assessment of myocardial viability is unknown, it is a promising area of investigation.

Finally, there are developing applications of radiopharmaceuticals which will potentially greatly enhance the role of SPECT in assessing myocardial viability. Preliminary reports suggest that a new agent, ^{99m}Tc-nitroimidazole metabolism (Patel et al. *Circulation* 1992;86(suppl):I-706 [Abstract]. Also, some vendors are attempting to design collimators and modify SPECT cameras to image the 511keV photon of ^{18}FDG. By combining blood flow imaging with a ^{99m}Tc agent with FDG to asses myocardial viability, a technique heretofore confined to a select few PET facilities would be available to many nuclear medicine laboratories. Iodine-123-MIBG, which is gaining popularity in Europe and Japan, may play an important role in selecting therapeutic agents for patients with heart failure and determining patients for which heart transplantation is indicated.

In conclusion, the recent development of new radiopharmaceuticals has been intensive and has enhanced the diagnostic capabilities of cardiovascular nuclear medicine, but no "ideal" agent has been developed. Thus, even in an environment of academic insecurity and cost constraints, radiopharmaceutical development must continue for us to maintain our competitive edge in a managed care environment.

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New Instrumentation for Cardiovascular Nuclear Medicine

DRIVEN BY DEMANDS FOR greater diagnostic accuracy, new pharmaceuticals, and competition from other modalities, cardiovascular nuclear medicine has experienced a revolution in instrumentation. SPECT systems designed specifically for cardiac imaging have become common. Corrections for photon attenuation, long promised by scientists, are finally making their way into the marketplace. Multi-headed camera systems (Figure1), digital circuitry in scintillation cameras, and increased computer power have all made these advances possible.

Multi-Headed SPECT Systems

The most obvious benefit of adding more camera heads to a scintillation camera system is the increase in sensitivity that comes from doubling or tripling the crystal area. While camera systems with two heads have been sold for many years, the current revolution in camera design was sparked by the triple-headed systems introduced by Ohio Imaging (now part of Picker International, Cleveland, OH) and Trionix Research Laboratory (Twinsburg, OH) in the late-1980's. Nearly every manufacturer now offers multiple-camera SPECT systems as an integral part of its product line.

The most popular systems are configured with two large field of view rectangular cameras mounted opposite each other (at 180°), increasing throughput of whole body bone imaging by allowing simultaneous acquisition of anterior and posterior images. These systems can also increase throughput for 360° SPECT imaging by halving the imaging time. In practice, the increase in sensitivity may be used to improve the image quality (improved resolution or statistics) rather than throughput.

The increased sensitivity of a second camera at 180° may mean very little for cardiac SPECT, if a 180° orbit (45° right anterior oblique to 45° left posterior oblique) is desired for thallium imaging. Counts collected from the second head would simply not be used. Dual-head SPECT systems with camera heads mounted at right angles (90°) are available from at least four manufacturers. The heart's small size allows the use of smaller camera heads than those necessary for bone imaging.

General Electric Medical System's (Milwaukee, WI) Optima and Elscint's (Hackensack, NJ) CardiaL are cameras designed specifically for cardiac imaging with two rectangular cameras mounted rigidly at 90°. A 180° orbit can be achieved by rotating the gantry (and thus each camera) 90°. Sopha offers the sophycamera DST. In this unique system, two heads are not mounted rigidly but may be set either 90° or 180° with a great deal of flexibility. ADAC's (Milpitas, CA) Vertex™ system also allows SPECT to be performed at 90° or 180° but has the advantage of full-size rectangular heads.

An added benefit of a system configured with two cameras at 90° is the ability to do bi-plane gated blood-pool (MUGA) scans. At the Instrumentation Symposium that followed February's midwinter SNM meeting, Gordon DuPuey, president of the Cardiovascular Council and director of Nuclear Medicine, St. Luke's-Roosevelt Hospital (New York, NY), spoke favorably of his experience with bi-plane gated blood-pool with the GE Optima system. Elscint is marketing an upright bicycle exercise machine for use with the CardiaL.

Drawbacks of double-headed cameras include the increase in quality control required by the addition of the second head and some loss of flexibility. These problems may make these cameras difficult to use for some types of imaging (such as gated blood pool) that often have their own difficulties in positioning the camera correctly. The cameras of different manufacturers show much variation in the movement allowed for planar imaging.

Triple-headed cameras are usually dedicated to SPECT imaging and have been marketed towards cardiac SPECT. As with double-headed systems, the three heads result in increased sensitivity that may be used to increase throughput, counts, or resolution. If 180° SPECT is required, the increase in sensitivity is only 50%; one head will not be used at all, the other used for only half of its 120° orbit. While triple-headed SPECT systems are best suited for clinics that have a heavy load of 360° SPECT work and can afford a camera dedicated solely to that, these systems have set a new standard of quality for SPECT.

Specialized collimators have recently been introduced by Siemens Gammatronics (Hoffman Estates, IL) to better use the company's triple-headed camera for 180° imaging. Two camera heads are fitted with 15° slant-hole collimators. Combined with the 60° spread between the cameras, this fitting results in a 90° view between the heads, doubling the sensitivity for 180° SPECT and freeing the remaining camera for a high sensitivity parallel hole collimator that might be used for first-pass studies.

Digital Cameras

Digital scintillation cameras have been defined as camera systems with a computer that is integral to the system and processes the scintillation event. Differences between cameras can somewhat be defined by the answer to the question: where are the electrical signals (which begin in the photomultiplier PM tubes) digitized? Most camera systems convert the position and pulse height signals generated from analog (Anger) circuitry in the camera to digital signals which may then be further corrected for energy and position through digital processing.

The first camera systems that claim to be fully digital have been introduced by Summit Nuclear (Twinsburg, OH) and Isis (Quebec, Canada). In these systems, the output of each PM tube is processed by its own analog-to-digital converter. All of the positioning and pulse height analysis may then be performed digitally, which should give greater processing flexibility, resulting in greater spatial resolution, energy resolution, and perhaps in higher count rate capability.

Converging Collimators

Some manufacturers are developing converging (fan-beam) collimators optimized for cardiac SPECT. These collimators allow more of the crystal to be used, increasing sensitivity. Converging collimators require special image reconstruction software that may result in much longer reconstruction times, a problem largely offset by advances in computer technology.

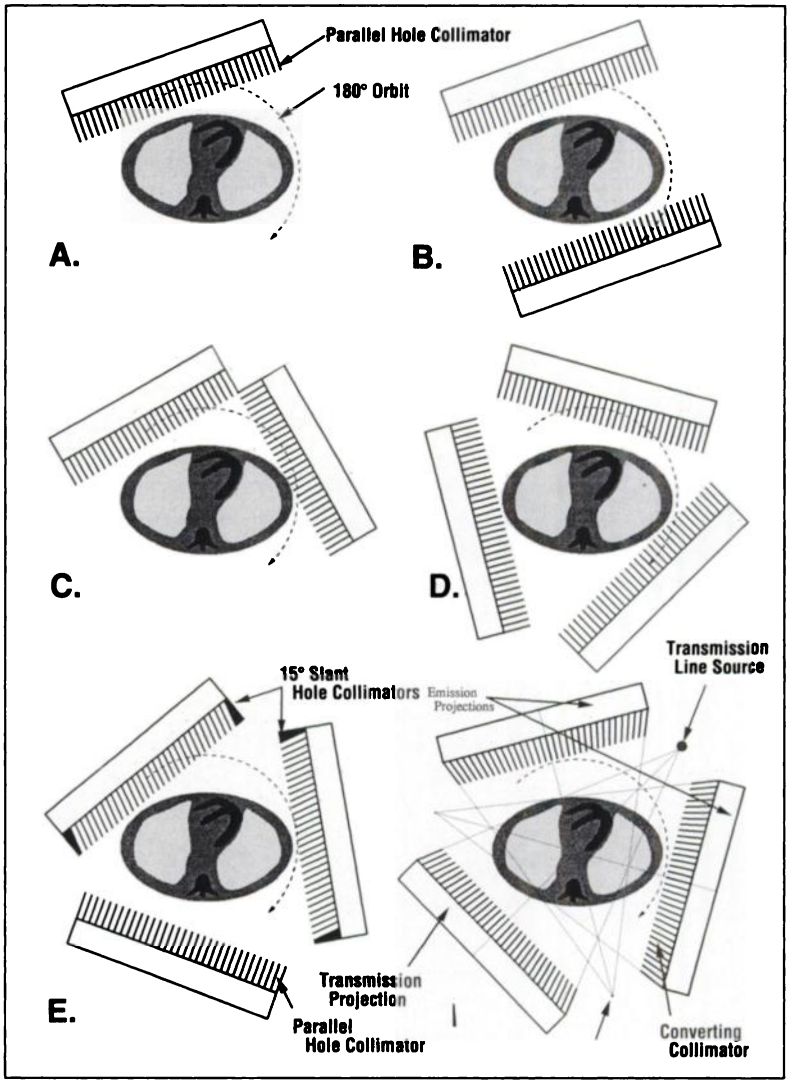

Figure 1. Configurations of different multi-headed camera systems.

One problem with converging collimators in cardiac SPECT is that, while the heart may remain in the field of view for the entire study, other parts of the body in the same plane as the heart may be clipped and produce reconstruction artifacts. One response to this problem is Siemens' Cardiofocal collimator, which varies in the degree of convergence over the face of the camera. In theory, this type of collimator will improve resolution and sensitivity in the heart region but still image the whole body.

Camera Orbits

The traditional orbit used for SPECT imaging has been circular, 360°, or 180°, with step-and-shoot motion. Advancements in radiopharmaceuticals and technology are making more complicated motions more appealing. The range of motions include the orbital arc, the shape of the camera orbit, and the camera speed.

◗ ***Orbital Arc***—For years, users have had two choices in camera orbital arc: 180° or 360°. One hundred eighty degree orbits have been preferred for some types of imaging (including cardiac SPECT) because of the severe photon attenuation experienced at some camera views. It is desirable, however, to exclude less than the full back 180° from the reconstruction. Arcs of 240° and 270° require modification of the reconstruction software and are available from a few manufacturers. Flexibility in choosing the arc may be a great advantage in multi-headed cameras, which acquire projections over 360°, regardless of whether they will be used.

◗ ***Step-and-Shoot, or Continuous Motion***—Most scintillation cameras move in a fashion called "step-and-shoot," as they orbit the patient. The camera moves, stops, acquires an image, moves again, stops, acquires another image. While the camera moves, counts are wasted—a significant waste because cameras take two to four seconds to move between stops.

Continuous orbit cameras represent an attempt at resolving this problem by acquiring counts at all times, even while the camera moves. Traditionally, continuous motion cameras move slowly and smoothly while counts from designated arcs are collected from the planar projections. The smaller the arc used for each planar, the less the blurring due to the camera's motion. Many manufacturers offer a hybrid motion, sometimes called "continuous step-and-shoot." The camera motion duplicates step-and-shoot, but the camera never stops acquiring.

◗ ***Body Contour Orbits***—One widely touted feature of many SPECT systems is the ability to do elliptical or body contour orbits. These orbits reputedly minimize the distance from the camera to the body throughout the tomographic acquisition, maximizing resolution. Some research indicates that body contour orbits may result in unacceptable image artifacts, particularly when 180° orbits are used, and thus the use of body contour orbits for cardiac SPECT has been highly debated.

Nuclear Medicine Computers

The trend in computers is toward more memory, more disk space, and faster processing units. These increased capabilities give the advantage of easier manipulation of larger images and have led to many of the important procedures recently introduced for nuclear medicine. Just doubling the matrix size of an image quadruples the memory and disk space required for that image. If the number of stops is increased, this further increases the storage needs. The number of operations required to reconstruct a SPECT image increases even more rapidly as the matrix size increases.

◗ ***Gated SPECT***—A gated SPECT is one study in which the large amount of data generated is an important consideration. Dividing the cardiac cycle into 16 frames and using 60 projections and 64 x 64 pixel matrices generates over 8 Mbytes of data per study. Also, the time needed for the reconstruction of a gated SPECT study is greater than for a standard SPECT study, roughly by a factor equal to the number of frames.

◗ ***Workstations***—The trend in computer systems toward standardization has fueled an explosion of systems called "workstations" that run an industry operating system (UNIX) and have a graphical user interface (GUI, X windows). The term *workstation* describes a computer smaller than a mainframe but larger and more powerful than a personal computer. Today's workstation capabilities exceed those of mainframes of a few years ago.

One advantage of an industry standard operating system is that software developed on one manufacturer's computer may be more easily transported to another manufacturer's system, so the use of third-party software is easier, and manufacturers may incorporate multipurpose software into their nuclear medicine system.

The standardization of the transfer of images between systems and modalities has been the focus of a joint committee of the American College of Radiology and the National Electrical Manufacturers Association. This effort has resulted in the DIA COM (Digital Imaging and Communication) standard.

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