Deep learning, another important tool for improving acquisition efficiency in SPECT MPI Imaging

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One way to continue to stay relevant as a cardiac imaging modality is to continue to innovate to answer the pertinent clinical questions being posed, and even more importantly to implement clinically these innovations. Innovations require enlightened researchers, armed with a body of knowledge and the needed data to develop and validate new tools and hypothesis. One of our field's main challenges is to answer the following question posed in 2010,¹ Can we increase the efficiency of our SPECT MPI acquisitions such that we reduce the radiation dose to our patients and staff, increase throughput and patient comfort while not compromising but rather optimizing diagnostic accuracy?

TOOLS TO INCREASE THE EFFICIENCY OF SPECT MPI ACQUISITIONS

Table 1 lists many tools that have already been reported to increase the efficiency of our acquisitions. Many of these tools have already been validated and clinically implemented.² Unfortunately, it could be argued that the innovations are not as widely utilized as required for the advancement of our field or the benefit of our patients. Stress-only imaging, by itself or as part of a stress-rest protocol, obviates the need for the higher dose resting study when the stress MPI is normal,

particularly when attenuation correction is used.³ Compared to filtered back-projection, OSEM iterative reconstruction has been shown to reduce radiation dose by 25% when used by itself⁴ and 50% or more when used in conjunction with wide beam reconstruction (WBR),⁵ a form of resolution recovery.⁶ Both OSEM and WBR use, even when applied to older scanners in a private practice setting, have been shown to reduce radiation dose while generating higher quality images that can be interpreted with higher confidence.⁷

An important principle somewhat forgotten over time is the effect of resolution improvement on required count density in high contrast MPI studies.⁸ Just by improving spatial resolution by 2 mm, e.g., on system B compared to system A, reduces the required counts on system B by a factor of four⁸ while maintaining the same defect conspicuity as system A. This is because image contrast increases rapidly with spatial resolution improvements in high contrast studies like SPECT MPI. Major improvements in image filtering like noise regularization,⁶ preserve this higher image contrast while reducing Poisson (high-frequency) noise. Regularization being a significant improvement over image smoothing that reduced noise at the expense of image contrast. Resolution improvement and noise regularization are two important reasons why newer cardiac-centric detectors with advanced reconstruction algorithms require a much lower count density compared to conventional SPECT cameras, even beyond that expected to the addition of more detectors.

CARDIO-CENTRIC MULTIPLE DETECTORS SYSTEMS

Beyond the novel acquisition protocols and software solutions listed above, are the well-reported, albeit it not as well disseminated, new generation of cardio-centric detector systems available to improve acquisition

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Table 1. Tools to increase the efficiency of SPECT MPI acquisitions

1.	Stress-only imaging ¹⁻³
2.	OSEM reconstruction ^{4,5}
3.	Resolution recovery
a.	Wide beam reconstruction ^{5,6}
b.	Increased resolution ⁸
4.	Noise regularization ⁶
5.	Cardio-Centric Multiple Detectors systems
a	Cardiofocal collimators (IQ-SPECT) ^{9,10}
b	CZT Camera (D-SPECT) ¹²
c	CZT Camera (DNM 530c) ¹³
d	ProSPECT ¹¹
6.	Deep Learning ¹⁶⁻¹⁸

efficiency in SPECT MPI. These systems gain imaging performance by imaging the left ventricle in the center of the field of view so it can be imaged simultaneously by two (IQ-SPECT,^{9,10} ProSPECT¹¹) or more (D-SPECT,¹² DNM530c¹³) detectors to increase count rate, magnified to increase spatial resolution using confocal (IQ-SPECT) or pinhole collimators (DNM 530c), improved image contrast using solid state detectors (CZT) to increase energy resolution (D-SPECT, DNM530c), and using larger hole, detector-centered parallel hole collimators to increase count rate (D-SPECT, ProSPECT). The acquisition efficiency performance gains afforded by the design and hardware in these novel scanners and is further complemented by the novel acquisition protocols and software solutions described above. These impressive combinations of hardware and software tools can gain conservatively a factor of 10 in imaging performance over conventional SPECT approaches.¹⁴

DEEP LEARNING

Deep learning is evolving as yet another innovative tool with the potential to improve the efficiency and accuracy of SPECT MPI procedures. Deep learning (DL) is a subset of machine learning (a subset of artificial intelligence) where algorithms learn from large amounts of datasets without necessarily being explicitly programmed to detect specific image features. Think of DL as a powerful outgrowth of artificial neural networks previously used in nuclear cardiology for automated interpretation of MPI studies.¹⁵ In this issue of the Journal, Shiri et al.¹⁶ used deep convolutional networks for SPECT MPI acquisition time reduction compared to standard acquisitions either by reducing the acquisition time to half per projection or the number of angular projections to half. The approach is to train the convolutional neural network algorithm with the lower dose SPECT MPI images (such as with time reduction projections or fewer projections) to perform an image-to-image transformation yielding the routine-dose SPECT MPI images. Although^{17,18} others have used a similar deep learning approach to reduce the dose in SPECT MPI acquisitions, Shiri et al.¹⁵ apply the approach to a prospective cohort of 363 patients with various clinical indications (normal, ischemia and infarction) referred for SPECT MPI acquired with the ProSPECT camera. Their results are still preliminary but promising showing that the predicted images generated from the half-time projections reconstructions resulted in better image quality than those from the half-projections reconstructions when compared to the original acquired SPECT study with full time and full projections.

Table 2. Potential applications of Deep Learning to improve the efficiency and accuracy of Nuclear Cardiology SPECT MPI Procedures

1.	Image Acquisition ¹⁶⁻¹⁸
2.	Image Reconstruction ¹⁶⁻¹⁸
3.	Attenuation Correction
4.	Motion Correction
5.	Enhancement and Visualization (denoising)
6.	Image Processing (e.g., segmentation, feature extraction) ²⁰
7.	Analytics
8.	Diagnosis ¹⁹
9.	Prognosis
10.	Guiding treatment

POTENTIAL APPLICATIONS OF DEEP LEARNING IN NUCLEAR CARDIOLOGY SPECT MPI PROCEDURES

Beyond the use of DL to help increase the efficiency of MPI acquisitions and reconstructions, DL has the real potential to transform every aspect of the MPI study. Table 2 lists practically every step in the MPI procedure that has been shown, predicted or speculated to be improved by DL. Although these techniques are usually first applied to assist with image interpretation to improve diagnosis,¹⁹ DL has already also been applied to left-ventricular segmentation and quantification.²⁰

One of the real concerns about developing DL tools is the need for large image libraries containing the pertinent information to be used for training the algorithms. In some applications this limitation may be circumvented by creating synthetic datasets. For example, to develop a DL algorithm to correct the planar projections from patient motion during SPECT MPI acquisitions, the developer can use a database of SPECT clinical studies with no patient motion and create synthetic studies with various types of motions simulated. The DL algorithm would then be trained by “teaching” the synthetic projections to appear like the projections with no motions. The applicability of the algorithm would depend on the realism of the synthetic projections.

CLINICAL IMPLICATIONS

As summarized here, SPECT MPI imaging enjoys a plethora of powerful tools to simultaneously and significantly increase acquisition efficiency, reduce dose and increase image quality. These tools are synergistic in that when several tools are used in conjunction their results are better than the sum of its parts. With the exception of DL, practically, all of the tools discussed here are commercially available.

As an individual, the reader should ask, how many of these tools am I using in my clinic? Proper implementation of these tools can only improve laboratory efficiency and patient outcome.

As a field, we need to ask ourselves, why instead of suggesting that these tools be used don't we require them from licensed laboratories? Moreover, we know that tools like respiratory gating and/or respiratory motion correction improve the accuracy of MPI imaging not only at standard but also at reduced doses.²¹ As discussed here, the excuse that we don't have enough counts in our acquisitions at the recommended doses to perform respiratory gating no longer holds true unless our laboratories are operating using very old standards.

PRACTICAL IMPLICATIONS

The clinical implementation of the tools discussed in this editorial also has significant cost, industry and regulatory implications. Reduction of the injected dose should also have a cost saving for the patient and the laboratory. This reduction can best be realized if lower single individual doses are available commercially. One challenge to this strategy is that the radiopharmaceutical package inserts of SPECT perfusion tracers approved 20 years ago carry a minimum injected dose requirement implemented before the higher efficiency tools discussed here were available. This is a regulatory challenge as to how our field would find the energy and resources to overcome them as it would be difficult to find in industry someone willing to do the necessary due diligence to change package inserts for radiopharmaceuticals with expired patents.

Deep Learning is a powerful tool with an extraordinary potential to improve all aspects of nuclear cardiology myocardial perfusion imaging. The strength of nuclear cardiology continues to be its large body of scientific work and many available large imaging databases, two important requirements for DL development. As the accuracy of these developments depends on the quality, i.e., robustness of the databases, we should take on the responsibility of being or finding curators of this information. It should be clear the potential of DL brings the paradigm shift that curated data are paramount and that the significance of the programming code has been significantly reduced. Shiri et al.¹⁶ have shown us the promise of using DL to improve the efficiency by how we acquire our studies. Even more importantly, they offer us hope that new talents in the biomedical sciences are willing to invest their efforts in our field.

Nuclear cardiology has a large armamentarium of tools to improve the overall quality of our clinical studies. These tools only have value if we used them.

Disclosure

Dr. Ernest Garcia receives royalties from the sale of the Emory Cardiac Toolbox and has equity positions with Syntermed, Inc. The terms of these arrangements have been reviewed and approved by Emory University in accordance with its conflict of interest policies.

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