Imaging Modalities in Assessing Cardiovascular Risk Factors

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Abstract

Cardiovascular disease (CVD) remains a leading cause of morbidity and mortality worldwide. Traditional risk assessment models, while valuable, often fall short in detecting subclinical disease. Advances in imaging modalities offer enhanced capabilities for early detection and risk stratification. This review synthesizes current imaging techniques utilized in assessing cardiovascular risk factors, highlighting their unique contributions and clinical potential.

Coronary computed tomography (CT) enables coronary artery calcium (CAC) scoring, providing a direct measure of atherosclerotic burden and serving as an independent predictor of cardiac events. Coronary CT angiography (CCTA) offers non-invasive visualization of coronary vasculature, detecting stenosis and high-risk plaque features. Magnetic resonance imaging (MRI), particularly cardiac MRI (CMR), assesses myocardial structure, fibrosis, and functional markers such as ascending aortic distensibility, emerging as a novel indicator of vascular aging and major adverse cardiovascular event (MACE) risk.

Echocardiography remains a first-line, cost-effective imaging technique, evaluating ventricular morphology, ejection fraction, diastolic function, valve pathology, and carotid intima-media thickness. Intravascular ultrasound (IVUS) and optical coherence tomography (OCT) provide high-resolution imaging of arterial walls and plaque components, offering critical insights into vulnerable plaque characteristics.

Retinal imaging, including OCT and fundus photography, combined with deep learning algorithms, has demonstrated potential in predicting future CVD events. Models trained on large datasets have achieved area under the curve (AUC) values of approximately 0.75 to 0.78, outperforming traditional risk scores like QRISK3.

Integration of multimodal imaging and artificial intelligence (AI) enhances risk stratification, enabling personalized preventive strategies. However, challenges such as ionizing radiation exposure, standardization across technologies, and AI interpretability must be addressed to translate these advancements into clinical practice effectively.

Key words: Cardiovascular disease, Risk assessment, Imaging modalities, Cardiac MRI, Echocardiography, Subclinical atherosclerosis, Echocardiography.

Introduction

Cardiovascular Disease (CVD) remains a primary global health concern. Although clinical risk factors such as hypertension, dyslipidemia, and smoking are well-studied, advanced imaging techniques now offer the promise of detecting subclinical disease and refining individual risk stratification. **(1)** This review synthesizes cutting-edge imaging modalities used for assessing cardiovascular risk factors, evaluating their unique contributions and clinical promise. **(2)**

Coronary Computed Tomography (CT)

Coronary Artery Calcium (CAC) Scoring

CAC-scoring via CT — formalized by the Agatston methodology — provides a direct visualization of atherosclerotic burden and is an independent predictor of cardiac events. Recent developments consider plaque diffusivity, volume, density, and anatomical distribution to bolster prognostic precision beyond traditional measures **(3)**

Coronary CT Angiography (CCTA)

CCTA offers non-invasive imaging of coronary vasculature, enabling detection of stenosis and high-risk plaque features (napkin-ring sign, positive remodeling). AI-enhanced evaluations of plaque morphology and stenosis severity are rapidly advancing, enhancing efficiency and predictive power **(4)**

Magnetic Resonance Imaging (MRI)

Cardiac MRI & Functional Markers

CMR is the reference standard for assessing myocardial structure, fibrosis (via LGE and T1 mapping), extracellular volume (ECV), and subtle tissue characterization that predict arrhythmia and heart failure risk Notably, ascending aortic distensibility—measured via MRI—emerges as a novel marker of vascular aging and major adverse cardiovascular event (MACE) risk, independent of traditional factors

Stress Perfusion MRI

Stress CMR perfusion testing provides functional insight into myocardial ischemia without ionizing radiation and demonstrates strong prognostic value in suspected CAD cases **(5)**

Echocardiography & Ultrasound Modalities

Echocardiography remains a first-line, cost-effective imaging technique. It evaluates ventricular morphology, ejection fraction, diastolic function, valve pathology, and carotid intima-media thickness or aortic stiffness—all insightful indicators of early cardiovascular risk **(6)**

Intravascular & Optical Methods

Intravascular Ultrasound (IVUS)

IVUS visualizes the arterial wall and hidden plaque components beyond the lumen, offering critical insights into vulnerable plaque characteristics not evident on angiography **(7)**

Optical Coherence Tomography (OCT) and Molecular Hybrid Imaging

OCT provides ultra-high-resolution imaging (~10× finer than IVUS) of coronary microstructure. When paired with near-infrared fluorescence or spectroscopy imaging, it can detect molecular-level inflammation and plaque vulnerability **(8)**

Retinal Imaging & Artificial Intelligence

Retinal OCT & Fundus Photographs

Recent work shows that retinal OCT and fundus images, combined with deep learning, can predict future CVD events. A model trained on UK Biobank data outperformed QRISK3, achieving AUC of ~0.75 in forecasting myocardial infarction or stroke. Integrating fundus and OCT in a novel multi-channel variational autoencoder improved risk prediction (AUROC ~0.78), underscoring their clinical potential for early screening **(9)**

Retinal Fundus Deep Learning Review

A comprehensive review of AI-based retinal imaging highlighted its capacity to non-invasively predict multiple risk factors—age, blood pressure, smoking status, HbA1c—demonstrating significant utility in large-scale screening **(10)**

Recent Landmark Findings

- A recent Radiology paper from University of Dundee demonstrated that simple cardiac MRI can reveal increased left ventricular mass up to a decade before heart attack or stroke, with a 2.3-fold risk in women and 3.2-fold in men, even when conventional risk assessment was negative **(11)**

- Complementing this, AI models trained on chest X-rays at Massachusetts General and Brigham & Women's Hospitals achieved predictive accuracy for 10-year CVD risk comparable to traditional clinical scoring methods, even among individuals without overt risk markers **(12)**

Discussion & Future Directions

Multimodal Synergy & AI Integration

Integration across modalities—structural imaging (CT, MRI), functional imaging, molecular-level resolution (OCT/IVUS), and AI-driven retinal analysis—promises comprehensive risk stratification. Automated AI assessments of CAC, plaque features (CCTA), and perfusion (CMR) personalize risk models and support proactive interventions **(13)**

Limitations and Research Gaps

- Ionizing radiation from CT-based methods remains a concern, particularly in younger patients and repeat screenings

- Standardization across scanner technology, scoring thresholds, and AI interpretability is needed to harmonize results and translate findings to diverse populations **(14)**

Conclusion

Cutting-edge imaging modalities, particularly when enhanced by AI and deep learning, are reshaping cardiovascular risk prediction. From CT-based calcium quantification to MRI-based functional measures, intravascular plaque imaging, and retinal biomarker discovery, these methods detect subtle pathology long before clinical events. Ongoing validation in broader cohorts, ethical algorithm transparency, and cost-effectiveness studies will be essential for integrating these modalities into mainstream prevention strategies.

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