An All-digital Nuclear Medicine Department

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An all-digital nuclear medicine department is described. Nuclear medicine images are acquired by a separate computer interfaced to each camera. The digital images are viewed, manipulated, and interpreted from remote display stations in an interpretation area. The interpretation is dictated into a Rapid Telephone Access System (RTAS), where the voice is digitized and stored. By dialing the patient's identification number, the referring physician can hear the interpretation over any telephone. The images are filed on large storage discs. The digital scans can be rapidly and easily accessed for later review by the use of several directory programs. This system has brought not only efficiency and cost savings, but the ability for remote viewing elsewhere in the hospital and telephone transmission of nuclear cardiology studies from community hospitals for interpretation in the digital nuclear medicine department.

KEY WORDS: Radiology and radiologists, departmental management, Radiology and radiologists, design of radiological facilities, Radiology reporting systems, Radionuclide imaging, instrumentation

TYPICALLY, nuclear medicine scans are photographed from a cathode ray tube or video monitor. The films are developed in an automatic processor, and after scan interpretation they are filed for long-term storage. This system of processing scans has several important disadvantages. Filmed studies are easily misfiled or lost and require increasing space in file rooms for storage. A photographed study cannot be manipulated to change contrast, gray scale, or background, and this often results in physician requests to the technologist to repeat the images to obtain films of different quality. This is also a serious drawback when comparing previous studies with current studies. Studies acquired in a cine mode, *e.g.*, gated cardiac studies, cannot be stored in this mode, and thus comparisons with prior studies are difficult and

incomplete. In addition, the cost of silver-based film continues to rise because silver is a precious metal, while digital storage media, such as magnetic media, have been falling in cost.

Digitally retained images have many advantages over photographically stored images. They can easily be manipulated by changing background, contrast, and gray scale. Such images can be superimposed for comparison purposes or displayed and stored in cine format. Digital studies can rapidly be accessed from storage on large random access discs and displayed on video monitors in various locations within a nuclear medicine department as well as at remote sites within the hospital. This easier access to studies can result in a significant savings of time for physicians who wish to review studies.

Because of the advantages inherent in digital storage of nuclear medicine images, proposals have been made for future systems that will use an all-digital storage framework.¹ We have developed an all-digital department of nuclear medicine, which is currently functioning with commercially available equipment and has re-

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Fig 1. Equipment in all-digital department. Each of four gamma cameras is interfaced to a separate computer. Studies are examined in the interpretation room using remote video monitors and keyboards interfaced to each computer. Floppy discs are used to transfer studies to the display computer where the current week's studies can be displayed. Studies are then transferred via floppy disc to a PDP-11 computer and 300-megabyte discs for long-term storage. Alternatively, serial lines can be used to transfer studies from each camera computer directly to a PDP-11 computer.

sulted in efficiency in both cost and operation. Our all-digital department includes the interpretation and long-term storage of all studies in a digital format, the dictation and selective telephone retrieval of digitized voice interpretations, and the telephone transmission from local community hospitals of digital images for processing and interpretation by our staff.

HARDWARE

Figure 1 is a schematic representation of the hardware for acquisition, display, and storage of images in a digital format. We have four gamma cameras, each with a dedicated computer. Each computer is connected to a remote display within our interpretation room. The

remote display, which was the subject of a previous communication,² consists of a video monitor, keyboard, and controls (for cine rate, background subtract, and window) in parallel with the computer monitor, keyboard, and controls. When a study is ready for interpretation the technologist changes a switch, allowing manipulation of the images from the remote display station. After the images are manipulated and enhanced by the nuclear medicine physician at the remote display station to derive maximum information, an interpretation is dictated into our Rapid Telephone Access System (RTAS). Our referring physicians can then call RTAS from any telephone and dial the patient's identification number (I.D.) to hear our dictated report.³

Table 1. Equipment in All-Digital Department

1. Technicare 410 portable camera (a) Technicare 550 computer
2. Picker LFOV Dynacamera 4/15 (b) DRI 1000 computer (c)
3. Technicare LFOV 420 camera (a) Technicare 560 computer
4. Elscint Digital Apex 415 camera (d) with rotating gantry for ECAT Apex 410 computer
5. DEC PDP 11/34 computer (e) Gamma 11 acquisition and color display SMS floppy disc drive (f) 2 CDC 300 megabyte disc drives (g) MCT disc controller (h) TS03 tape drive 2 RK05 disc drives
6. DRI 1000 display computer with floppy disc drive and 30 MB Winchester disc (c)
7. RTAS Radiology Reporting System (i)

(a) TechnicareCorp., Solon, OH; (b) Picker International Inc., Northford, CT; (c) Diagnostic Resources, Inc., North Boston, NY; (d) Elscint Corporation, Brookline, MA; (e) Digital Equipment Corp., Maynard, MA; (f) Scientific Micro Systems, Mountain View, CA; (g) Control Data Corp., Minneapolis, MN; (h) Minicomputer Technology, Palo Alto, CA; (i) Sudbury Systems Inc., Sudbury, MA.

Table 1 lists the equipment in our department. A central Digital Equipment Corporation (DEC) 11/34 computer provides access to central storage on two 300-megabyte¹ (MB) discs, and is used for more complicated analysis of cardiac, renal, or lung studies.

Each computer has a floppy disc drive and a serial line, each of which can be used to transfer images from that computer to the central mass storage or to the DRI computer used for display of recent studies. The serial line interprocessor communications and the floppy disc transfer have been the subject of prior reports.^{4,5}

The Diagnostic Resources, Inc. (DRI) computer holds about one week's worth of studies on its 30-megabyte Winchester disc. This display computer is used to show studies to referring physicians or for conferences. The central PDP 11/34 computer is used for long-term storage on 300-megabyte discs. The studies can be recalled by a directory on the system disc.

SOFTWARE

Our central PDP 11/34 computer uses the DEC Gamma-11 software under the DEC RT-11 operating system. Special programs were written to allow us to transfer studies *via* serial line or floppy disc between the Technicare VIP, the Elscint Apex, the DRI, and the DEC

Gamma-11 computers.^{4,5} Since RT-11 supports discs that are less than 32 megabytes, the device handler (supplied by Minicomputer Technology) has to divide each of the 300-megabyte CDC discs into 8 sections of 30 megabytes (the formatted capacity of the drives is 254 megabytes).

A directory program was written that records the locations of all of the studies on all of the disc packs. The directory is stored on the system's disc so that it is always available. The directory program performs three functions: (a) directory initialization, (b) directory updating, and (c) directory searching. At the time of initialization, the user selects the size of the directory and the data that are to be kept in the directory. Any combination of fields from the Gamma-11 administrative data block can be selected for inclusion in the directory. The fields that we have selected are patient name, patient number, study type, and study date. In addition, the name and section of the pack where the study is located are stored for each entry.

Directory updating is simple and reasonably error tolerant. Directory searching can be performed on any combination of the stored fields. In addition, matching can be performed on a combination of substrings within a field. Thus, a search could be performed on the last name and two digits of the hospital number if that was the only information available about the patient. The matching entries are displayed for the user, who can then select the entry (s)he wishes. The program then reports the location

¹One megabyte equals 2²⁰ or about 10⁶ bytes.

of the study and informs the user to mount a disc pack if the study is not currently on line. As the directory has grown over the last year, some operations have slowed. To solve this problem, a search algorithm based on B-tree data structures will be implemented.⁶

Each image of our static studies is acquired in a 128×128 pixel format, with each pixel containing 16 bits. The number of frames depends upon the study. Each view of our dynamic studies is acquired as frames of 64×64 16-bit elements. Our cardiac studies consist of four views: dynamic first pass, gated modified left anterior oblique (MLAO), anterior, and left posterior oblique views. Each view has 28 frames.

The 28 frames of each view are compressed to a 14-frame playback buffer combining the data from pairs of two consecutive frames into a playback buffer suitable for cine viewing. The original 16 bits per pixel is changed to 4 bits per pixel, preserving the 4 most significant bits. The playback buffers of the four views are then merged into a single 128×128 playback buffer for simultaneous multiviewing and interpretation. The original 28-frame data from the MLAO view are then used for computer analysis of ventricular function and wall motion. These data are then stored on a 300-megabyte disc.

Periodically, the contents of part of the disc, excluding the studies that have been merged into cardiac playback buffers, are compressed from the original 16 bits per pixel to 8 bits per pixel, preserving the 8 most significant bits. This compression represents a 2:1 compression for the static studies and an overall 4:1 compression for the gated cardiac studies. The studies are then transferred to a 300-megabyte long-term storage disc.

Backup is an important concept in the all-digital department, since disc crashes can occur on any of our discs and operator errors may occur. Disc crashes have so far been only a theoretical possibility, because we have not experienced a crash during the two years we have been using these 300-megabyte discs. Studies are transferred from each camera-computer to the display computer *via* floppy disc, where they remain for one week. After a week the study is transferred to a 300-megabyte disc and a second

300-megabyte disc as backup. When the oldest section of a disc is compressed and transferred to a long-term storage disc, a copy is made on a second backup disc.

REMOTE ACCESS

Our display computer is also being connected *via* coaxial cable to video monitors and remote keyboards in our division of cardiology and our department of radiology viewing rooms. Personnel in these departments will be able to call up studies from the past week for their own viewing. If they wish to access studies acquired more than one week previously, such studies will be transferred *via* floppy disc from a 300-megabyte disc on the PDP 11/34 central storage computer to the 30-megabyte disc on our display computer.

A telephone communications link *via* modems has been established with community hospitals, which allows them to transfer gated cardiac radionuclide ventriculograms to our DRI display computer. We analyze these studies on our computers and dictate our interpretations into our reporting system described below. Our transfer program is set to accept such studies whenever a telephone call is placed to a modem connected to our display computer. Further details on this function are found in another report.⁷

RTAS REPORTING SYSTEM

Reports dictated into our RTAS (Rapid Telephone Access System) radiology reporting system are available over the telephone either inside or outside the hospital simply by having the referring physician dial the system number followed by the patient I.D.³ The dictated voice is digitized, compressed, and stored on a 70-mega-byte Winchester disc. Standard or normal reports are printed automatically. All other reports are accessed by our transcriptionist for hard-copy typing. Physicians whose patients' gated cardiac studies are sent to us for interpretation *via* telephone can also use RTAS to hear the reports on their patients. A transcriptionist in the radiology department at the remote hospital also accesses RTAS *via* telephone to transcribe the dictated report.

COST EFFECTIVENESS

We have found significant cost savings associated with digital storage of studies. Photographed studies have the cost of technologist time associated with the taking, developing, mounting, and filing of films. There is also the cost of the film processor and its chemicals and maintenance, and the image formatter and camera. In addition, there is the cost of film, filing envelopes, and filing space.

If one analyzes these costs,⁸ photographic storage costs about \$3.46/study. The cost of digital storage of studies can also be derived. This includes the depreciation of the disc drive and controller, the cost of the disc packs, maintenance, and service. If we assume that the nuclear medicine department already has a computer necessary for routine clinical analysis, the cost of digital storage is \$1.19/study. This results in a savings of \$2.27/study using digital rather than photographic storage. If we were to include the depreciation of the DRI display computer, remote monitors, and keyboards as well, this would amount to about \$2.19/study, or a savings of \$1.27 per study. Since our department does about 6,000 studies per year, this results in a savings of up to \$13,620 per year.

DISCUSSION

We have been able to transform our department to all-digital data collection, analysis, and archival storage using commercially available equipment purchased over a number of years. Our referring clinicians have been particularly pleased with our all-digital format. Access to studies is instantaneous, without time wasted in searching through the file room. The ready manipulation of the images to contrast and highlight abnormalities they now consider essential to appreciate lesions properly on the scans. The ability to access an interpretation automatically over any telephone has been very helpful in making rapid diagnostic decisions. Analysis of the RTAS data indicates that over a one-month period 52% of all interpretations were accessed between 5:00 P.M. and 8:00 A.M.

Several individuals contributed software to this development, but the total effort was about

two man-years. The floppy disc communication and large archival store that were key to this transformation have been in operation for two years. We have experienced relatively few growing pains and find that our system not only provides us an excellent data base for research but also is easy to use on a day-to-day basis.

Putting together our system required us to write some special-purpose software to maintain a large data base and to communicate between the systems supplied by several vendors. Although one large computer could replace all of our microprocessor-based computers as well as our central minicomputer, there is the advantage of redundancy and backup inherent in having many stand-alone processors, each of which can operate independently in the event of a failure in another processor.

Currently, each of our 300-megabyte discs contains all of our studies for three months. If we wish to access older studies, we consult the directory on the system's disc to locate the disc that contains the desired study. It would be far more convenient if all studies for the past five years were accessible on the same disc. Such a disc would have to contain greater than 6 gigabytes, although further compression of our data would decrease the storage requirements.⁹ If nuclear medicine matrix displays become routinely 512×512 or 1024×1024 , the storage requirements could easily become 25 or 100 gigabytes. Technology for this may be provided by optical digital discs using laser light for recording and playback. Such discs currently cannot be erased; however, for archival storage, permanent recording is an advantage, not a disadvantage.

We hope that the nuclear medicine vendors will provide support for large data bases and for standard communications. The advantages of an all-digital department, in cost, data manipulation, and easy digital data retrieval, would then be provided without the need to write special-purpose software.

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