Leveraging latest computer science tools to advance nuclear cardiology

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Nuclear cardiology has unique advantages compared to other modalities, since the image analysis is already much more automated compared to what is currently clinically performed for CT, MR, or echocardiography imaging. The diverse image and clinical data available to assess coronary disease function, perfusion, flow, and associated CT data provide new opportunities, but logistically these additional assessments increase the overall complexity of SPECT/PET reporting, necessitating additional expertise and time. The advances in artificial intelligence software can be leveraged to obtain comprehensive risk predictions and diagnoses from all available data. They will allow nuclear cardiology to retain competitive edge compared to other modalities and improve its overall clinical utility. These tools will enhance diagnosis and risk prediction beyond what is possible by subjective visual analysis and mental integration of data by physicians.

Noninvasive imaging is widely used for the diagnosis, risk assessment, and management of coronary artery disease (CAD)—providing crucial information about myocardial perfusion, function, and anatomy. Myocardial perfusion imaging (MPI) by SPECT and PET is widely used, with 15 to 20 million SPECT MPI scans being performed annually worldwide.[1-3] In addition, noncontrast CT can reliably detect coronary artery calcium (CAC), a specific marker of coronary atherosclerosis, providing complementary information to MPI. SPECT and PET scanners have evolved significantly in recent years,[4,5] allowing for simultaneous gains in sensitivity and resolution.[6,7] Many new systems come hybrid configuration with CT scanners for CT-based attenuation correction (CTAC). In parallel, image reconstruction methods with resolution recovery and time-of-flight for PET have enhanced image quality. While CTAC maps are obtained without ECG-gating, it is possible to extract useful CAC information from them.[8,9] It has been shown that scores obtained automatically from PET CTAC correlate well with CAC scores from standard, ECG-gated CAC scans[10] and that visual identification of CAC on CTAC scans improves the diagnostic accuracy of MPI.[11]

While regional relative quantification of total perfusion deficit (TPD) and ischemia detection by MPI are in wide clinical use, these approaches may underestimate extensive CAD—most notably when there is global diminution of myocardial blood flow (MBF). MBF by PET complements perfusion imaging, with diagnostic[12] and prognostic information.[13,14] Additionally, PET MBF improves diagnosis of CAD over CAC and relative perfusion.[15] However, currently SPECT is used more widely than PET—representing over 95% of MPI.[16] Can MBF also be estimated from SPECT? Many recent reports have confirmed the feasibility of SPECT flow measurement with an early scan.[17-24] Several sites are commencing clinical SPECT flow protocols. PET flow tools are being adapted and validated for SPECT flow measurements. Intriguingly, aside from flow, the early SPECT scan allows measurement of functional reserve at peak stress[25]—a robust marker of multivessel disease in PET.[26] The flow measurements need to be considered together with standard perfusion and

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function measurements to provide the final diagnostic and prognostic assessment.

MPI is extensively validated for risk assessment, but the main supporting studies utilized visual analysis.[27,28] However, recently the quantitative risk stratification by quantitively measures was performed.[29-31] In a large multicenter study, we showed that TPD allows more precise risk gradation for MACE, even in categories traditionally considered normal.[32] However, most MPI risk-stratification studies used perfusion defect size alone, without considering other imaging (PET flow, CAC), stress test, or clinical variables—or considered only subset of these variables. While physicians mentally attempt to combine all stress test and clinical variables when interpreting MPI, such integration is subjective and affected by individual bias and expertise. There are currently no integrated guidelines on how to use all this new imaging information holistically to provide diagnostic and treatment recommendation after the MPI test.

In recent years, new highly efficient artificial intelligence (AI) tools have emerged. These methods are radically reshaping many fields, including health care. New AI-based approaches are revolutionizing image analysis and could further enhance MPI interpretation. In particular, convolutional neural networks (CNN)—a subclass of ''deep learning''—gained considerable attention[33] due to significantly improved classification of natural images.[34] These new tools can be efficiently leveraged for direct extraction of information from MPI and CT, eliminating human subjectivity. Few studies now showed that deep learning can detect CAD directly from polar maps,[35-37] outperforming current quantitative methods, both on a regional and per-patient basis,[35] including joint analysis of multiple maps,[36] which is a visually challenging task.

The diverse image and clinical data available to assess CAD function from MPI, perfusion, flow, and associated CT data provide new opportunities, but logistically these additional assessments increase the overall complexity of SPECT/PET reporting, necessitating additional expertise and time. Consequently, the burden placed on nuclear cardiology physicians is increasing. They are required to constantly improve the objectivity and precision of their findings with this additional information—while absorbing the cost. It seems that the natural approach to consider all this available information together to provide a final precise diagnosis and risk estimate tailored to the specific patient is to leverage the latest AI methods developed in computer vision and machine learning fields.

Nuclear cardiology has unique advantages compared to other modalities, since the image analysis is already much more automated compared to what is currently clinically performed for CT, MRI or echocardiography imaging. Large imaging registries with MPI images and outcomes are available for fully automated analysis.[38] The images are small in size and well standardized allowing implementation of clinically practical software. While there is an ongoing research in automation of CT angiography, MRI, and echocardiography, the current clinical levels of automation and quantitation in nuclear cardiology is probably at least 5 to 10 years ahead, compared to other cardiovascular modalities. Standard image processing of nuclear cardiology images demonstrated already diagnostic equivalence to experienced readers in large studies.[39] Recently, new AI tools have been proposed for nuclear cardiology. Machine learning has been demonstrated to achieve improved prediction of disease and outcomes from SPECT MPI, by combining imaging[40] and clinical parameters.[41-43] AI has been deployed to create final clinical reports.[44] In studies using clinical and SPECT MPI data to predict revascularization, AI had similar to, or better performance than, expert visual interpretation.[43,45] AI surpassed clinical interpretation of MPI for MACE prediction.[42] These studies demonstrate the significant gains in disease diagnosis and prognostication attainable by integrating imaging and clinical data.

Where is it going? The advances in software allowing comprehensive risk prediction and diagnosis from all available data (e.g., clinical data flow perfusion, function, CTAC) will allow nuclear cardiology to retain competitive edge compared to other modalities and improve its overall clinical utility. These tools will improve risk prediction beyond what is possible by subjective visual analysis and mental integration of data by physicians. The increased precision and accuracy of novel software strategies will provide a paradigm-changing solution for nuclear cardiology. These developments will not threaten nuclear cardiologists' jobs. Rather, these developments will provide a new tool in the physicians' arsenal to improve the accuracy of their diagnosis, and enable them to select the appropriate therapy for their patients in a scientific, precise, and quantitative manner. The precise quantitative results can be presented to clinicians (and patients) in easy-to-understand terms (e.g., % risk per year), or as the relative risk of one therapy compared to the alternative for a specific patient. The same quality and quantitative precision will be available regardless which part of the world the studies were performed. Surely, other imaging modalities will follow the same path, but nuclear cardiology is in the position to be the vanguard of these upcoming changes in medical imaging.

Disclosures

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