3D iterative reconstruction can do so much more than reduce dose

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Recent advances in software and hardware for cardiac SPECT have the potential to revolutionize nuclear cardiology. It is easy to use these technologies to maintain the status quo and lower radiation dose, despite the fact there is very little evidence that lowering patient dose in already low dose imaging protocols confers any benefit to patients. Cardiac SPECT has tremendous potential for risk stratification, molecular tracers, and high temporal resolution management of patients with electrophysiological disorders. In addition, these new reconstruction techniques can offer spatial resolution that is comparable and sometimes even superior to PET. Lastly, recent research has also held out the potential for performing absolute blood flow qualification using SPECT instrumentation. As these new technologies become available, the goal should be to make images better and improve patient care first, then optimize the dose.

Key Words: Image reconstruction • modalities • instrumentation

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INTRODUCTION

Since the discovery of the X-ray in the early 20th century, ionizing radiation has revolutionized the practice of medicine in ways that are hard to fathom. Its impact on the care of patients with heart disease, specifically using radionuclides, has meant earlier detection, better outcomes, and better patient care. All these benefits came with few contraindications or side effects. The approval of Tl-201 in 1979 allowed for a whole body radiation dose of up to 40 mSv.¹ In the 1990s, technetium tracers with their shorter half-lives simultaneously reduced patient dose to 18 mSv while increasing overall image quality.² The initial recommendations for Tc 99m sestamibi was a 30 mCi dose on the first day followed by a second 30 mCi dose on the second day.

This protocol was improved upon by validating a same day, low 10 mCi resting dose followed by a higher dose, 30 mCi dose at stress, with a corresponding dose reduction from 18.6 to 12.6 mSv. At each step along the way, image quality was improved alongside the reduction of radiation. These protocols, in conjunction with dual headed angler camera instrumentation, became the backbone of nuclear cardiology throughout the 1990s and 2000s.

More recently, professional societies and government agencies have raised concerns that given the increased number of radiological studies patients receive over their lifetime, there may be a potential risk of radiation induced carcinogenesis.³⁻⁵ This risk from diagnostic ionizing radiation is based off a linear extrapolation of radiation effects at very high radiation dosages to the low radiation exposure used in medical imaging, referred to as the linear no-threshold (LNT) model.⁶ Much of these data come from nuclear power plant accidents and atomic bomb survivor data. Though this is the most commonly accepted model, there is considerable evidence that radiation induced carcinogenesis does not obey this model.⁷⁻¹⁰ There is even more recent evidence suggesting DNA repair mechanisms are activated when exposed to low doses of

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radiation, decreasing cellular sensitivity to radiation.^{11,12} The LNT model for radiation effects in these acute exposure settings bare little similarity to the conditions in diagnostic radiology. This is not to say that nuclear cardiologists should ignore recommendations to avoid unnecessary radiation exposure, rather it is to look carefully at what is really meant by unnecessary. Specifically, when efforts to reduce radiation exposure prevent nuclear cardiology from innovating and improving image quality, it neither serves the patients nor the public.

Pretorius et al. present an excellent analysis of 3-D iterative reconstruction with resolution recovery and attenuation correction to demonstrate comparable reader accuracy at one quarter of a conventional dose. They demonstrate that global sensitivity and specificity is similar for full dose and one quarter dose myocardial perfusion imaging when data were reconstructed using OSEM with resolution recovery, scatter correction and attenuation correction. Filtered back-projection demonstrated a significant degradation in reader performance at lower injected doses. But how should we use this conclusion? One way would be to be satisfied with the same image quality as was available in 1995 using one quarter of the dose. Another way would be to maintain the same acquisition times, and the same dosages and achieve significantly higher image quality in terms of lower noise, spatial and temporal resolution, allowing for earlier detection of disease, or detecting subtle changes in a patient's coronary disease when symptoms change.

A recent position statement from the American Heart Association and the American Society of nuclear cardiology recommended nuclear cardiology laboratories upgrade their computing capabilities to include iterative reconstruction.¹³ This would improve image quality substantially and reduce image artifacts at a relatively small cost to nuclear laboratories. It had also been recommended that upgrading high-resolution scanning technologies such as CZT could greatly improve overall image quality and minimize image artifacts.^{14,15} This statement specifically identified image quality improvement as being the greatest need in SPECT.

ALARA is often misunderstood to mean, "all radiation is bad". The Health Physics Society 2010 position paper states that for annual dose estimates of < 50 mSv and cumulative lifetime doses of < 100mSv, extrapolated "risk estimates should not be used".¹⁶ This position is based on NCRP 1997 "emphasizing the inability to detect any increased health detriment" at these dose levels.¹⁷ The overstatement of radiation risk can have the unintended consequence of patients avoiding important diagnostic testing and limiting research into potentially lifesaving diagnostic advances. Some

opportunities that could be missed by over emphasizing radiation risk are high temporal resolution gating, high-resolution localization of disease, absolute blood flow, and the development of new tracers.

HIGH TEMPORAL AND SPATIAL RESOLUTION ECG GATED SPECT

New management strategies for heart failure and arrhythmia require accurate functional information, something ECG gated SPECT obtains routinely. This is an important advantage of ECG gated SPECT has over CT and MRI-based functional imaging. Most modern SPECT cameras routinely image patients using 16 ECG gates (< 70 ms per time bin). This extraordinarily high temporal resolution allows for regional assessment of the heart rhythm and wall motion abnormalities (see Figure 1). When compared to conventional CT, with the rotation speed of 0.5 seconds, the temporal resolution can exceed 200 ms. For MRI, ECG gating is even more challenging with the inability to scan the entire cardiac volume and acquire a 12 lead ECG necessary for stress testing. Even ⁸²Rb PET is typically limited to eight ECG time bins (> 120 ms per time bin). It is possible with the advanced reconstruction techniques to achieve 32 ECG gates per study (< 40 ms per time bin) with excellent image quality. This temporal resolution could prove critical in managing heart failure and EP patients as newer therapies become available.

HIGH-SPATIAL RESOLUTION SPECT

The accuracy of myocardial perfusion SPECT in detecting overall sensitivity, specificity and accuracy is well understood; however, upon closer examination SPECT performs poorly in determining the location of a coronary lesion¹⁸ (see Figure 2). Results for myocardial perfusion PET demonstrate that with higher resolution, and scatter and attenuation correction it is possible to obtain good localization of coronary lesions. The current study examined sensitivity and specificity as global variables; however, in real world patient management, it is more important to identify specific regions of ischemia. In addition, only a small portion of patients referred for perfusion testing are truly CAD naïve. Patient management in nuclear cardiology more typically involves comparisons of subtle changes from one year to the next, patency of grafts and stents, and small changes in ejection fraction. All of these clinical endpoints benefit from high-resolution, high quality perfusion images.

Figure 1. Very high temporal and spatial resolution SPECT greatly improves the diagnostic utility of ECG gated SPECT. Above is an iterative reconstruction, with resolution recovery image of a patient with a severe inferior and infero-lateral defect. This study was performed using 3.2 mm pixel size and 16 ECG gated time bins. Displayed is the end-diastolic and end systolic frames (left) and perfusion and function polar maps. In this example, ECG gated frames are reconstructed with 1/16 the dose of the perfusion study to achieve an incredible image of a single diastolic and systolic frame with 60 ms temporal resolution.

SPECT FOR MYOCARDIAL BLOOD FLOW

Myocardial perfusion PET has been revolutionized by the introduction of absolute myocardial blood flow and blood flow reserve measurements.¹⁹ More recently, there has been considerable interest in extending these advances to myocardial perfusion SPECT.²⁰ Performing absolute myocardial blood flow with SPECT has many challenges such as lower resolution, lower temporal resolution, and more challenging radionuclide kinetics. Despite these challenges several investigators have reported success in performing the dynamic imaging necessary for calculating myocardial blood flow. The

potential benefit to patients of adding absolute blood flow and blood flow reserve information to the relative perfusion data is undeniable; however, poor signal-to-noise could compromise its utility.

SPECT FOR MOLECULAR TRACERS

Finally, adding new molecular tracers to the current stable of perfusion tracers offers the potential for further revolutionizing nuclear cardiology. Recent phase 1 data of a Tc-99m deoxyglucose molecule have opened the possibility of imaging active ischemia, and ischemic

Figure 2. Overall sensitivity, specificity and accuracy of conventional FBP SPECT is similar to high cost modalities such as PET (left). By vessel, conventional FBP SPECT has a significantly lower sensitivity due to its lower resolution and artifacts (right). This inability to localize disease limits the usefulness of conventional SPECT.

memory using SPECT instrumentation. Iodine-123 has been well documented as an important radionuclide for monoclonal antibodies and other physiologically active molecular agents, such as in MIBG and BMIPP. Despite iodine-123 obvious chemical benefits, its long half life (12 hours) implies most imaging protocols will have a higher whole body dose when compared to technetium for PET agents. These molecular imaging agents could have immense lifesaving potential, so long as we keep in perspective the importance of imaging first and optimizing dose second.

CONCLUSIONS

Pretorius et al. have done an excellent job presenting the importance of iterative reconstruction with scatter, attenuation, and resolution compensation for improving image quality. In the simplest sense we could be content with using this conclusion to drive down radiation exposure without compromising image quality. Alternately, this conclusion could be used to spark new research into how the newer reconstruction and image processing techniques can enable the next phase of nuclear cardiology.

Disclosure

Dr. Case receive royalties for Cardiovascular Imaging Technologies for ImagenSPECT, a SPECT processing environment.

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