systemic physiology. Imaging modalities—particularly those capturing temporal signals

such as echocardiographic motion or Doppler waveforms—encode rich, high-dimensional information about these processes. AI excels at extracting patterns from such data, enabling the identification of latent phenotypes that extend beyond conventional classifications. Indeed, unsupervised and similarity-based approaches have demonstrated the ability to define clinically meaningful subgroups with distinct prognostic trajectories, often outperforming traditional frameworks.

Digital Twins and Autoresearch in Cardiovascular Care

Within this evolving landscape, the concept of the digital twin has emerged as a powerful paradigm.³ A cardiovascular digital twin represents a computational model of an individual patient that integrates imaging, physiological signals, and clinical data to simulate cardiac structure and function. Rather than providing a static snapshot, digital twins enable continuous representation of disease states and their evolution over time. AI-enabled imaging serves as a critical foundation for constructing these twins, providing the high-resolution, multidimensional data required to model cardiac dynamics. Such models have the potential to predict disease progression, simulate therapeutic interventions, and personalize treatment strategies—transforming care from reactive to anticipatory.

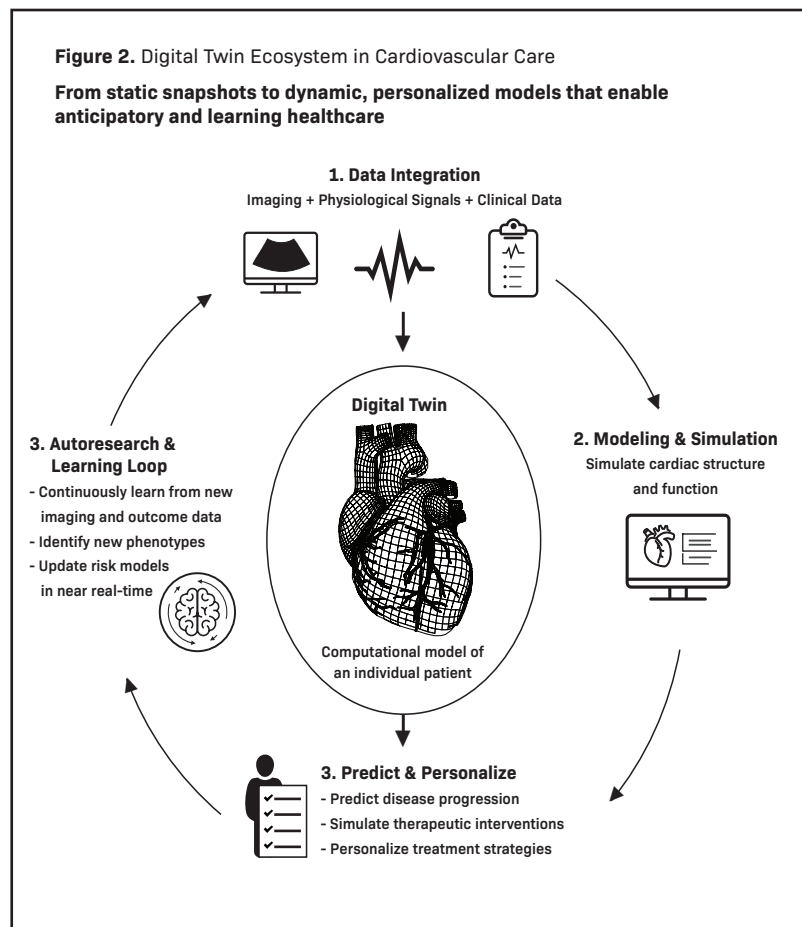
Closely related is the emerging concept of automated AI and autoresearch, wherein AI systems not only analyze data but iteratively generate, test, and refine hypotheses within

“The future of cardiac care lies in making cardiovascular risk visible, dynamic and personalized through high resolution imaging and AI.”

clinical datasets. In cardiovascular imaging, autoresearch frameworks can continuously learn from incoming imaging and outcome data, identifying new phenotypes, uncovering previously unrecognized associations, and updating risk models in near real-time. This represents a shift from static research paradigms toward a learning health system, in which knowledge generation is embedded within routine clinical care. By integrating autoresearch with digital twin models, it may be possible to move beyond population-level inference toward individualized, continuously evolving representations of disease.

Multimodal AI and Global Accessibility

The convergence of these concepts is further amplified by advances in multimodal AI. Modern systems increasingly integrate imaging data with electronic health records, genomics, and physiological signals such as the electrocardiogram (ECG). The PRIME 2.0 framework highlights this transition toward multimodal and generative AI, emphasizing the need for rigorous evaluation and integration across diverse data types.¹ In this context, the relationship between electrical and mechanical cardiac function becomes particularly relevant. AI models capable of translating between modalities—for example, reconstructing mechanical function from ECG signals—offer the potential to extend imaging insights to scalable, low-cost platforms.⁴



This capability is critical for addressing the global burden of cardiovascular disease. Advanced imaging modalities, while informative, are resource-intensive and not universally accessible.⁵ By contrast, widely available tools such as ECG or wearable sensors can serve as entry points for AI-driven phenotyping when linked to imaging-derived representations. In this framework, imaging informs the creation of high-fidelity digital twins, while scalable modalities enable their deployment across populations—

bridging the gap between precision medicine and public health.

Augmented Intelligence and Implementation Challenges

Importantly, these advances must be viewed through the lens of augmented intelligence. AI is not a replacement for clinical expertise, but a tool to enhance it—integrating complex data, reducing cognitive burden, and supporting more informed decision-making. The

goal is to enable clinicians to move beyond isolated measurements toward a more holistic understanding of cardiovascular disease, while preserving the nuance and contextual judgment that define clinical practice.

Significant challenges remain.⁶ Cardiovascular imaging data are inherently heterogeneous, with variability in acquisition, annotation, and quality that complicates model development and generalization. Ethical considerations—including bias, fairness, and data privacy—must be addressed to ensure equitable deployment. Moreover, prospective validation and real-world implementation studies are essential to demonstrate meaningful clinical impact beyond technical performance.

Conclusion

In conclusion, AI-enabled medical imaging is poised to play a central role in addressing the changing

cardiovascular disease landscape. It's true potential lies not only in automating existing workflows, but also in redefining disease representation—through continuous phenotyping, digital twin modeling, and autoresearch-driven discovery. By making cardiovascular risk more visible, dynamic, and personalized, these approaches can shift care from reactive treatment to proactive prevention. In doing so, they offer the possibility of not only reducing mortality but also extending healthy life expectancy in an increasingly complex and interconnected world.

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