Teaching Editorial

Sinograms and Diagnostic Tools for the Quality Assurance of a Positron Emission Tomograph

Positron emission computed tomography (PET), a complex nuclear medicine imaging modality, is rapidly gaining in use for clinical applications. Unfortunately, greater complexity and probability of equipment failures are expected with PET compared to traditional nuclear medicine instruments. It is anticipated that as PET technology becomes more widespread and shortages of PET physicists occur, the nuclear medicine technologist will have more responsibility in the areas of instrument diagnostics, quality assurance (QA), and troubleshooting. In addition, PET instruments in the clinical environment must be operated under the added pressure of having to withstand high patient throughput while maintaining quantitative accuracy.

Although several excellent texts have treated quality control for nuclear medicine in general (*1–3*), very little published work relates to the practical, detailed aspects of quality control for PET. This paper reports on the use of sinogram display or gray scale displays of raw data sets and other specialized software and hardware systems that have proven useful in identifying and diagnosing imaging instrument problems. Practical examples are given for an actual PET instrument, the PC 4600 Neuro-PET,* which has a total of 4,096 detectors and 13 imaging planes (*4*). Although system-specific differences are anticipated, the methods presented have general application to any emission computed tomographic imaging system.

THE PC 4600 NEURO-PET

The PC 4600, more fully described elsewhere (*4*), is a five-ring PET system with a 28.5-cm diameter and a 11.2-cm thick field of view. Each ring consists of 96 (1.9 cm diameter, 3.8 cm deep) bismuth germanate crystals arranged on a 60-cm diameter circle. Individual crystals are connected in coincidence with 21 opposing detectors in the same ring as well as in both adjacent rings. The system has 12 coincidence gates/plane and 13 coincidence planes.

The PC 4600 may be utilized in a stationary mode, or wobbled continuously in a circular orbit to increase the sampling by a factor of eight. Random corrections may be performed using measured singles rates and known detector resolving times. The system is equipped with a 10-mCi ^{68}Ge/^{68}Ga orbiting rod source. This is used for automatic gain adjustments, detector inhomogeneity corrections and transmission measurements.

DAILY PET QUALITY ASSURANCE

Each morning, prior to the arrival of personnel, the computer automatically tunes the energy thresholds for all detectors and collects an empty port scan (EPS) for both wobbled and non-wobbled scanning models using the ^{68}Ge/^{68}Ga transmission rod source. A 17.8-cm diameter, 30.5 cm long uniform water-filled phantom is then centered in the port, and a transmission scan (TS) is collected. The phantom is then filled with a known amount of positron-emitting isotope. A wobbled emission scan (ES) is obtained, typically using a 40-min data collection. Reconstructions are made of both the EPS and TS, and attenuation and detector inhomogeneity (relative sensitivity) correction factors are obtained. If suspicious images were obtained at any part of the QA process (which includes using the PET in all of its possible modes), sinograms are examined for help in the specific identification of problems.

SINOGRAMS

Sinograms are gray scale displays of raw PET data which aid in the diagnosis of various types of hardware or software failures through recognition of their characteristic visual representations (*5*). In a sinogram display, the coincidence counts obtained for each detector pair are represented as a single picture element with the gray scale corresponding to magnitude of the count data and position in the sinogram unique to that detector pair. For an ideal sinogram, the spatial arrangement of the raw detector pair data is such that the failure of specific hardware components or groups of components is readily identified by an abnormal sinogram appearance. Distinct patterns for problems with individual detectors, coincidence gain integrated circuits (ICs), data acquisition boards, or memory, for example, are quickly recognizable in the affected sinogram. A determination of the precise component failing is possible from the location of the abnormal pattern in the sinogram. Rapid and easy problem diagnosis is the major advantage of sinogram usage. The production and

For reprints contact: Kimberlee J. Kearfott, ScD, Dept. of Electrical and Computer Engineering, Arizona State University, Tempe, AZ 85287-5706.

display of the sinograms bears only minimal computational and analysis costs.

For the PC 4600 system, each row of picture elements in the sinogram represents an angle of view of the tomograph. In this sinogram, all points corresponding to a given detector map along a diagonal line unique to that detector. Failure of a detector thus results in an easily recognized abnormally light or dark line in the sinogram. Similarly, problems with boards appear as abnormalities in characteristic parallelograms in the sinograms associated with those boards.

For the PC 4600, both wobbled and non-wobbled data sets may be displayed, and each plane produces a separate sinogram. Data sets are easily displayed for ES and TS data collections. Sinograms thus are available to allow quick testing of the system under its different operating conditions. The character of the sinograms varies both with the type of data collection and the source distribution. For example, for a PET tomograph design such as the PC 4600 and a uniform source covering the field of view, not all detector pairs detect counts from the same integral activity because of system geometry. A uniform sinogram will thus not result even with ideal hardware performance. When the transmission rod source is utilized with the PC 4600, however, each detector views the same activity, and a more uniform sinogram will result. The comparison of wobbled and stationary EPS and TS sinograms with their expected ideal appearance could, however, assist the technologist in further understanding problems, and assure the operator that no problem is missed during QA procedures.

The sinograms of both the EPS and TS collected during the daily PET QA procedure for the PC 4600 were visually examined for problems. Those detectors and detector pairs exhibiting erratic behavior that could not be corrected by simple detector inhomogeneity correction are determined using a movable cursor on the display of the sinogram which automatically prints out indexes of the errant detectors or detector pairs. Following each correction applied to the raw data, it is possible to interrupt reconstruction and observe the effects of the corrections. This is done when artifacts are observed that could not be otherwise explained. The sinogram display of various correction factors, such as attenuation, also is found to be occasionally diagnostic of problems.

Corrections for some of the abnormalities uncovered using the sinograms were made using software. One program was written to replace all individually specified coincidence pairs (which are bins) in the raw data set corresponding to specified detectors by the average of their two surrounding values. An option is available to search the raw data set and replace all bins whose values were one tenth of the value interpolated from their nearest neighbors, or bins having values exceeding some specified value, by the interpolated values.

PET CAMERA DIAGNOSTIC SOFTWARE AND HARDWARE

To further assist in maintenance, additional diagnostic software was developed. This software includes:

1. An automatic gain control diagnostic to check the automatic gain set capabilities of the system by printing out single counts collected for specific fast coincidence board or the gain adjustment value to a single detector.
2. An automatic gain control register cycling program which sends a series of gainset values to all detectors, cycling from the lowest value to the highest value and back down again, thus allowing real time diagnosis of gain adjustment circuitry problems.
3. A data memory diagnostic which performs four tests to trouble shoot the data memories.
4. A program that compares two transmission scan studies and writes an error message for any new singles value or coincidence pair value which deviates from an old value.
5. A motor diagnostic program which performs six tests for trouble-shooting the wobble, rotation, couch, and transmission source motors.
6. A program that prints raw singles and coincidence data.
7. A program that prints the sums of all counts for each detector.

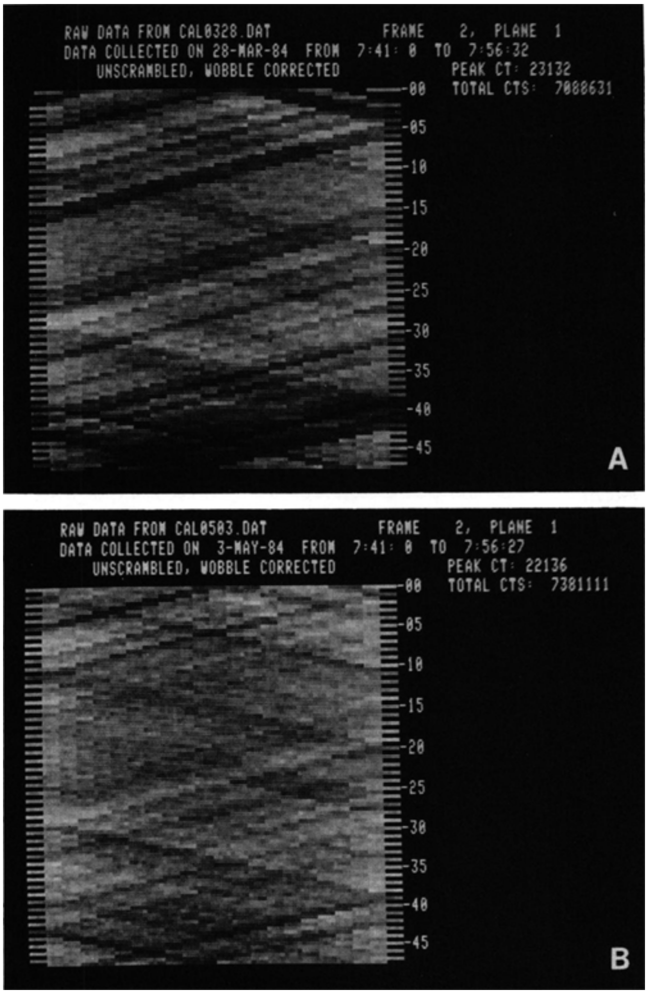

FIG. 1. Sinogram displays of EPS obtained (A) before detector adjustments performed as preventive maintenance, and (B) after detector adjustments performed as preventive maintenance.

8. A program that prints the numbers in the body of a reconstructed image.
9. A program that prints raw data and image headers.

A real time channel monitor (RTCM) was built for system diagnosis. The RTCM has a remote monitor and output for oscilloscope or logic monitor triggering and plugs directly into any of the controller inputs, facilitating easy access to any plane. Front panel switches may be used to select the desired coincidence bin or individual detector for singles readout. A digital monitor, which plugs into the interface between the camera and computer, provides a readout of the coincidences of any plane or total coincidences or singles for any ring.

RESULTS

The patterns observable using sinograms are particularly useful for rapidly determining the nature and significance of PET instrument problems. Figure 1 shows sinograms of the EPS collected before and after manual hardware tuning adjustment was completed by a service person. Although no obvious artifacts were present in the images, the inhomogeneity in the upper sinogram helped in the decision to perform the preventative maintenance. The effect of the detector inhomogeneity correction is illustrated in Figure 2, where an ES data set before and after correction is displayed. If tuning is not possible, this correction is critical for maintaining image quality.

In Figure 3A, a bad detector, represented by a single vertical line in this sinogram of daily PET QA ES data, is immediately apparent. The corresponding reconstructed image revealed a small artifact, but did not allow diagnosis of precisely which detector failed, or even that a single detector was responsible for the problem. This is possible by examination of the sinogram. After using interpolated data to replace the information from the failed detector and performing the detector inhomogeneity correction, the situation is improved (Fig. 3B). It is therefore not necessary to repair the detector prior to performing patient studies on a particular day.

Two different problems occurring during high count rate tests are included in Figure 4. The sinograms provide rapid diagnosis of these problems as arising from coincidence gain ICs and a data acquisition coincidence board. The use of the sinograms enables a more rapid tomograph repair and return to clinical operation. Figure 5 illustrates two occurrences of spikes in the sinogram, due to a software problem with data

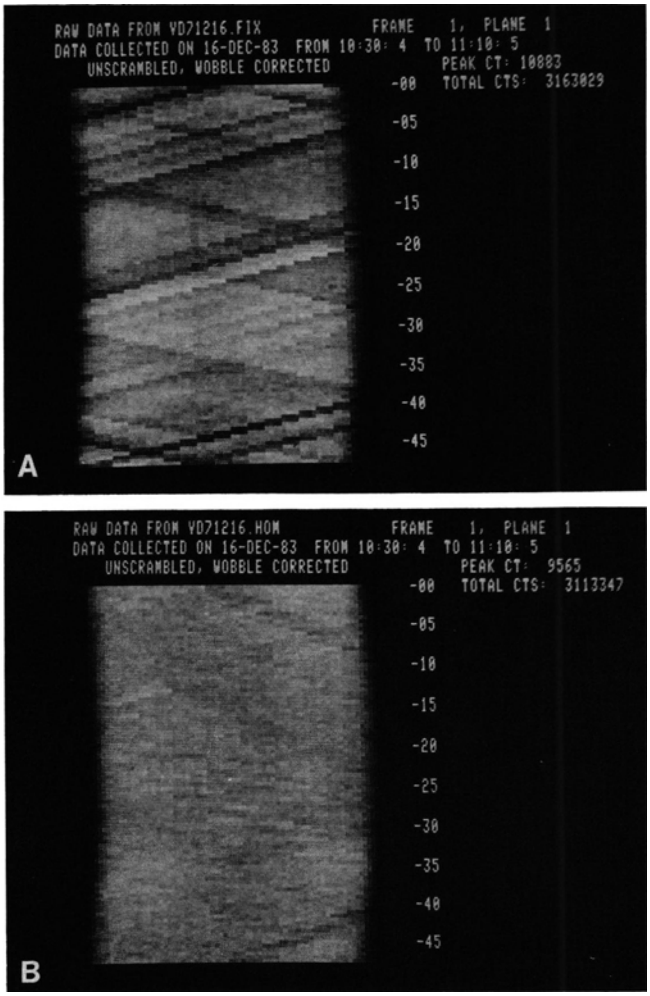

FIG. 2. Sinogram displays of a typical daily QA ES shown (A) before any corrections are applied, and (B) after detector inhomogeneity correction is applied. Note the marked improvement in the uniformity of the response in the data set.

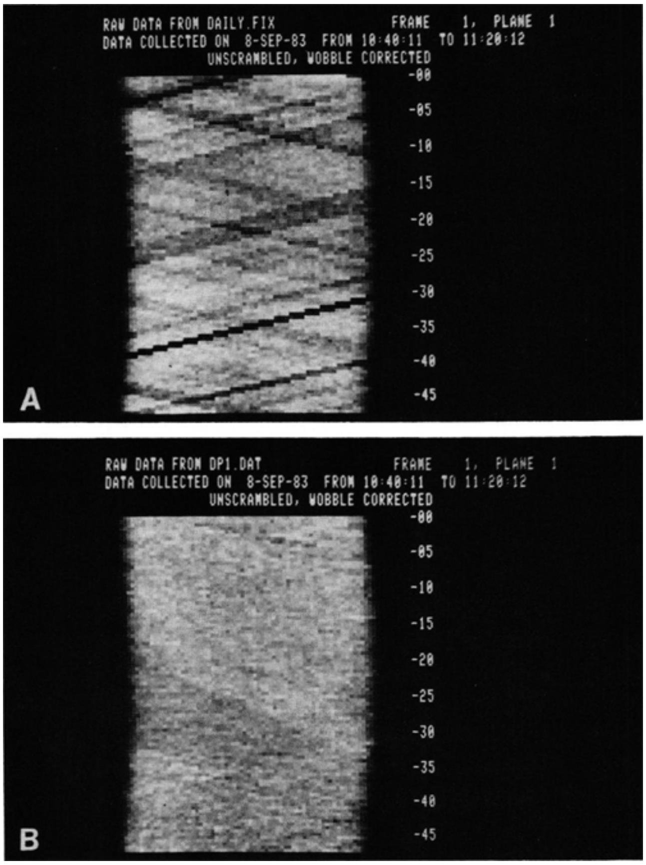

FIG. 3. Sinogram display of a daily QA emission scan (ES) having a bad detector present, apparent as a black line in (A). The sinogram following correction of the data set using interpolation and detector inhomogeneity correction is shown as (B).

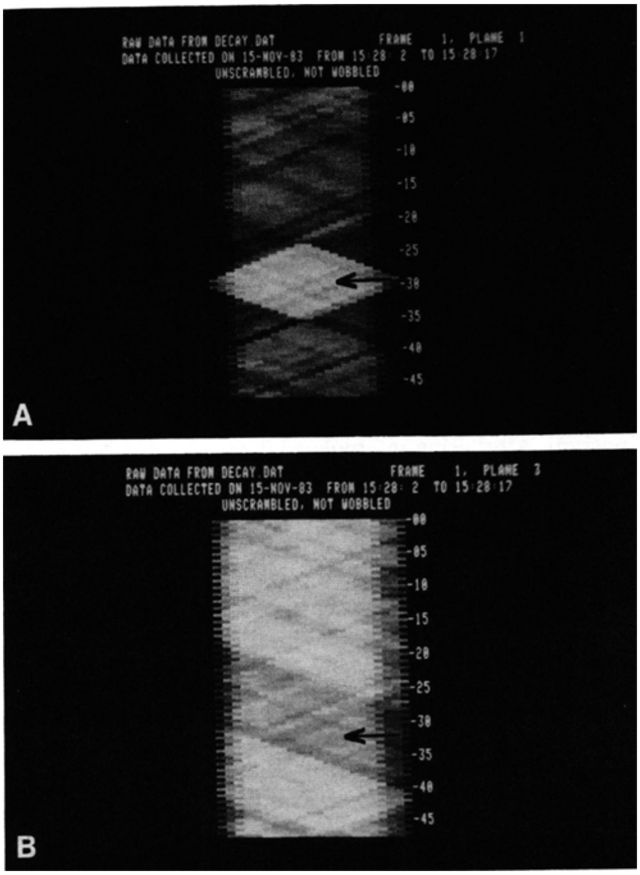

FIG. 4. Sinograms illustrating two PET camera problems, which occurred during high count rate QA tests. They correspond to problems with (A) coincidence gain ICs and (B) a data acquisition coincidence board.

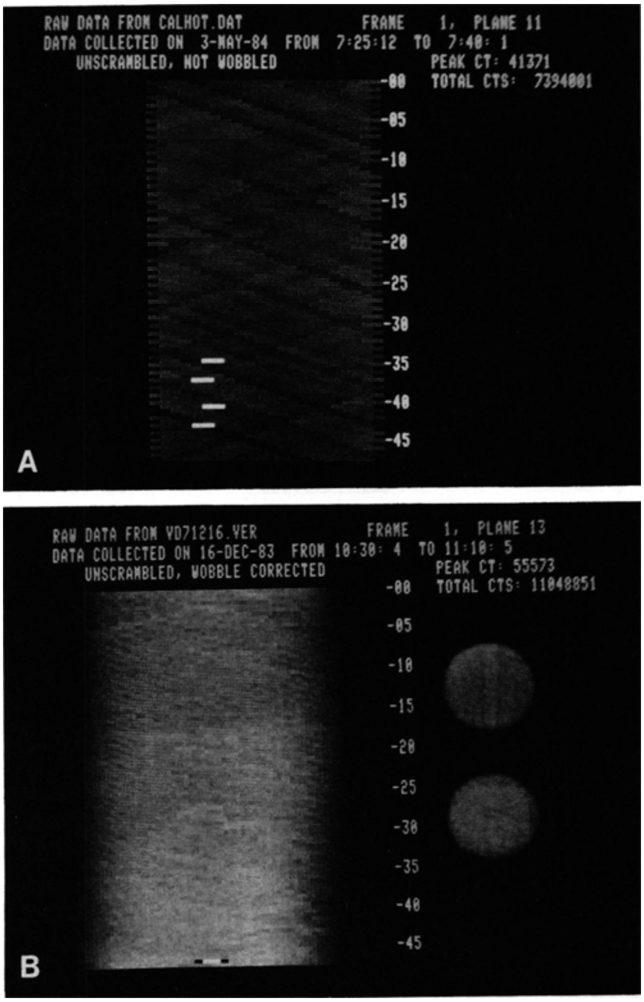

FIG. 5. Sinograms illustrating problems producing only subtle visual artifacts in the daily QA images. Note that these artifacts are strikingly apparent in the sinograms. They arose from a software problem during some transmission rod source data collections. Both artifacts were correctable using specialized software interpolations on the raw data sets.

collection that was apparent only during some of the transmission rod source data collections. Subtle, sometimes barely visible artifactual bars appeared in images as a result of these problems, corresponding to 3%–6% regional sensitivity variations. The problems, however, would have an effect on the quantitation accuracy and are strikingly evident in the sinograms. Both problems were correctable using software once the software bug was recognized and removed.

Even when multiple problems are simultaneously present in the PET instrument, they are quickly diagnosable using sinograms. This is exemplified in the examples of Figure 6.

DISCUSSION

Daily PET QA experiments should test the PET scanner under its conditions of use and provide the operator with immediate feedback on developing system problems. Visual inspection of sinograms of both ES, TS, and EPS are particularly useful for quickly providing additional information about the nature of failures and the conditions under which they occur.

Raw data, as is readily analyzed by viewing sinogram displays of it, are generally preferable to reconstructed image data for revealing and identifying system problems. This is primarily true since the process of reconstructing images requires a certain amount of time to perform and consists of multiple steps which may obscure or confound the nature of the faculty condition. Furthermore, the reconstructed data set is related to the imaged object, and not specifically organized to match the hardware configuration. Although a particular hardware failure could produce a recognizable artifact in the final image, it is doubtful that the specific components responsible for the artifact could be identified from such an image.

For the PC 4600, a failure of five detectors represents a loss of only 1% of the total detectors. However, failure of a single detector resulted in a loss of ~ 2% of the counts in a given plane, which not only decreased the apparent sensitivity of the system but could produce quantitation artifacts in the final reconstructed images. Hence the replacement of data from aberrant bins and detectors, indicated most sensitively by sinograms or other diagnostic software, proved to be a useful procedure. The quantitative significance in failures of individual detectors in newer systems having greater numbers

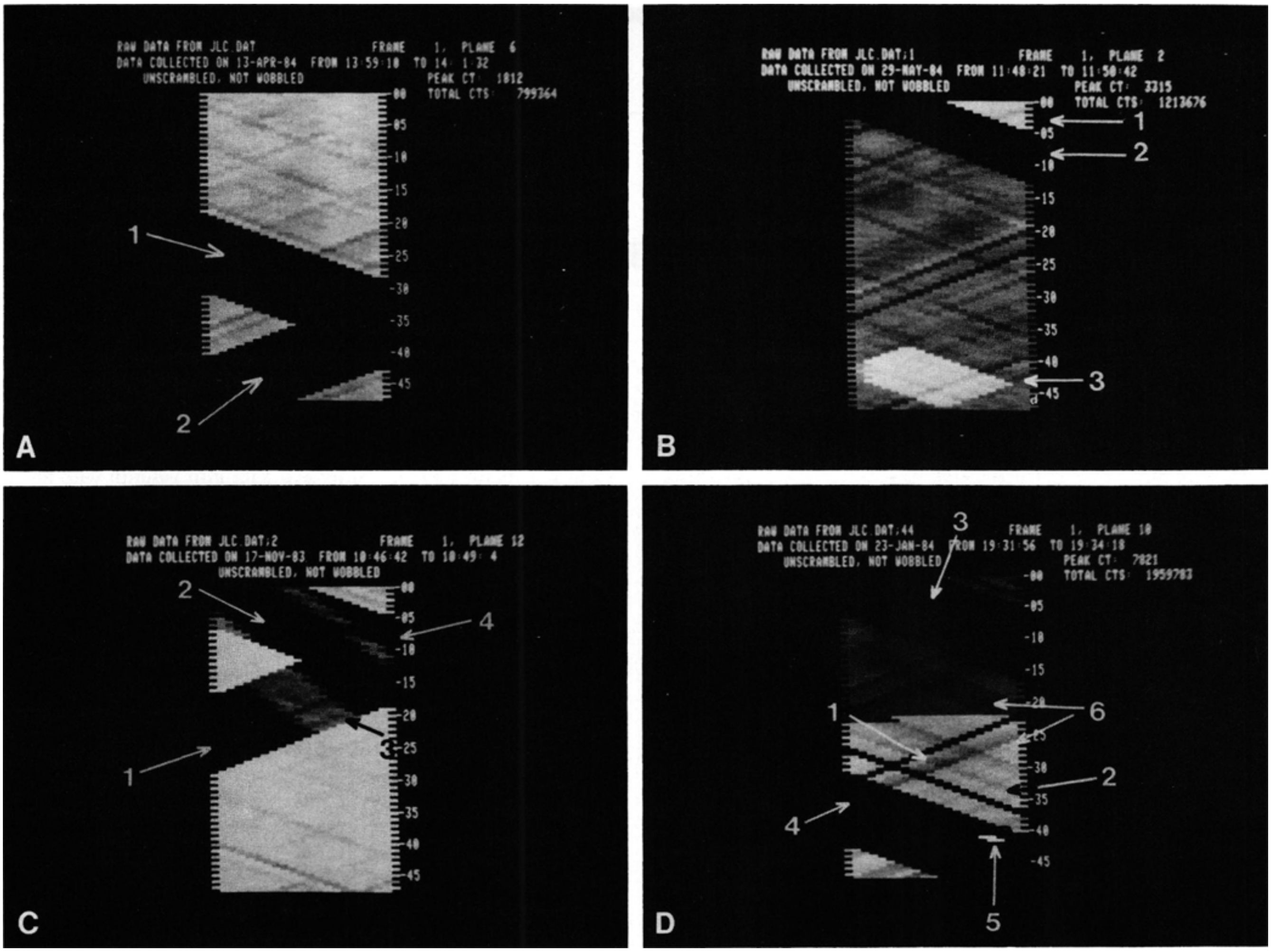

FIG. 6. Sinograms useful in diagnosing multiple problems that are present simultaneously. Sinogram (A) shows failure of two data acquisition boards. Sinogram (B) illustrates problems with adjustment of a data acquisition board (1 and 2), and failure of a data acquisition board (3). The problems in the sinogram (C) correspond to failures of specific data acquisition boards (1 and 2), and with collection of an angle of transmission data (3 and 4). In sinogram (D), problems include failure of two detectors (1 and 2), failure of two data acquisition boards (3 and 4), a problem during transmission rod source masking (5), and a data acquisition memory failure (6).

of detectors would not be as serious as those of the PC 4600, an older generation instrument. Nevertheless, prudent purchasers of PET instrumentation should insist upon user-friendly diagnostic tools, such as sinograms and software diagnostics, to ensure smooth, continuous clinical operations with a minimum of downtime.

Kimberlee Kearfott
Arizona State University
Tempe, Arizona

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NOTE

*PC 4600, The Cyclotron Corp., Berkeley, CA

REFERENCES

1. Rhodes BA. *Quality Control in Nuclear Medicine: Radiopharmaceuticals, Instrumentation, and In Vitro Assays.* St. Louis: C.V. Mosby Co.; 1977.
2. Rollo FD. *Nuclear Medicine Physics, Instrumentation, and Agents.* St. Louis: C.V. Mosby Co., 1977.
3. Sorenson JA, Phelps ME. *Physics in Nuclear Medicine,* 1st ed. New York: Grune and Stratton; 1980.
4. Kearfott KJ, Carroll LR. Evaluation of the performance characteristics of the PC 4600 positron emission tomograph. *J Comput Asst Tomogr* 1984;8:502–513.
5. Evans B, Harrop R, Heywood D, et al. Engineering developments on the UBC-Triumf modified PETT VI positron emission tomograph. *IEEE Trans Nucl Sci* 1983;NS-30:707–710.