Simultaneous Acquisition of Physiological Data and Nuclear Medicine Images

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A technique has been developed that allows the simultaneous acquisition of both image and physiological data into a standard nuclear medicine computer system. The physiological data can be displayed along with the nuclear medicine images allowing temporal correlation between the two. This technique has been used to acquire images of gastroesophageal reflux simultaneously with the intraluminal esophageal pH. The resulting data are displayed either as a standard dynamic sequence with the physiological data appearing in a corner of the image or as condensed dynamic images.

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Nuclear medicine has been moving in the direction of more dynamic measurements. Numerous techniques have been developed to characterize dynamic processes, e.g., esophageal transit studies (*1,2*). In conjunction with this change in the nature of nuclear medicine, it has become desirable to record images simultaneously with physiological parameters in a method which allows precise correlation between the two. Unfortunately, most computer systems developed for nuclear medicine do not allow the simultaneous acquisition of both images and physiological data into one data set.

Several techniques have been used to record images and physiological data simultaneously. The most common is a gating technique (*3,4*). Several groups have also used the dual acquisition capability of some computers, e.g., gathering image data using the Z_1 input and physiological data using the Z_2 input (*4*). Another technique is that of Heller et al. (*5*) who used a device similar to that described in this paper, multiplexing physiological and image data. However, their system does not allow for the simultaneous display of both the image and physiological data in a simple manner. Recently, Hack et al. (*6*) developed a dedicated computer system for the acquisition of both image and physiological data. While this is advantageous, there is currently no direct method for most nuclear medicine computer systems to acquire both types of data with good temporal correlation.

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We have developed a technique which allows the simultaneous recording of both image and physiological data into the same data set. These data are directly correlated in a manner similar to that developed by Heller et al. We designed a multiplexor which allows switching between the nuclear medicine camera and some other device for input into the data acquisition system.

This technique was developed to record simultaneously intraluminal esophageal pH and gastroesophageal reflux images following a technetium-99m (^{99m}Tc) sulfur colloid labeled apple juice meal in children. The utility of simultaneous scintigraphic and pH probe acquisition has been shown previously for studying esophageal clearance in adults (*7*), even though time correlation between the two technologies was cruder than that presented here. It enables the direct temporal comparison of the two different measurement techniques for detecting gastroesophageal reflux. The technique also allows the recording of essentially any data, such as cardiac phase (not cardiac gating) and respiratory phase data. The device interfaces between the nuclear medicine gamma camera and the computer system.

MATERIALS AND METHODS

The system consists of a multiplexor (Fig. 1 and Table 1), which switches between a Raytheon Step 1/ Step 2 gamma camera (FOV 42 cm) and a Fisher (model 810) pH system into a 60 MB Standalone Microdelta computer system (Siemens Medical Systems, Des Plaines, IL). Following list mode acquisition, the data are transferred to, formatted by, and

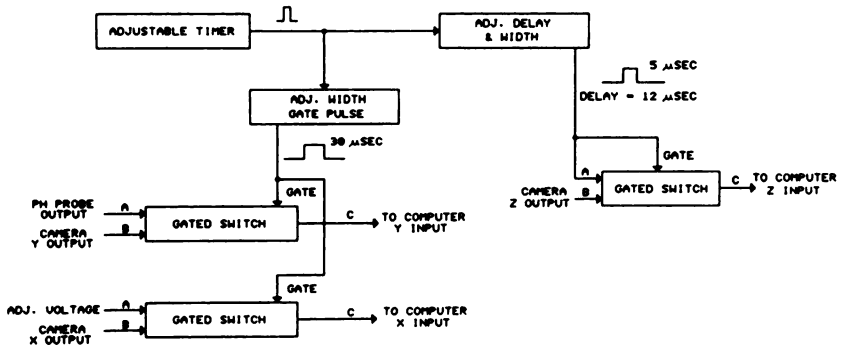

FIGURE 1
Block diagram of the multiplexor logic. The multiplexor acts as a gated switch where normally input (B) is connected to the output (C) for x, y, and z signals. Whenever the timer sends out a gating signal, the gated switches connect input (A) to output (C) with input (B) isolated from the output.

processed by a VAX 11/750 (Digital Equipment Co. (DEC), Maynard, MA).

The multiplexor (see Appendix) consists of a free-running oscillator which can be varied from 1 to 200 Hz. Each time the system switches from the gamma camera to the physiological device, the multiplexor provides a z pulse similar to that produced by the gamma camera, a voltage signal proportional to the output from the physiological device, and a set, level voltage for the other position coordinate. As currently configured, the output from the pH probe is placed into the y channel, and the set level voltage into the x channel. The x, y position of the physiological information along with the offset and gain are adjustable through the multiplexor. Output from the gamma camera is not affected by the multiplexor. The system maintains the impedance of all input and output connections at 50 Ω.

Before use, the multiplexor is adjusted so that output from the pH probe is displayed along one edge of the image display where the gamma camera sends no data. The variable voltage output from the pH meter is displayed as a "bouncing" pixel with the vertical position proportional to the voltage output of the pH probe. The system was calibrated with standard solutions of pH 2, 4, and 7. The gain and offset of the multiplexor are adjusted to keep physiological data out of any possible image and yet maintain a large enough dispersion for detecting any change in pH. Typical dispersions have been 0.15 pH units per pixel.

Data are acquired by three different methods. For phantom studies, static images are acquired using a 128^2 matrix. Clinical studies are performed using two different acquisition schemes: One, during feeding frame mode images are acquired (64^2 acquisition matrix), and two, during observation for reflux list mode acquisition is performed (with subsequent reformatting into a 64^2 matrix).

List mode data are processed by two methods: They are first formatted into standard frame-mode dynamic sequences of images that incorporate both the distribution of radioactivity and the pH signal, and from these frames condensed dynamic images (CDIs) (*1*) are generated that have a temporal and a spatial dimension. To achieve this, we define a region of interest (ROI) that encompassed the esophagus and some of the adjacent pharynx and stomach and create a modified file of images that exclude image data outside the ROI. Each of these frames is compressed into a column one pixel wide by summing the counts along horizontal rows, and then the columns are assembled in temporal order side by side. The process is repeated using an ROI that encompasses the pH-record portion of the images. The resulting CDIs are displayed simultaneously on the computer monitor. The time resolution of the CDIs is 10 sec/pixel.

TABLE 1
Multiplexor Parameters

Input impedance, all lines	50 Ω
Output impedance, all lines	50 Ω
Frequency	1–200 Hz
Output, voltage x and y	−3 to 3 V
Output, z pulse, TTL	+5 V
x,y Pulse width	30 μsec
z Pulse width	5 μsec
Adjustments for physiological data	
Gain x and y	
Offset of x and y	
Pulse widths x, y, and z	
Pulse timing of z	
Adjustments for camera image	
None, output = input	

Phantom Studies

The multiplexor was tested using standard nuclear medicine phantoms. The system was tested with and without the multiplexor. Standard flood, quad bar, parallel bar, and Anger phantom images were acquired. For each test, the time of acquisition for data acquired with and without the multiplexor was kept fixed. Images were acquired using a 128 × 128 matrix and word mode. Intrinsic images used a ^{99m}Tc point source with an activity of 280 μCi and all extrinsic images (using a high resolution collimator) were acquired using a cobalt-57 (^{57}Co) flood source, activity ~1 mCi and switching rate of 150 Hz.

Clinical Studies

This system has been used for studying gastroesophageal reflux in children (*8*). Informed consent was obtained from the parents according to an institutionally approved protocol.

Prior to each clinical study a micro-pH probe was calibrated and placed transnasally in the infant's esophagus at the level of the right atrium in order to monitor the child for 24 hr for acid reflux events. We then calibrated the pH and multiplexor systems. The infant was then fed apple juice (2 ml/cm height, pH ~4) tagged with ^{99m}Tc sulfur colloid, 150 μCi, followed by a cold chaser of 5 ml of a neutral electrolyte maintenance solution (pH ~6) (Pedialyte, Ross Laboratories, Columbus, OH). During the feeding, dynamic frame mode images of the esophagus and stomach were acquired (64^2 matrix, word mode

at 1 frame/sec and switching rate of 60 Hz). The time resolution of the pH data will be the same as the frame rate used for frame mode acquisition. Following feeding, the image and physiological data were acquired by list mode with subsequent reformatting into 64^2 matrix and word mode. The infant was observed for a period of one hour resulting in $\sim 4 \times 10^6$ events recorded.

RESULTS

Phantom Studies

The change in deadtime for the system was measured along with resultant image uniformity and resolution as a function of counting rate and frequency of switching. The results of these measurements indicated that the increase in deadtime for the system was statistically no different from that expected for an increase in activity, i.e., counting rate. Deadtime refers to the time that the acquisition system is not able to record another event and is reported as the percent time that the system is busy. The actual deadtime induced by the multiplexor will be dependent on the rate of switching. Each time, though, that the multiplexor is triggered, for 30 μsec any event recorded by the gamma camera will not be recorded by the computer as the camera's X, Y, and Z outputs are isolated by the multiplexor from the computer. At switching rates of 200 Hz the deadtime associated with this is only 0.6%. The results from intrinsic and extrinsic phantom studies using ^{99m}Tc and ^{57}Co sources, a uniform flood, and Anger, quad bar, and parallel bar phantoms displayed no change in image quality (i.e., resolution, uniformity, and linearity) with and without the multiplexor connected to the system. Figure 2A shows an image of a quad bar phantom without the multiplexor attached to the system; Figure 2B shows the image acquired with the multiplexor used. Both images contain the same number of counts and have no statistically significant difference in deadtime. These results were validated up to a counting rate of 12 kHz and a multiplexor switching rate of 150 Hz.

Clinical Studies

Figures 3 and 4 present parts of a sample study from an infant who refluxed several times. Figure 3 shows standard image frames of the esophagus and stomach before and during reflux. The intraesophageal radioactivity is visible, as is a decrease in pH. Using the CDI method, Figure 4 presents a longer segment of the same study, including the data of Figure 3. Again, it is possible to observe the reflux events by both techniques, and, in addition, to note the character of clearance for these two different data acquisition methodologies. A pH probe reflux event is defined as a drop in pH to below 4. In most cases, we noted that when a reflux event was observable by both methods, the esophagus cleared the activity relatively quickly, while pH data indicated a much slower return to a pH above 4. The decrease in activity represents the bulk clearance of the esophagus, and the pH rise represents neutralization of residual acid, a much slower event.

DISCUSSION

The multiplexor presented here offers a simple solution to the problem of acquiring both image and physiological data in temporal correlation. The method of display allows a quick visual determination of the patient's intraesophageal pH. This method contrasts with that of Heller et al., who display their data as a dot whose intensity is proportional to the output of the physiological device using a voltage-to-frequency converter. While their technique provides the same data, visual interpretation of the data is more difficult.

The multiplexor described here has been found to be very useful in following two parameters simultaneously. In comparison to Hack's dedicated computer system (*6*), this system has, by virtue of its simplicity, the limitation of only being able to acquire one set of independent image and physiological data. However, the simplicity of this system allows it to be used by any nuclear medicine computer system which is not slaved to a gamma camera. If more than one set of image and physiological data needs to be acquired, then a dedicated system such as Hack's or a more sophisticated multiplexor system is required. The sampling rate of the physiological data is dependent on the framing rate

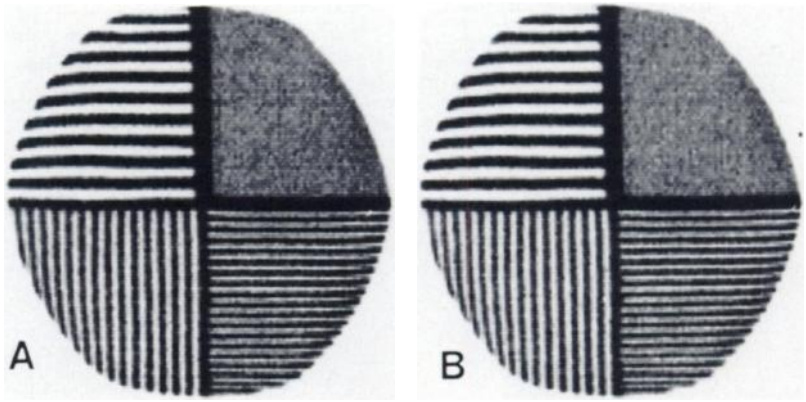

FIGURE 2
An intrinsic quad bar image acquired without the multiplexor (A) and (B) an image of the same phantom as in (A) using the same acquisition parameters, but with the multiplexor being utilized. Count rate is 12k cts/sec and the multiplexor is switching at 140 Hz.

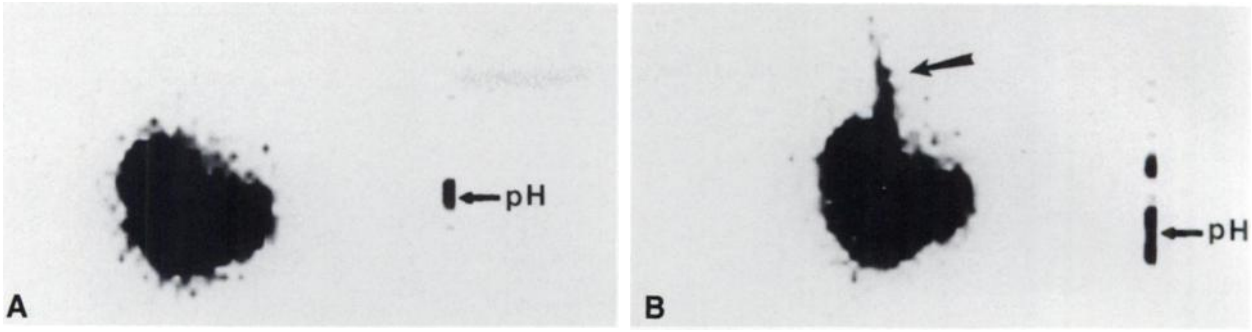

FIGURE 3
Results of gastroesophageal reflux study formatted into 10-sec frames. A large amount of activity is present in the stomach. The pixels at the right edge of the images (arrows) represent the intraesophageal pH. More acid values cause the signal to move to a pixel closer to the bottom of the image. A: Activity and pH in the seventeenth frame of the study, immediately prior to a reflux episode, pH ~5.5. B: Activity and pH in the eighteenth frame, during the reflux episode. Note the small amount of activity in the esophagus (arrow) and the change in position of the pH signal, pH ~3.0.

used during processing and also on the time rate of change of the biologic system's response as the multiplexor can switch at any arbitrary frequency.

For the case presented here, the time rate of change of the patient's pH is slow, therefore the sampling required to correctly follow the patient's pH need not be fast and in addition only frame mode acquisition is required. For those studies where the patient's physiological response is rapid then list mode acquisition would be required with the multiplexor running at 200 Hz or faster. In general the temporal resolution required is dependent on what is being recorded and its time rate of change.

The multiplexor described here can be used with any computer system which accepts analog information from a gamma camera. The data acquired during our clinical studies use ~10 MBytes of disk space on our standalone Microdelta system. Because of the design of our department and our policy of not performing data processing on any acquisition computer, this requires that our VAX be used for achiving, storage, and processing of the data. This is not, though, a prerequisite for use of this system.

In addition, even though our clinical studies could be done, in principle, by frame mode acquisition instead of list mode, within the Microdelta computer system it is not possible to acquire an uninterrupted 1 hr frame mode study with several different time resolutions. Therefore, we use list mode acquisition and following the study reformat the data.

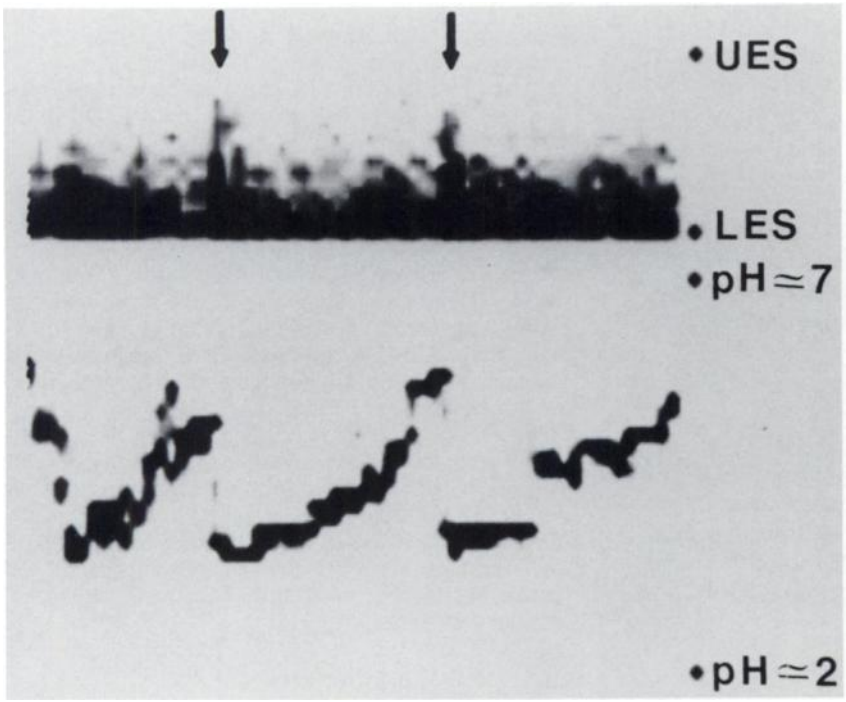

FIGURE 4
Results of the study of Figure 3 displayed by the CDI technique, encompassing the first 10 min of the study with time framing of 10 sec per horizontal pixel. Top part represents activity and the bottom pH. The dots at the right indicate for the top part the locations of the upper esophageal sphincter (UES) and lower esophageal sphincter (LES), and for the bottom part indicate pH values of 7 and 2. Arrows indicate reflux episodes appearing as spikes of radioactivity and pH drops in the top and bottom parts respectively. The seventeenth and eighteenth columns, under the first arrow, were derived from the image frames of Figure 3.

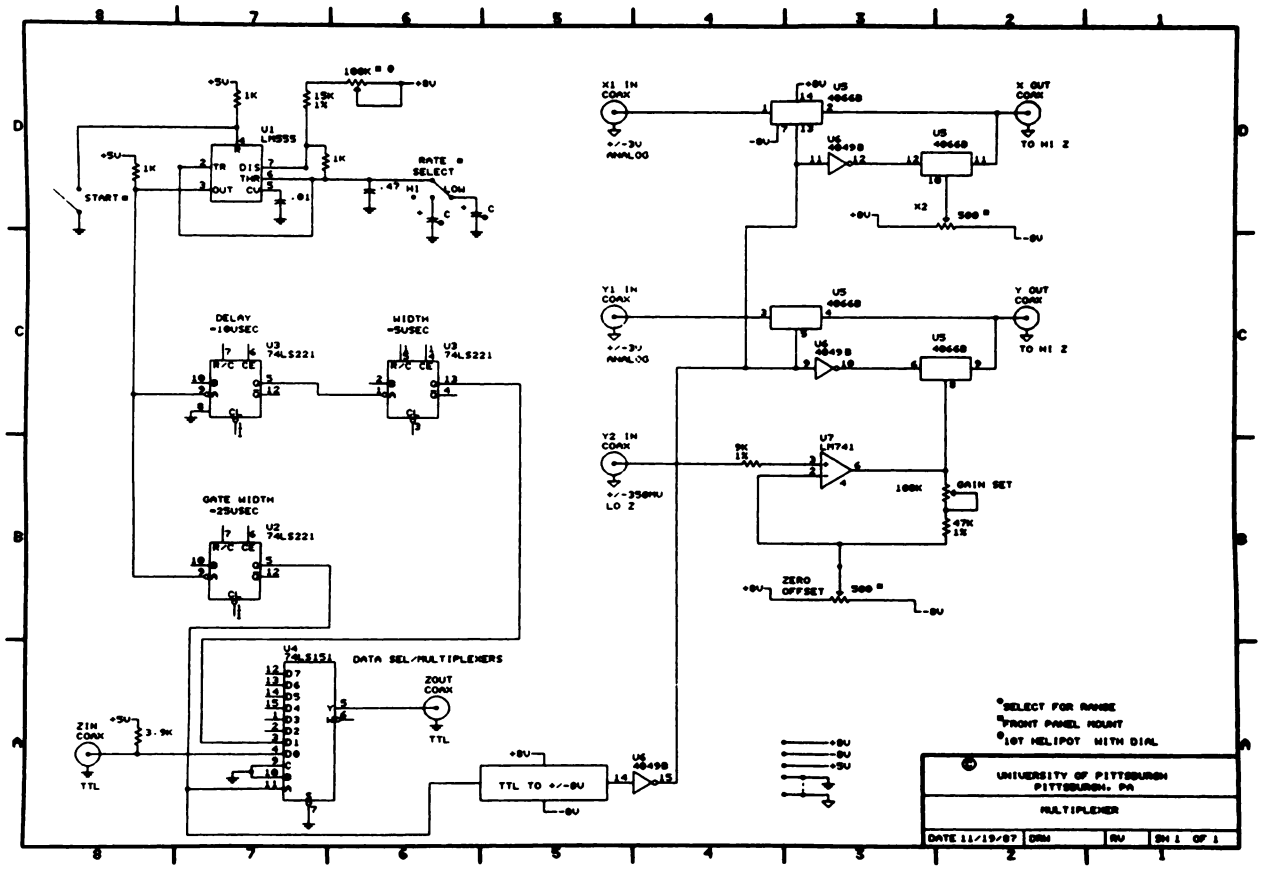

FIGURE 5
Block schematic of the multiplexor. This drawing shows all the essential logic of the system.

In conclusion, the multiplexor system presented here provides a simple and inexpensive means to record any of several different types of data simultaneously with dynamic nuclear medicine images preserving precise temporal correlation.

APPENDIX

The estimated cost of the multiplexor was $400. This includes both parts and labor. The parts for this device cost approximately $150.

Figure 5 presents an incomplete schematic of the multiplexor. This schematic details completely the circuit logic of the system. For simplicity, most discrete components are not displayed.

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