Pakistan Journal of Medical & Health Sciences Vol.20 (05), 2026 www.pjmhsonline.com

ISSN (P&E): 1996-7195, (O): 2957-899X **DOI:** https://doi.org/10.53350/pjmhs02026205.1

EDITORIAL

The Future of Coronary CT Angiography: Artificial Intelligence as a Catalyst for Precision Cardiovascular Care

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This Editorial may be cited as: Muneeb M; The Future of Coronary CT Angiography: Artificial Intelligence as a Catalyst for Precision Cardiovascular Care. Pak J Med Health Sci, 2026;20(05):1-3.

Received: 02-02-2026
Accepted: 15-05-2026
Published: 30-05-2026

Coronary artery disease (CAD) is the most common cause of death and disability-adjusted life years worldwide and it causes about seven million deaths in the world every year. Cardiovascular disease in the United States alone causes an estimated economic cost of almost US$219 billion each year in the United States, with CAD being the most common and fatal form of the disease. Though invasive coronary angiography (ICA) has long been accepted as the diagnostic gold standard, it is too invasive, is associated with procedural risks, is expensive, and fails to characterize atherosclerotic plaque composition in all aspects thereby restricting its application in routine screening and longitudinal studies. This has led to a change of clinical practice towards non-invasive imaging investigations and more specifically patients with suspected CAD should have a first-line investigation in the form of coronary computed tomography angiography (CCTA). Nonetheless, the dramatic rise in demand of CCTA has posed significant difficulties such as the lack of skillful cardiovascular radiologists worldwide and the amount of time taken to interpret images manually. Complete interpretation of three-vessel CCTA scan can take up to 90 minutes, which restricts the workflow and clinical scalability. Artificial intelligence (AI) has proven to be a revolutionary product with the capabilities to automate the process of image analysis, increase the accuracy of diagnosis, and create a paradigm shift in an entirely anatomical evaluation to a more individualized, prognosis-focused, cardiovascular treatment approach[1-5].

Technical foundations of AI in cardiovascular imaging

The effective implementation of AI in cardiovascular imaging is based on three key enabling elements, namely big clinical data sets, powerful computing platforms, and sophisticated algorithm design. AI also includes the concept of machine learning (ML) and a more advanced form, deep learning (DL). Machine learning programs can detect detailed patterns in large volumes of data to create prediction models by supervised, unsupervised, or reinforcement methods. Deep learning is a multilayered artificial neural network that is based on the human brain design, which can directly learn with raw imaging data. Convolutional neural networks (CNNs) are among those models that have become the foundation of medical image analysis due to their outstanding capability to recognise, classify, segment and extract pixel-level features. Radiomics supplements these technologies by transforming traditional medical images into quantitative data in high dimensions by extracting imaging biomarkers that to the human eye are typically impossible to observe. These characteristics can be used to generate meaningful information about tissue properties, plaque formation, and underlying histopathological changes and, thus, enhance the diagnostic capabilities of cardiovascular imaging (3-8).

Intelligent playing with AI and computerized image acquisition and reconstruction.

Radiation dose reduction has been one of the first clinical uses of AI in CCTA. Due to the repeated imaging of patients with CAD, the reduction of cumulative radiation exposure is an essential clinical concern. Deep learning-enhanced reconstruction algorithms and generative adversarial networks (GANs) can be effectively employed to eliminate noises in low-dose acquisitions and maintain important detail during reconstruction. Technical limitations related to the CT image acquisition are also tackled with the help of AI. Heart rates or cardiac arrhythmias result in motion artefacts that tend to reduce the image quality and diagnostic confidence. Motion correction algorithms via CNN can estimate and counteract heart motion, significantly enhancing temporal resolution without making any hardware adjustments. More so, AI-based acquisitions protocols democratically adjust tube voltage and tube current to patient-specific anatomical features and body mass index, rendering consistent quality of images across different groups of patients, including obese patients[5-9].

Improving the efficiency of workflow

Conventional CCTA interpretation involves several and very laborious steps, such as coronary artery segmentation, vessel centreline extraction and anatomical labeling. Deep learning algorithms are becoming more popular in automating these repetitive tasks. CNN-models capture the coronary centrelines well without the human intervention, including those with severe coronary stenosis or extremely tortuous vessel. Further automated labeling of the coronary arterial tree, by graphical means allows to report anatomically in a standard way and reproducible clinical interpretation. The effect of AI-based automation on the efficiency of workflow is high. In a prospective randomized trial including 1,801 patients, completely automated AI image processing required a further segmentation and reconstruction only about 121 seconds, compared to over 433 seconds with semi-automated procedures. Under an average scan-to-report turnaround time in hours was reduced by 39, 10.5 hours to 6.4 hours showing that AI can be significant in productivity improvements in time with growing clinical demand[7-11].

Accuracy of diagnosis in measuring coronary stenoses

Despite having a great negative predictive ability to rule out CAD, CCTA traditionally has been low in specificity to identify obstructive coronary lesions, especially in vessels with heavy calcium in which bloomingartefact may produce overestimation of the severity of stenosis. In this context, artificial intelligence has brought about a great success in terms of performance in diagnosis. Deep learning models that are compared with quantitative coronary angiography (QCA) have the diagnostic accuracies of 88.4-94.7% at patient and vessel levels. Interestingly, AI systems are always more specific than skilled human readers, especially in the assessment of calcified plaques, which will minimise false-positive diagnoses and redundant invasive studies[7-10]. In addition to anatomical analysis, AI-based fractional flow reserve computed tomography (CT-FFR) allows a non-invasive analysis of the lesion-specific haemodynamic relevance. Concoronary anatomy combined with learned haemodynamic relations is accurate in predicting myocardial ischaemia by deep learning models with an area under the receiver operating characteristic curve (AUC) of about 0.93 with much lower computational times than traditional computational fluid dynamics methods.

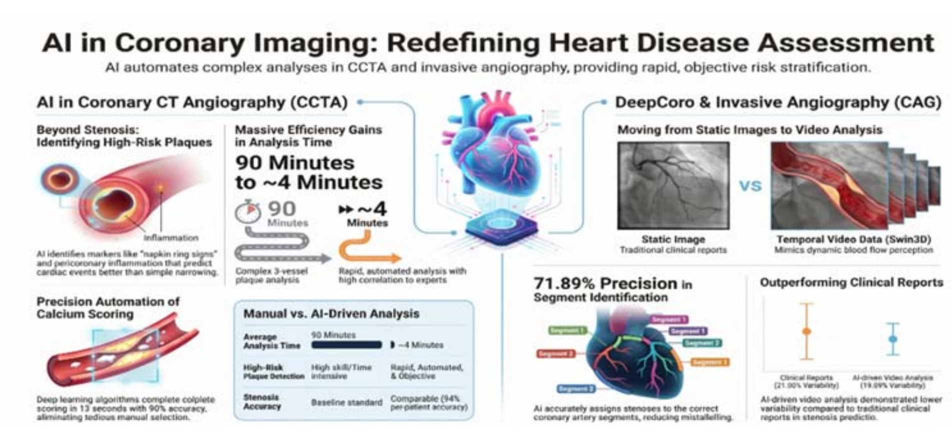

Figure 1: AI in Coronary Imaging

Perivascular fat analysis is a non-invasive biomarker of imaging coronary inflammation

Such a bedrock of atherosclerotic development and unstable plaque is inflammation. Until recently, objective imaging biomarkers of coronary inflammation were few. Quantitative analysis of pericoronary adipose tissue (PCAT) represents advancements of AI in this area. Mediators discharged by inflamed coronary arteries modify the structure of surrounding adipose tissue, making it more watery and altering its radiographic attenuation. The changes are measured through fat attenuation index (FAI) which is a non-invasive aspect of the biomarker of vascular inflammation. In more recent developments, radiomic imaging characteristics have been used in conjunction with transcriptomic profiles collected using tissue specimens using radio transcriptomic methods, thus allowing specific definition of inflammatory pathways. These combined biomarkers are able to differentiate between patients with acute myocardial infarction and those with stable CAD and have an independent ability to predict future Cardiovascular mortality independent of the severity of stenosis[11-14].

Reconceptualizing Personalized Cardiovascular Risk Stratification.

The end goal of AI integration is to promote accurate cardiovascular medicine. Conventional clinical risk scores often either under- or over-estimate the actual atherosclerotic burden of any individual. In awareness of these constraints, the 2024 Quantitative Cardiovascular Imaging (QCI) Study Group came up with a paradigm shift of plaque-based personalized risk assessment[13-14].

Challenges and Future Direction Current Challenges and Future Direction

Regardless of extraordinary progress, numerous major obstacles may restrict large-scale clinical use. The black box problem of poor interpretability of deep learning models can be seen as one of the fundamental obstacles. These algorithms may be significantly better than human observers, but their non-transparency in decision making can cause clinician hesitation and make them less readily accepted. The issue of model generalizability is also a major problem as it is in any case typical that algorithms that are trained on a dataset of one particular institution perform less well when they are applied to other populations due to variations in scanner technology, imaging protocols, and patient population demographics[12-16]. Moreover, legal and ethical aspects of the privacy of patients, the rules in charge of data, cybersecurity, and the responsibility of algorithms would need a thorough regulatory supervision.

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