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EDITORIAL

Doing Well Under Pressure: Dedicated SPECT Cameras Come of Age

A diamond is a lump of coal that did well under pressure.

Anonymous

Over the past decade, SPECT has been practiced as an accessory to regular imaging. Cameras have been designed primarily for planar imaging with SPECT capabilities often added as an afterthought. Cost, unstable technology and reimbursement problems appeared to conspire to make SPECT imaging an unprofitable, although scientifically and clinically rewarding, endeavor. Recently, the picture has changed. Systems optimized for SPECT imaging or, in some cases designed exclusively for SPECT imaging, have become widespread and have been profitable for their vendors. More than 100 dedicated SPECT systems have been sold during the past twelve months in the United States alone.

WHY NOW?

The advance of dedicated SPECT systems is due to the convergence of developments in technology assessment, camera construction, tracer development, collimation, computing and reimbursement practices.

Growth in nuclear cardiac imaging over the past decade has been enormous. Although SPECT has been developing for years, only recently has hard data appeared attesting to its superior clinical results. Fintel et al. (*1*) have shown that thallium SPECT imaging is superior to planar imaging. The development of ^{99m}Tc-sestamibi and ^{99m}Tc-teboroxime and effective ^{99m}Tc-labeled heart tracers has advanced the use of SPECT. To take advantage of the higher photon flux offered by these tracers, the interfering effects of adjacent liver and bowel activity that would otherwise obscure the inferior wall must be eliminated. Planar imaging of these tracers is clearly inferior to SPECT (*2,3*). The emergence of ^{123}I-iodoamphetamine, ^{99m}Tc-HMPAO and ^{99m}Tc-ethyl-cysteinate dimer for brain imaging has opened a vast new territory to the clinical practice of nuclear medicine (*4*). These tracers are only of value when imaged tomographically. The detailed structure of the brain demands the highest imaging quality possible and, in many centers, has driven the move to dedicated SPECT imagers.

Perhaps the most important development in dedicated SPECT cameras has been the reintroduction of multidetector systems. Dual-headed, SPECT-capable gamma cameras were available over a decade ago but were not particularly successful. Although many aspects of SPECT imaging technology have improved since that time, the primary obstacle with these units was difficulty in aligning the two detectors. In an attempt to provide maximum flexibility, camera designers furnished multiple independent axes of motion for each detector. In addition to orbiting around the patient, detectors could be tilted in several different directions through various gimbal mounts. A camera so equipped could theoretically be used for the entire gamut of planar imaging as well as

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for SPECT. However, in the absence of sophisticated computer correction techniques, it was virtually impossible to physically align both detectors in all axes of motion and was therefore extremely difficult to acquire projection data with both detectors capable of being combined into one sharp, well-aligned image set.

The *limitation* of detector movement was essential to the current resurgence of multidetector SPECT. Perhaps counter-intuitive, this reduction in flexibility has led to the improved image quality and clinical utility of modern systems. Other than a circular orbital motion, detector movement is restricted to radial movement in and out about the physical center of rotation; no tilting or swiveling is allowed. These systems are large, heavy units by design and thus minimize the possibility that flexion of supporting structures will degrade detector alignment. Some units sport multiple mounting points for each detector to further reduce the possibility of detector-sagging with time. One system has two perpendicular detectors "welded" together in a single case for maximum alignment stability. To a great extent, detector alignment in all of these units is "fixed at the factory" and only minimal adjustments are available to the user. In fact, most of these adjustments involve software alterations of the computed center-of-rotation rather than physical adjustments to detector orientation. The key perception, that of moving from small, flexible systems to large, rigidly braced and relatively inflexible systems, has produced a quantum leap in image quality and has made this new age of dedicated SPECT systems possible.

Surprisingly, recent reductions in reimbursement for nuclear procedures have provided an incentive to acquire multidetector SPECT systems. Financial restrictions have made the cost-effective, rapid performance of "bread and butter" procedures a top priority. Since cardiac imaging and whole-body bone imaging currently account for the lion's share of clinical imaging, any methodology that permits a higher throughput brings a cost benefit. The ability to shave 10–15 min off each cardiac SPECT acquisition by using multiple detectors allows imaging an additional patient per day per scanner. This brings in added revenue of over $1000 per day at present rates. It doesn't take too long for this to pay back the added cost of a multidetector system.

Dual-headed SPECT systems that are capable of whole-body imaging are particularly cost-effective in that they may be used for a variety of planar studies as well as high-quality SPECT. The ability to put 10–15 bone scan patients per day through a two-headed scanner pays back the added cost in a surprisingly short time. Multidetector designs with larger detectors have been introduced to optimize utility for whole-body and general-purpose imaging while maintaining the advantages of a rigid multidetector system. The financial advantages of a high-throughput system are greatest in a high-volume department.

The theoretical advantages of focused collimation have been known since the beginning of scintigraphic imaging. Focused collimators, e.g., fan-beam or cone-beam, provide both higher resolution and higher sensitivity over the desired field of view when compared to their parallel hole counterparts (*5,6*). Fan-beam collimation is now widely available from a variety of vendors and focused collimators designed for brain or cardiac imaging on a single-detector SPECT system are commercially available.

Computer reconstruction algorithms for focused or astigmatic collimators originally took many hours to execute, rendering them unsuitable for routine clinical practice. The computer workstations now coupled with essentially all dedicated SPECT systems can perform these reconstructions in seconds per slice. Many of these units have special hardware "reconstructor" boxes capable of handling this complex math at high speed. Due to the increasingly high speed of basic computer systems the main CPU is now often capable of better performance than the dedicated hardware reconstructor. Newer systems with relatively low-cost workstations or, occasionally, enhanced personal computers, are capable of reconstruction feats in software far surpassing those of the hardware of three or four years ago. In fact, the speed and ease of SPECT reconstruction on these systems is a key factor in their current acceptance. Although knowledge and understanding remain the keys to success, it no longer requires a dedicated "computer technologist" to process SPECT studies. A single technologist can often process a reasonable number of SPECT studies during or immediately after acquiring them.

QUALITY CONTROL AND ACCEPTANCE TESTING

As Kouris et al. (*7*) point out, the modern multidetector SPECT system is a complicated beast requiring substantially more attention to quality control than the typical planar system (*8*). Although today's systems boast a level of stability far exceeding those of a few years ago, several points deserve special attention.

It has been clear for several years that collimators good enough for planar imaging are often not good enough for SPECT (*9*). Collimator uniformity must be superb (*8,10*) and the angulation of collimator holes must be perfect (*11*). As Kouris et al. (*7*) point out, buying from a reputable manufacturer is not enough to guarantee these virtues. Although some uniform flaws may be correctable by software, don't sign the check without testing the merchandise.

Not only must all detectors in a multidetector system be properly adjusted for energy, uniformity and linearity, but each must be matched to the others. During early-acceptance testing of a multidetector device in my own institution, we discovered that photopeaks could be appropriately centered for each detector when viewed individually, but all photopeaks were not identical. Since the photopeak set at the console applies to all heads equally, some heads were being peaked correctly while others were not. Not only did this result in image degradation, but it also caused substantially different sensitivity from detector to detector. Visible nonuniformities in the reconstructed data resulted. Although quickly solved by the field service representative, this problem exemplifies that single-detector quality assurance is not sufficient for a multidetector system. If the measure of sensitivity for each detector is not essentially identical when peaking, suspect a problem. In some systems, the spectra from each detector can be overlaid, permitting visual inspection.

All detectors must have their own reference (correction) floods. Collimators assigned to each head should be identified and the reference floods for uniformity correction applied to the correct collimator. Each detector in a multidetector system must be aligned exactly, not only with the gantry but also with each other. If this were not the case, a point source would appear at different places within the field of view with each detector and reconstruction resulting from the summation of each detector's data would be significantly degraded. Many systems now calculate a separate software center-of-rotation correction for each detector to ensure alignment.

UNIQUE FEATURES OF ACQUISITION

The wide variety of collimation available for modern SPECT systems, ranging from high-sensitivity parallel-hole collimation to ultra-high-resolution fan-beam, mandates careful selection. A well proven but not generally appreciated concept comes to play here (*9,12,13*). In SPECT, it is better to have a somewhat count-poor but otherwise sharp image than a high-count blurry one. The use of multiple detectors provides sufficient sensitivity to allow one to use the highest resolution collimators available and still achieve adequate information density. The benefits from using such fine collimation are well appreciated on multidetector systems.

Fan-beam collimators are relatively new on the clinical scene. Although difficult to construct, major advances have been made along this line. If the part of the body to be studied, typically the brain, fits appropriately within the field-of-view of the fan-beam collimator, improved resolution comes with a sensitivity improvement. The resulting improvement in information density and image quality is well worth the added expense. The Kouris paper (*7*) outlines their methodology for testing such collimation. They found some problems, but it remains to be seen how frequently such problems occur. The moral here is *caveat emptor*—the buyer should do his own performance testing before acceptance.

Imaging of phantoms is extremely important. The Hoffman phantom in either the two-dimensional or three-dimensional version may be quite useful. There is some recent evidence, however, that the 4:1 gray-white matter ratio Kouris et al. used is too high. Recently presented work (*14*) suggests that the ratio should be closer to 1.8:1. We have found it extremely useful to check our system on a cylindrical phantom filled with a uniform concentration of tracer. It is much easier to visualize ring and arc artifacts on a uniform field than on a complex object such as a Hoffman phantom or a real patient. The uniform phantom is also useful in detecting "ringing" artifacts caused by incorrect filtration. These are especially common when using the resolution-enhancing or restoration filters provided with many systems.

When using a dedicated SPECT system, avoid using too few projections. Sixty projections over 360° severely undersamples the periphery of the field-of-view. While this may not be grossly apparent with an older low-resolution system, it makes no sense to invest in a high-resolution system and then throw the resolution away. With modern systems, consider 120 projections as the minimum number, especially when using a 128 × 128 or larger reconstruction matrix (*15*).

Likewise, don't use too small a reconstruction matrix, especially during quality acceptance testing. Although it may be argued that motion in structures such as the heart renders added resolution unnecessary—why throw away image quality? Well-filtered images from a properly adjusted and calibrated multidetector SPECT system are noticeably better on 128 × 128 matrix than a 64 × 64 matrix. The costs of going to a higher resolution matrix are computer memory and CPU time. These days, both are cheap.

Most of the current generation multidetector systems permit rapid sequential acquisitions, i.e., acquisition of multiple 360° data sets with minimal, if any, pause between them, thus permitting acquisition of dynamic data that may be useful for assessing tracer washout (*16,17*). Perhaps more important for clinical practice, the use of a rapid sequence of SPECT acquisitions gives one the ability to compensate to a certain extent for patient motion. Consider, for example, acquiring a brain SPECT study not as one 30 min acquisition but rather as three 10 min acquisitions. If the patient moves during one of these acquisitions, these data can be discarded and data from the remaining acquisitions added together for reconstruction. The result is an image set with lower counts but without the artifacts caused by patient motion. By routinely imaging patients at risk for involuntary motion this way, many otherwise unusable acquisitions can be salvaged.

THE FUTURE

Dedicated SPECT systems with variable geometry have come on the market offering a camera optimized for brain and body SPECT, cardiac SPECT *and* whole-body planar imaging. Will they be rigid enough? Only time will tell. The first commercial version of a ring detector derived from the Aspect system has recently become available (*18*). Such a system is highly optimized for SPECT imaging of a limited volume but is less suitable for whole body imaging. The potential for this or other ring devices (*19*) has yet to be realized. Likewise, the potential for helical or other systems to combine SPECT and whole body imaging in a manner similar to that of PET scanners remains to be seen.

Contrary to many predictions, the technology of the gamma camera has advanced dramatically over the last few years. This has occurred despite, and to a certain extent because of, the financial imperatives of modern practice. Don't tell Hillary, but hard times continue to bring out the best in us.

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