New Equipment in Nuclear Medicine, Part 1: Solid-State Detectors

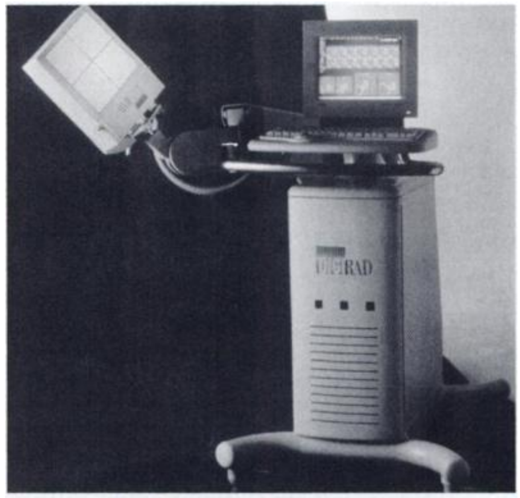
Cameras that capture photons for nuclear medicine images are breaking free of several restrictions imposed by traditional scintillation/photomultiplier detector technology. New solid-state detector technology will enable the camera head to zoom in close to small body parts while making the whole system smaller, lighter, and portable. On another technology front, engineers have developed systems that diminish the borderline between positron emission tomography (PET) and single-photon emission computed tomography (SPECT): Some dual-head SPECT systems can produce images from positron tracers that may provide a clinically validated substitute for PET scans. These hybrid SPECT/PET systems will make fluorine-18-fluorodeoxyglucose (FDG) scanning available to many oncology patients who don't live anywhere near a PET scanner.[1]

Solid-State Detectors Reflect State-of-the-Art Technology

Solid-state technology, which replaces scintillation crystals and photomultiplier tubes with solid-state crystals and semiconductor electronics, may change nuclear medicine imaging in the same way it revolutionized television sets and computers by making vacuum tubes obsolete, predicted Karen Klause, president and CEO of Digirad Corp., San Diego.

In a traditional Anger camera, a gamma ray strikes a sodium iodide (NaI) scintillation crystal, which transforms that into a flash of light; a photomultiplier tube then transforms the light photon into an electric charge, completing a two-step process. With a solid-state detector, a gamma ray strikes a different type of crystal, such as cadmium zinc telluride (CdZnTe, or CZT), which is a semiconductor that converts the photon directly to a digital electronic signal, a one-step process.

"A semiconductor detector is digital in the position sense because each pixel is actually a separate detector, and the photon either hits a detector [pixel] or it doesn't. On the other hand, with the NaI detector, each photon is absorbed somewhere in a big crystal and each photomultiplier tube flashes for each event," explained F. Patrick Doty, PhD, a principal member of the technical staff at Sandia National Laboratories, Livermore, CA. To pinpoint the origin of each event, a complex algorithm compares the relative signal strengths from all the photomultiplier tubes. "That's why NaI detectors have poor energy resolution. And because of their analog position sensing, they have poor contrast," said Doty, formerly a principal materials scientist at Digirad.



Recently cleared for marketing by the FDA, the Digirad 2020*tc* Imager substitutes semiconductors for vacuum tubes.

In June 1998, Sandia and Digirad signed a three-year cooperative research and development agreement. Solid-state detector research at Sandia primarily focuses on large-volume spectrometers for nuclear safeguards and treaty verification, but the technology can sometimes transfer to nuclear medicine, noted Doty, since "all gamma cameras are essentially spectroscopic imagers."

The Digirad 2020*tc* Imager (Fig. 1), cleared for marketing by the U.S. Food and Drug Administration (FDA) in June 1997, substitutes semiconductor electronics for vacuum tubes. According to Klause, the direct digital conversion improves energy, contrast and spatial resolution.

Under the medical directorship of William L. Ashburn, MD, the company has collected clinical data, including direct comparisons with conventional gamma cameras, at several hospitals and outpatient clinics in southern California. "Because it's portable, we don't have to install the camera for very long at any one location. We roll it in, plug it in, and it's ready to go. We collect patient images, leave it there for a couple of days, then move it to a different site," said Klause. The camera head weighs about 50 lbs (22.5 kg) and the whole system, including camera and cart, weighs less than 300 lbs (135 kg). On the other hand, a traditional gamma camera system can weigh 3,000 to 5,000 lbs (1,350 to 2,250 kg).

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1 Hybrid PET/SPECT will be covered in Part 2 of this series.

and to HCFA its advocacy of separate payments for radiopharmaceuticals, apart from APCs, and its insistence that payments should be made on the basis of reasonable costs. Alternatively, radiopharmaceuticals could be paid under one of the following "backup" proposals:

A separate payment might be based on a national price list for radiopharmaceuticals similar to the list developed in 1995 by the Florida Medicare carrier. This "Florida list" passed the test of time and is considered reasonably balanced by Florida providers and the insurer.

Another option involves distinct APCs for radiopharmaceuticals, paid separately from (and in addition to) the APCs for nuclear medicine procedures. HCFA proposed such separate APCs for chemotherapy drugs, and the task force believes that there is equally strong justification for having separate APCs for radiopharmaceuticals because of the similarly broad price range and the lack of correlation between the price of the drug and the price of the procedure in which the drug is being used.

Finally, if payment for the radiopharmaceutical were to be included in the APC payment, the component reflecting radiopharmaceuticals should be derived from the most recent cost reports available to HCFA and other reliable data sources for radiopharmaceuticals, which the task force believes would more accurately portray radiopharmaceuticals than the data from 1996.

Since radiopharmaceuticals may be introduced into the market in the middle of a fiscal year, we also recommend that HCFA makes clear that outlier payments should be available to hospitals to pay for the costs of new and innovative radiopharmaceuticals whose costs have not been incorporated into the APC payment.

Additionally, in July, the Council on Radionuclides and Radiopharmaceuticals, Inc. (CORAR) commissioned an additional study of HCFA databases to gather more up-to-date and more complete reimbursement data for radiopharmaceuticals.

The "saga" of development and implementation of APCs will most likely continue during 1998, 1999 and even the year 2000. Comments on the September 8, 1998, APC proposal must be submitted to HCFA by the Nuclear Medicine Task Force and other interested parties by November 9, 1998. *Newsline* updates like this one are designed not only to keep JNM readers informed about important reimbursement developments, but, very importantly, to strongly encourage you to submit constructive comments and data to the task force and to HCFA.

Finally, the Nuclear Medicine APC Task Force is an excellent example of how coordinated efforts among the members of the nuclear medicine community can bring together all key organizations to address important federal policies, develop workable solutions and seek to educate HCFA and related federal decision-makers on the important medical role of nuclear medicine and radiopharmaceuticals.

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Solid-State Detectors

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Added Views in Scintimammography

The detector is small (8 in × 8 in or 20.3 cm × 20.3 cm) and flat so it can be positioned close to small body parts, a feature particularly useful for breast imaging. "Conventional cameras can provide only lateral views of the breast, but with the solid-state detector, our camera can acquire medial, craniocaudal, lateral, and axial views, which enables scintimammography to simulate the same types of images as a mammogram," said Klause.

Anger cameras require oversampling, explained Doty, which means that the detector must have photomultiplier tubes around the edge of the crystal, outside the field of view. When a conventional detector is placed against the chest wall, most of the breast lies against a wide perimeter of dead space. With a solid-state detector, however, there is little dead space (0.5 in, 1.3 cm), so that the detector edge can be positioned perpendicular to the chest wall for a medial view of the breast.

"Adding the medial view enhances lesion detectability in medially located cancers and may increase the detection rate of those cancers," said Iraj Khalkhali, MD, director of breast imaging at Harbor-UCLA Medical Center in Torrance, CA, who worked with nuclear medicine physicians and technologists in the mid-1990s to develop the scintimammography procedure using technetium-99m sestamibi (Miraluma, DuPont). Preliminary results of a recent multicenter trial using conventional gamma cameras, in fact, found that the sensitivity of sestamibi in nonpalpable lesions was only 47.6% for medial cancers compared with 65.8% for lateral cancers.[2]

By using a split-view biplane collimator with the Digirad solid-state camera, the system may serve another role in breast imaging by providing scintimammographic data for stereotactic biopsy, said Linda Diggles, CNMT, who works with Khalkhali at Harbor-UCLA. "The lesion can be located more precisely when the camera obtains the same image from two different angles," she explained. The biplane collimator was used frequently for cardiac imaging before the advent of SPECT, she added.

2 Khalkhali I, Mishkin F, Diggles L, Ashburn W. Value of adding medial views to routine breast imaging - experience with a solid-state (CdZnTe) gamma camera. *J Nucl Med* 1998;39(5)(suppl):139P. Abstract 546.

Upright Chair Increases SPECT Fields

For SPECT applications, Digirad has designed an upright rotating chair so patients rotate in front of the detector instead of vice versa. The chair, which is not yet FDA-cleared for marketing, enables cardiac imaging patients to sit with their arms resting on a bar in front of them, allowing the diaphragm to drop down and out of the way.

With a diverging collimator, the field increases to lung-scan size (14 in × 14 in or 35.5 cm × 35.5 cm). Although initial interest in the Digirad camera came from departments that wanted to replace an old portable gamma camera, Klause said that the solid-state system can serve as an all-purpose camera. "The only procedure it doesn't do is a whole-body bone scan because we don't have a moving table that enables the camera to cover the whole body," she said. Whole-body bone scans can be done on a large-field-of-view camera, and then the patient can be moved to the solid-state camera for spot views, she added, a scenario that could improve patient throughput.

According to Michael S. Kipper, MD, one of Digirad's clinical investigators, "I think the camera has a particular niche for imaging small organs and for portable imaging in the emergency room, intensive care unit and cardiac care unit." Kipper went on to note substantial progress with the technology. "Over the next few years, we'll see a refinement as it moves toward becoming a general-purpose camera," he said.

Major nuclear medicine equipment manufacturers are also planning solid-state detector technology development. General Electric Medical Systems, for example, is working with Elscint in its ELGEMS joint venture to develop SPECT systems with solid-state detectors based on CZT crystals. Plans are also under way at Siemens Medical Systems, Inc., to use CZT solid-state detectors in future SPECT systems.

One of the advantages of CZT crystals for nuclear medicine is that they are readily fabricated as monolithic pixellated arrays.

With current crystal growth technology, according to the consensus among experts, typical efficiency is 4%, "meaning that 4% of the crystal is operational for solid-state detector applications, but 96% is not," explained Shimon Klier, CEO of Imarad Imaging Systems Ltd., Rehovot, Israel. According to Klier, the company has developed new technology that yields a higher percentage, "almost by an order of magnitude," of operational CZT crystal, which would substantially lower the cost of producing solid-state detectors for gamma cameras. "There's no point in offering something really good that nobody can pay for," noted Mr. Klier.

Bicron, Newbury, OH, supplies NaI scintillation crystals to all of the major gamma camera manufacturers. The company also is actively developing CZT-based solid-state detectors, with production capacity and product offerings planned for 1999.

"The principle focus of our research program is to better understand all the characteristics of the CZT crystal to try to develop ways to grow it more cost-effectively," said Phillip Corvo, general manager for scintillation products at Bicron. "This is a classic price-performance issue. Nuclear medicine physicians will pay some premium for the better energy resolution and higher count rates obtained with solid-state detectors, but not a large premium," said Mr. Corvo. When CZT crystals can be produced at lower cost, solid-state gamma cameras will have larger detector heads.

Harrison H. Barrett, PhD, regents professor at the University of Arizona Optical Science Center in Tucson, foresees that in 5 to 10 years, every gamma camera will use a solid-state detector. "The technology is advancing very rapidly. I also think we'll progress to detectors with much higher spatial resolution," said Barrett. He and colleagues are working on increasing spatial resolution with high numbers of very small pixels (*J Nucl Med* 1998; 39 [suppl]:173P). "The system we're operating has a 0.38-mm pixel size, much smaller than the pixel size any manufacturer is talking about with solid-state detectors," he said.

"We work closely with NASA Goddard Space Flight Center. They've built a quite fantastic array with about a half-a-million 0.1-mm pixels. If you want my opinion on the future of nuclear medicine detectors, that's it: Very large numbers of pixels. Some major advances in nuclear medicine technology are coming out of the gamma-ray astronomy field," Barrett said.

Challenge of Solid-State Detectors for Hybrid SPECT/PET Systems

Bicron predicts that gamma cameras may incorporate solid-state detectors within 5 to 10 years but at an incremental pace. "Right now the big driver in nuclear medicine is PET, and there are some limitations to CZT for PET applications," said Mr. Corvo. With the higher 511-keV energy emitted by ^{18}F-FDG, the crystal needs more stopping power, like a catcher's mitt needs extra padding.

For hybrid SPECT/PET systems, the market has moved from thin NaI scintillation crystals (3/8 in. [1.0 cm]) to thicker NaI crystals (5/8, 3/4 or 1 in. [1.6, 1.9 or 2.5 cm]). "That's no problem with NaI. We grow big ingots of NaI crystal, and we can just cut a thicker slice. However, CZT is a semiconductor, and there are some problems with 'charge collection,' or pooling of electrons across the crystal, when CZT is cut to a thicker depth," said Mr. Corvo. Until crystal growers solve this problem, there will be no wide-scale use of solid-state detectors in nuclear medicine because most facilities that buy a new camera will want hybrid SPECT/PET capability.

Today, solid-state detectors can be introduced to nuclear medicine through niche markets of scintimammography, small-organ studies, portable imaging and surgical applications. As CZT production becomes more cost-effective, and when thicker crystals for hybrid SPECT/PET systems become available, solid-state detectors may eventually go mainstream for all gamma camera systems.

—Linda E. Ketchum