# Review of Instrumentation Developments at the SNM 1996 Annual Meeting

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Our report describes new advances in nuclear medicine instrumentation and computer software shown by commercial companies during the 43rd annual meeting of the Society of Nuclear Medicine (SNM) held in Denver, CO, June 3-5, 1996. We have focused on the description of new detectors, attenuation, scatter correction, reconstruction, computer platforms, automated image processing, cardiac software, multimodality image fusion and connectivity. The commercial technology often has been developed in collaboration with physicians and scientists who presented abstracts at the meeting relating to the new products. We have cited these abstracts, which can be found in the May 1996 *JNM* Abstract Proceedings Book.

**Advances in Detectors**

Continuing a trend begun at last year's meeting, almost all vendors marketed their new gamma cameras as "digital." We found differences in the interpretation of this term. Many vendors now deliver detectors with one analog to digital converter (ADC) per one photomultiplier (PM) tube. Table 1 shows a comparison of the new camera features. New developments in cameras include the Siemens ECAM dual-head system with variable angle geometry (90-180). The system features nonuniform profile attenuation correction option as works in progress, and it is designed for coincidence imaging. It also uses HD3 (high-definition digital detector) detectors. Siemens emphasized energy-independent characteristics (uniformity, linearity) of the detector achieved by software-based correction of the scintillation light transfer function.

**(Table 1)** Comparison of Selected Features of Cameras and Acquisition Modes

| Vendor | Variable angle two-head | L-shape dual-head | Triple-head | Fan-beam | ADC at each PM | Nonuniform attenuation correction | Scatter correction | Coinc. image† |
|---|---|---|---|---|---|---|---|---|
| ADAC | Yes | Yes | No | Yes | Yes | Vantage | EXSPECT | Yes |
| Elscint | Yes | Yes | No | Yes | Yes | TransACT | CFI | Yes |
| GE | Yes | Yes | Yes* | No | No | Yes | No | Yes |
| Hitachi | Yes | No | No | Yes | Yes | wip | Yes | No |
| Park | Yes | No | No | Yes | Yes | No | Holospectral | No |
| Picker | No | No | Yes | Yes | No | STEP | No | Yes |
| Siemans | Yes | No | Yes | Yes | Yes | Music Profile | No | Yes |
| SMV | Yes | No | No | Yes | No | TAC | Restore | Yes |
| Toshiba | No | No | Yes | Yes | No | Transview | TEW | No |
| Trionix | No | No | Yes | Yes | No | No | No | No |

*Neurocam - available only in Europe. †Acquired coincidence images were demonstrated.

Another new camera is the GE Millennium 2 MG variable-angle, dual-head system with 48 square PM tubes in each head. In this camera, PM-tubes are digitized by row and column but not individually. Despite bigger tubes, the same spatial resolution is achieved and the incident count rate at 20% loss is quoted at 325K cps. Hitachi now markets the SpectraDigital, 150, 260 V250DS series digital cameras (older DS models were previously shown by Summit Nuclear and SMV). The new SpectraDigital V250DSP camera has digital signal processors, slip-ring and is designed for coincidence detection.

The use of gamma cameras to perform positron imaging with PET radiopharmaceuticals has been a major focus of research and development. To improve sensitivity and resolution of 511-kev imaging, several companies were demonstrating dual-head cameras operating in PET-like coincidence mode without collimators. In general, these devices offer better imaging characteristics than SPECT but are inferior to conventional PET. The upgrade cost to coincidence instrumentation is estimated at $100,000 to $200,000 by most vendors. The count rate of cameras operating without collimators remains a technical problem, since only a small fraction of counts detected in coincidence is used to form the image.

ADAC had improved their molecular coincidence detector (MCD) system over the past year. At this year's meeting, they targeted oncology FDG imaging with a thicker crystal, 5/8 inch, which slightly degrades conventional SPECT system resolution (from 7.4 to 7.6 mm @ 10 cm with a low-energy, high-resolution collimator). The efficiency of the 5/8-inch crystal is improved by 10% with $^{99m}$Tc.

ADAC also designed a faster detector that achieves 2.4 million cps for each head (all counts including singles), resulting in effective clinical coincidence count rate of 10-20K cps. The high count rate is achieved by a combination of pulse clipping and digital calculation of local centroid. Count rates in the range of 2M cps seem to be the practical maximum due to saturation with random coincidences. ADAC displayed clinical FDG tumor images that are more difficult to acquire with their MCD system than the FDG brain scans shown last year. This difficulty occurs because coincidence mode requires significant computational resources due to the file size of raw list mode data, which is on the order of 800 MB for a typical oncology scan.

Other vendors also demonstrated clinical coincidence systems this year. Elscint described their use of CT-like, slip-ring technology on their Varicam camera, which allows processing of partially acquired coincidence images during the acquisition. Elscint Varicam camera has 100 MB of RAM and three digital signal processors on the acquisition board which allows three-dimensional multislice rebinning with interpolation of coincidence events. The camera uses flash ADCs and digitizes energy signals with a high sampling rate (50 nsec) to allow for shape analysis and better discrimination.

**(Table 2)** Comparison of Nonuniform Attenuation Correction Methods

| Vendor | No. of heads | Source | Isotope | Activity (mCi) | Geometry | Acq. mode | Algorithm |
|---|---|---|---|---|---|---|---|
| ADAC | 2 | dscl | $^{153}$Gd | 250 | Parallel | sim | MLEM |
| Elscint | 2 | dscl | $^{153}$Gd | 300 | Parallel | sim | IPR+FBP |
| GE | 2 | dscl | $^{153}$Gd | 500 | Parallel | seq | MLEM |
| **Picker** | | | | | | | |
| STEP 2000 | 2 | scl | $^{153}$Gd | 800 | Parallel | sim | OSEM |
| STEP 3000 | 3 | cl | $^{57}$Co/$^{99m}$Tc for $^{201}$Tl<br>$^{153}$Gd for $^{99m}$Tc | 20<br>60 | Fan-beam | sim/seq | OSEM |
| **Siemens** | | | | | | | |
| Profile | 2 | mcla | $^{153}$Gd | 2×75 | Parallel | sim | IPR+FBP |
| Mμsic | 3 | cl | $^{241}$Am | 150 | Asymmetric fan-beam | sim | IPR+FBP |
| SMV | 2 | dscl | $^{99m}$Tc/$^{153}$Gd | 300 | Parallel | sim | FBP+IC |
| Toshiba | 2 | us | $^{99m}$Tc/$^{153}$Gd | 25 | Parallel | sim | FBP+IC |

dscl=dual-scanning collimated lines; scl=scanning collimated line; cl=collimated line;mcla=multiple collimated line array; us=uncollimated sheet; sim=simultaneous, seq=sequential; MLEM=maximum likelihood expectation minimization; OSEM=Ordered subsets expectation minimization; IPR=iterative pre-reconstruction; FBP=filtered backprojection; IC=iterative Chang.

**(Table 3)** Comparison of Selected Features or Computer Software/Hardware Platforms and Application Programs*

| Vendor | Hardware/ Operating system | User interface | Prop. display board | Dicom | Auto. motion corr. | Auto. image fusion | Quant. brain | Auto. cardiac SPECT | Quant. gated SPECT |
|---|---|---|---|---|---|---|---|---|---|
| ADAC | SUN/SunOS | Sunview Motif | Yes | Yes | Yes | No | Yes | Yes | Yes |
| Elscint | PC/OS-2 | PM | Yes | Yes | Yes | Yes | wip | Yes | Yes |
| GE | HP/UNIX | Motif | No | Yes | No | No | wip | wip | Yes† |
| Hitachi | HP/UNIX | Motif | No | Yes | No | No | wip | wip | No |
| Park | SUN/Solaris | Motif | No | No | Yes | No | wip | wip | wip |
| Picker | Alpha/OSF | Motif | Yes | Yes | Yes | Yes | Yes | No | Yes |
| Siemans | Mac/System7 | Mac | No | Yes | No | wip | Yes | wip | Yes |
| SMV | IBM RISC Unix | Motif | No | Yes | Yes | No | Yes | Yes | Yes |
| Toshiba | SUN/Solaris | Motif | No | Yes | No | No | No | wip | wip |
| Trionix | SUN/SunOS | Sunview | No | No | No | No | No | No | Yes |

*We did not include programs requiring interactive repositioning/reorientation.
†Only on the older STARCAM computer.
Auto= automated; prop.= proprietary; Quant.= quantitative; corr.= correction.

Current coincidence count rates on the Elscint Varicam are 1-2K cps and the goal is 10-15K cps in about 1.5 years. Elscint has one such system installed the U.S. The Siemens ECAM coincidence detection will include software-controlled integration time and pile-up correction. Siemens also talked about a new scintillation material, lutetium oxyorthosilicate (LSO) for 511-keV imaging crystals which would overcome some of the disadvantages of NaI(Tl). This material is developed by CTI.

Siemens also showed a low-end, three-dimensional PET scanner, ECAT ART, with rotating block detectors. It lists for less than $1 million so it can compete with gamma camera coincidence systems. Picker has works in progress positron coincidence detection (PCD) on its dual-head system with redesigned amplifiers for high count rates; the first clinical installation is planned in two months. They also plan to provide coincidence events on the triple-head PRISM 3000. They implemented Chang-like uniform attenuation correction for coincidence images. Picker currently evaluates 5/8-inch crystals for coincidence imaging.

SMV has coincidence imaging (VCAR) on their DST, DST-XL and FX-80 cameras. They use five flash ADCs that digitize the signal from a local centroid after some analog preprocessing. The signals are deconvolved with a patented D3 algorithm to reduce pile-up. Achieved system resolution is 4.5 mm. GE has a coincidence imaging project on its Maxus camera which has been redesigned for a higher count rate (500K cps). Abstracts 203, 1008 describe initial experiences with coincidence systems. So far, none of the coincidence systems allows for nonuniform transmission map attenuation correction, which is standard on PET equipment.

In addition to digital detectors and coincidence imaging, several other developments in instrumentation were presented by vendors. GE exhibited a prototype of a very compact imaging camera based on a cadmium zinc telluride (CdZnTe) solid-state detector. The futuristic looking model (without the actual detector) had a built-in 1280 × 1024 active matrix display and a cordless mouse for acquisition control; it somewhat resembled an ultrasound system. The detector size will be 16 × 16 cm. GE says that this technology may be available within a few years and could be used for imaging small organs and to assist in surgery.

Park Medical revived the concept of coded aperture collimation, which achieves 6-mm resolution and five to six times the sensitivity of a standard gamma camera. Planar images of phantoms were shown. Park plans to use it for SPECT together with a regular collimator on one head to aid the reconstruction algorithm. The coded aperture collimator weighs about 200 pounds.

Siemens CeraSPECT has shown works in progress liquid optical interface between crystal and PM tubes in its dedicated brain scanner which would allow better light transmission than the traditional design. Siemens also has a new detector for scintimammography.

The one bit of corporate news: Picker acquired ScintiCor company which produces the multi-crystal camera SIM-400 which can achieve a high count rate of 1 million counts per second for first-pass imaging.

#### Towards Quantitative SPECT

Vendors' research and development efforts are mostly concentrated in the area of attenuation correction, scatter compensation and resolution recovery—all of which are needed for quantitative SPECT. They exhibited new or improved hardware and software for nonuniform attenuation correction. Most manufacturers are using line sources to obtain simultaneous or sequential transmission attenuation maps for SPECT. The transmission geometry is fan-beam or parallel depending on the orientation of the line source(s). Transmission data acquired simultaneously with SPECT are corrected for emission energy window contamination (cross-talk). Attenuation compensation can be done by Chang's iterative method, pre-reconstruction techniques or maximum-likelihood reconstruction. The important features of nonuniform attenuation and scatter compensation are summarized in Table 2.

Siemens presented an array of 16 collimated $^{153}$Gd transmission line sources in two arc-shaped holders for the new ECAM camera. The two central line sources have a maximum strength of 15 mCi, and the strength of the others decreases with increasing distance from the center. The effect is that of well-collimated stationary sheet sources. Every six months, as the line sources decay, two central ones are moved to the edge, and two new ones are put in their place. This transmission setup has also been installed on the DIACAM camera and is being tested at one site. Siemens also presented another method for obtaining attenuation maps called Factor. Factor uses a segmentation algorithm to define structures in the attenuation map with pre-assigned attenuation coefficients based on emission measurements. An additional dose of $^{99m}$Tc-MAA defines lung tissue, and a $^{99m}$Tc body wrap highlights patient body contour. Picker presented STEP 2000 attenuation correction on the dual-headed Prism 2000 XP using a $^{153}$Gd collimated line source outside the collimator of one detector. It is currently undergoing clinical trials. GE and Picker scanning line sources use high activity (500-800 mCi), but the sources are covered with attenuating material that is gradually removed as the source decays, thus prolonging the use of the source.

Park Medical intends to estimate attenuation maps analytically instead of from transmission measurements. These maps can be estimated by using scatter data in a maximum-likelihood algorithm as first approximation of the body contour. Attenuation maps can also be obtained analytically from ECT and scatter energy window data (see Krol et al.; *J Nucl Med* 1995; 36:50P). Park intends to pursue both of these methods.

GE uses fast sequential TCT and ECT rather than simultaneous acquisition to avoid cross-talk (Abstract 311). Currently, none of the vendors offers nonuniform attenuation correction on single-head systems.

In addition to attenuation correction, scatter correction is needed for quantitative SPECT. ADAC exhibited scatter compensation and depth-dependent resolution recovery (EXSPECT) which can be applied with or without nonuniform attenuation compensation. The scatter correction is similar to the dual-energy window method (Jaszczak R et al.; *IEEE Trans Nucl Sci* 1985; NS-32: 786-793). EXSPECT has been clinically evaluated (Abstract 313), and its resolution recovery is based on the frequency-distance principle. Attenuation correction with and without EXSPECT is being tested in a multicenter clinical trial. One method, TransACT, uses a multiple-energy-window scatter correction algorithm Compton Free Imaging (CFI) developed by Elscint researcher Dr. Gideon Berlad. Elscint also demonstrated correction for emission contamination in transmission data using a lower-energy window (Abstract 65).

Park Medical uses holospectral imaging to remove scatter (see Gagnon A et al.; *IEEE Trans Med Imag* 1989;8:245-250) and Toshiba uses triple-energy-window (TEW) scatter correction (see Ichihara T et al; *J Nucl Med* 1993; 34:2216-2221). Picker implemented scatter correction using a split-energy window technique (similar to the triple-energy-window TEW method) (Abstracts 952, 962). This technique is being evaluated at two sites. SMV and ADAC have also implemented methods to correct for depth-dependent resolution recovery in SPECT.

ADAC and GE use maximum-likelihood expectation-minimization (MLEM) algorithm, for SPECT reconstruction with attenuation correction. With filtered backprojection, attenuation compensation is performed before (Bellini's, Morizumi's method) or after image reconstruction (iterative Chang's method). In MLEM, attenuation compensation, scatter and detector response can be incorporated directly into the reconstruction algorithm. The main disadvantage of MLEM is that it is computationally intensive.

There were several presentations on a variant of maximum likelihood reconstruction known as ordered subset expectation maximization (OSEM) (Abstracts 239, 240, 241, 243; see also Hudson HM et al.; *IEEE Trans Med Imag* 1994;13:601-609).

This method achieves significant acceleration by reconstructing the projection data divided into subsets. Currently OSEM is being implemented by Picker.

Siemens has implemented a rapid iterative reconstruction algorithm using Gaussian diffusion (IterW2) developed at Mallinckrodt Institute of Radiology. This algorithm incorporates attenuation and a three-dimensional Gaussian blur function and accelerates iterative reconstruction by the inclusion of a ramp filter (Abstract 244). These fast algorithms allow for clinical use of reconstruction methods previously used only by researchers.

Most of the preliminary results from the clinical trials presented at the meeting indicate that attenuation compensation, with or without scatter compensation, results in significantly improved specificity rates for the detection of coronary artery disease but does not affect the sensitivity significantly (Abstracts 311-313). Image truncation poses a problem in attenuation correction for large patients and on cameras with small fields of view.

**Latest Computer Systems and Software**

Vendors have altered or introduced new computer platforms over the past year. Siemens abandoned a Unix workstation called Phoenix, which was shown at last year's meeting. They are porting the Phoenix software on the Macintosh ICON, which has been renamed "Open ICON." The multimodality image fusion software (MAPS) shown last year on the Unix system is being ported on the Macintosh. SMV has dropped the proprietary system inherited from Sopha and now uses only the IBM RISC 6000 and Unix system (previously Summit Nuclear). The Hitachi system is virtually identical to GE GENIE implemented on a HP Unix workstation. This software has been developed by GE with support from ISG (Toronto, Canada). GE and ISG are licensing this software to Hitachi (pending a final agreement in July).

GE has a new acquisition station for their new cameras that is compatible with a GENIE processing station. It is a Pentium-based system running Lynx, a commercial real-time Unix system; it is source-compatible with the HP platform. Although all systems are now based on standard hardware and operating systems, some still use dedicated display boards, which may cause software compatibility problems with new computers. This perhaps could explain why ADAC did not show the SUN Ultrasparc as their platform. Some vendors offer fully functional processing software on laptops (Elscint, Toshiba, Siemens). Selected features of computer systems and application software are characterized in Table 3.

User macro programming utilities have improved since last year. Elscint introduced AutoLearn, a new graphical macro on their Expert workstation. ADAC improved its Provision /Macrovision macro tools based on a general-purpose image processing tool kit AVS. Siemens will use IDL, another image processing tool kit, on the Macintosh to provide high-end imaging tools and programming language. This tool will eventually replace their macro programming environment. They have already implemented nonuniform attenuation correction and iterative reconstruction in IDL. Most of the available macro programming tools have visual character and do not require users to type any commands.

Several new clinical applications were shown at the meeting. ADAC demonstrated slightly improved AUTOSPECT, a fully automated reconstruction/reorientation software for cardiac SPECT. Some other companies exhibited similar software (Table 3). Several companies had licensed the automated quantitative gated software SPECT QGS package from Cedars-Sinai (see Germano G et al.; *J Nucl Med* 1995;36:2138-2147). The identical package ran on the ADAC, Siemens, Elscint SMV, and Picker systems. It is available as an option for approximately $2000. This package allows quantification of wall motion, wall thickening, LV volumes and LV ejection fraction and provides three-dimensional display. It may become standard for gated SPECT processing.

ADAC has also run software from Cedars-Sinai for quantification of transient ischemic dilatation on gated SPECT. Some other new clinical packages include: Elscint QUANTEM quantitative renal package for MAG3 from Emory, Atlanta, GA; ADAC XMOCO, a cross-correlation based motion correction; and SMV "Restore," a package for motion correction based on sinogram fitting and scatter compensation. Picker has added automated registration capability to its multimodality fusion program based on a surface matching algorithm (see Besl PJ et al.; *IEEE Trans PAMI* 1992;14:239-256). In general, however, the multimodality fusion and registration software is still not a standard application on nuclear medicine workstations.

Connectivity has been an important issue this year for most vendors. All vendors offer image export and import based on Interfile 3.3 file exchange standard. Interfile, however, does not address communication needs. DICOM protocol provides this functionality and several vendors now offer DICOM 3.0 "send" and "receive" capabilities. More advanced DICOM features are currently under development.

ADAC was connected to the DICOM booth located in the meeting registration area, and it was possible to transfer patient images during the show. They also demonstrated "Webview", the software for exporting images and reports in HTML format for remote review. Siemens could read images from a DICOM booth via CDs. Siemens emphasized connectivity and were showing competitors' workstations at the booth (GE and Trionix) from which they could directly read images.

A live demo showing teleconferencing via a direct ISDN interface with physicians at St. Louis University ran at various times during the exhibition. The software was "Meet-me" (H.320 standard), a teleconference package on the Macintosh which allows remote clinical image viewing, direct audio-video conferencing and file transfer. The full hardware/software cost of connecting two institutions is around $5000. Several manufacturers also have web pages containing product information.

The most important delevopments in cameras and computer systems at this year's SNM meeting were:

- Several vendors now offer detectors with an all-digital design, digitizing individual signals on each PM tube.
- Gamma camera positron imaging in coincidence mode is being developed by many vendors.
- Nonuniform attenuation compensation has improved since

last year and results from several clinical trials have been reported.

- There is a recent trend towards incorporating attenuation, scatter compensation and resolution recovery into SPECT reconstruction algorithms.
- A new automated quantitative gated SPECT software, QGS from Cedars-Sinai, is now available from several vendors.
- Linking nuclear medicine computer systems is an important issue, and Dicom 3.0 may offer some solutions. Most nuclear medicine workstations currently have some limited Dicom 3.0 capabilities.

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Commentary

# Proposed NEMA Standards for Residents in Nuclear Medicine

The Nuclear Education in Medicine Association (NEMA) requires postgraduate trainees to fulfill the following requirements prior to completion of residency training:

1. Must pass "Acceptance Testing" to enter the program: inspection, filtering and backprojection of his/her profiles.
2. Requires 486 or faster mental processor in brain, with 64 GigaBytes of RAM, to accommodate all the data installed over 4 yr (expandable to 5 yr).
3. Must possess a semipermeable blood-brain barrier, to allow diffusion of all aspects of nuclear medicine administered, which will be traced using compartmental analysis.
4. Be able to absorb information, with a fast compenent whose half- life is measured in milliseconds, without significant attenuation.
5. Have a deadtime of neurons as short as possible, and all functional components that are nonparalyzable.
6. Have visual perception sufficient to see the patient through the scan, and read the requisitions with a modulation transfer function of 1.
7. Must possess strong vestibular apparatus with a perfect COR, to maintain balance while rotating between departments and using different protocols.
8. Be able to return quickly to the department after Interhospital Rounds, with minimal time of flight.
9. Must possess an energy level of at least 1.022 Mev.
10. Should have high emission rate of information at examinations, with significant proportion being coherent interactions, and with minimal crosstalk.
11. Should be adequately shielded to keep demands as low as reasonably achievable and complaints below the minimal detectable level.
12. Have the ability to suppress annihilation reaction when overburdened. With apologies to the other NEMA and to nuclear medicine physicists!

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