INCLUSION OF PHYSIOLOGIC DATA INTO COMPUTERIZED NUCLEAR MEDICINE DYNAMIC STUDIES

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A general technique has been developed for the multiplexing of time-dependent analog signals into the individual frames of a scintillation camera dynamic function study. A pulse train, frequency-modulated by the physiologic signal, is injected into a test input of a preamplifier servicing an outer phototube of the camera head. These tail pulses mimic photoevents occurring at a point outside of the camera's field of view, chosen to occupy a data cell in an unused corner of a computer-stored image. By selecting a region of interest encompassing this pulser peak, the resulting time–activity curve displays the desired physiologic variable in temporal synchronism with the radiotracer distribution.

The interfacing of the Anger camera to a digital data processor has greatly advanced quantitation of dynamic studies in nuclear medicine. The coordinates of scintillation events (X,Y) are digitized by analog-to-digital converters and stored, either in dynamic histograms or event-by-event in list mode. The resulting data can be displayed as a series of sequential images, and the count rate in a carefully selected region of interest can be integrated to generate time–activity curves depicting the course of the radiotracer through a specific anatomic volume. The radiocardiogram, renogram, pulmonary washout, and brain flow study represent clinically accepted procedures in which the diagnostic decision hinges on a quantitative evaluation of the time rates of tracer-concentration changes.

In cardiac and pulmonary dynamic studies, the need to correlate the image data with the physiologic state of the imaged organ has been appreciated (*1*). This is ideally achieved by monitoring the output signal of an appropriate transducer and recording it directly in the individual scintillation camera images (*2*). Obvious examples of monitored signals in angiocardiographic studies include electrocardiograms (ECG), carotid pulse tracings, heart sounds, and valve status as observed by A-mode ultrasound. Similarly, in pulmonary studies, the recording of pneumotach, expired gas, and blood gas information would give the clinician access to a much wider perspective of lung function. The present work describes a simple and effective way to include these ancillary data into dynamic radiotracer studies.

MATERIALS AND METHODS

The basic idea described here is the coding of a voltage signal V(t) into the count rate in a single matrix cell $\Delta x \Delta y$ at some position (X,Y) in serial camera images. Circular camera images stored so as to be completely included in a square computer-based matrix leave a minimum of 22% of the matrix cells unused and thereby available for the storage of many different coded voltage signals in the empty matrix corners. An ECG signal is chosen here as a specific example.

In practice, the inclusion of a voltage signal into camera images can be performed easily by hardware signal mixing in a two-step process. First, the ECG voltage V(t) must be made to look like a fictitious gamma photon source whose intensity ("disintegrations"/sec) directly reflects V(t). Secondly, these fictitious gamma photons must be injected into the camera–computer signal processing chain in parallel with the legitimate scintillation events. We have mounted test inputs into the preamplifiers servicing outer phototubes in our Searle Radiographics and General Electric cameras (Fig. 1). This modification resulted in no deterioration of camera performance,

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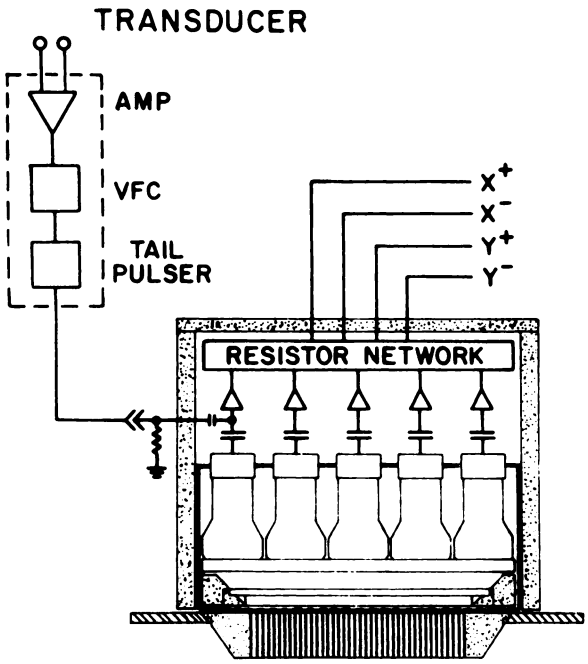

FIG. 1. Block schematic showing capacitive coupling of test input to preamplifier that services outer phototube in scintillation camera head. Tail pulses, frequency-modulated by chosen physiologic signal, appear outside of camera field of view.

although the flood-field uniformity required realignment in the latter camera. A tail pulser is capacitively coupled and the test pulse amplitude is fixed so that the summed energy (Z) pulse falls in the pulse height window of the emitter being imaged. The coordinates (X,Y) of this test pulse will be correctly interpreted by the position circuitry in the camera head as belonging to a scintillation event occurring *outside* of the field of view of the NaI crystal, since a real gamma-photon detection event at the extreme edge of the crystal will still share some of its scintillation light with the inner phototubes. In this way, the outer preamplifiers act as convenient access points to twelve unused data cells in the digitized image, representing storage for twelve auxiliary data channels. The ECG voltage V(t) is fed into a simple voltage-to-frequency converter. The tail pulser is driven by the output of this converter, whose frequency-modulated pulse train contains the ECG information. Since frequency must always be positive, the electrocardiogram V(t) must be offset so as never to cross zero. In addition, the time-averaged frequency should be kept below a few kilohertz to avoid loading the camera electronics with nonscintillation data. In our typical high-frequency cardiac studies, these conditions are easily met since the sum of all ancillary (ECG, carotid pulse, and live-time pulser) data rates is kept below 10% of the 50-kHz total-image counting rates.

RESULTS

The results of inclusion of biotelemetric data into a high-frequency cardiac flow study shows the potential usefulness of the technique. Ten millicuries of $^{99m}TcO_4^-$ in 1 ml volume were injected into the antecubital vein of a subject and flushed with 25 ml of saline. The electrocardiogram, carotid pressure, and a constant-frequency pulser data were fed into three test inputs installed in the General Electric Radicamera II. Data were stored in a PDP-11/40 computer in the histogram mode at 20 frames/sec for 25 sec. A left-ventricular end-diastolic image is shown in Fig. 2, where the parallel physiologic-data channels appear as the pulser peaks in the lower portion of the image. Flagging regions of interest over the left ventricle (A), electrocardiogram (B), carotid pulse (C), live-time pulser (D), and total image generate the time–activity curves shown in Fig. 3. List-mode data acquisition would make it possible to choose the sampling rate a posteriori to examine temporal detail in physiologic and radiotracer data up to 100 Hz.

An ominous note is evident in the 50% count rate losses monitored by the constant-frequency pulser, denoted as losses in Fig. 3. The cumulative effect of pile-up, baseline restoration, and analog–digital conversion times results in losses that cannot be corrected by any analytic operation on the *observed* count rate. The reason for this is that the observed

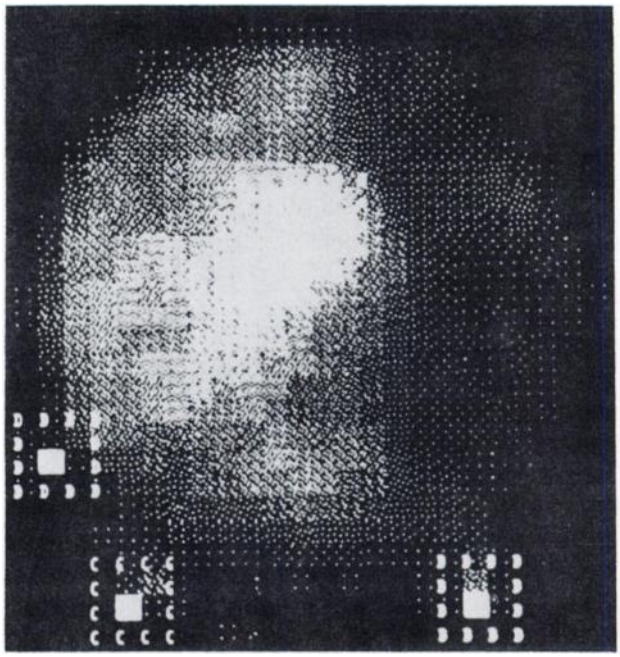

FIG. 2. An end-diastolic left anterior oblique cardiac image corresponding to $6.50 \leq t \leq 6.65$ sec in Fig. 3. Outlined regions of interest represent left ventricle (A), ECG (B), carotid pressure (C), and live-time pulser (D).

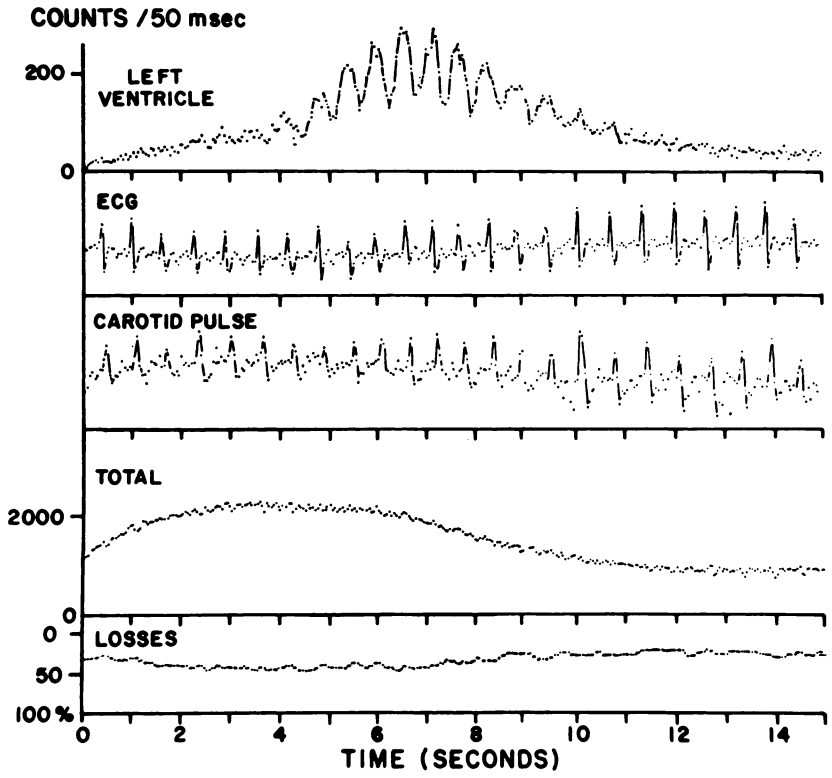

FIG. 3. Time–activity curves corresponding to left ventricle, ECG, carotid pulse, and system losses, following flushed intravenous injection of 10 mCi of $^{99m}TcO_4^-$ taken at 20 frames/sec.

"photopeak" counting rate does not uniquely reflect the load seen by the analog circuitry in processing the lower-energy scattered radiation that dominates the spectrum in a clinical situation. Any attempt to condense the complex time-dependent scattering situation into a single constant parameter such as system "deadtime" is futile. This can be seen by the following simple test. Fix a low-activity ^{131}I source to the collimator face of the scintillation camera to generate a constant 364-keV peak counting rate of several kilohertz. Then unmask an intense ^{99m}Tc source in the camera field of view, simulating a severe scattering situation. The dramatic change in the observed count rate in the 364-keV window indicates that any effort to correct for count rate losses must reflect the total data rates seen by the camera head, not just the fraction that satisfies the full-energy pulse-height criterion. The proper live-time correction involves masking a portion of the collimator field, injecting a constant gamma-photon flux from a fixed point sample of the radiotracer being imaged (*3*). The near-equivalence of a noisy pulser will be discussed in detail in a subsequent note.

CONCLUSIONS

The inclusion of ancillary information into computer-based scintillation camera dynamic studies can be performed by the simple scheme of analog multiplexing tail pulsers into the camera head. It has been found useful to dedicate such parallel data channels to:

1. frequency-modulated physiologic parameters;
2. gamma-photon count rates from individual probes viewing organs outside of the camera field of view;
3. constant-frequency pulsers to monitor losses at high data rates.

This simple modification of the existing circuitry considerably extends the data-handling flexibility of the scintillation camera–computer system in quantitative dynamic studies now performed in the nuclear medicine clinic. Current cardiac studies are utilizing ECG data to effect frame collection corresponding to gating after the fact. More generally, a motion-picture camera is being interfaced to condense dynamic studies onto a cyclic film strip, with the camera driven under software control through a dedicated CAMAC interface (*4*). Finally, the inclusion of pneumotach data into list-mode lung and liver scans is being studied in an effort to assess image degradation due to respiratory motion.

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REFERENCES

1. GREEN MV, OSTROW HG, DOUGLAS MA, et al: An EGG-gated scintigraphic imaging procedure for studying ventricular function. *J Nucl Med* 15: 497, 1974

2. NICKLES RJ, NELSON PJ, POLCYN RE, et al: Radioactive gases in the evaluation of left ventricular function. In *Cardiovascular Investigation with Radionuclide, Miami, Fla., March 12, 1975*: to be published

3. WOLF J (Searle Radiographics, Inc.): Private communication, 1974

4. Esone Committee of the Joint Nuclear Research Center: *Document EUR 4100e (CAMAC Instrumentation Convention)*, Italy, Ispra Establishment, March, 1969