Electronic Imaging in a Teaching Hospital Intensive Care Unit: Evaluation of the Clinical Review System

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An intrahospital image-communication and display system was installed and is in continuous use. All images obtained in the medical intensive care unit (MICU) are digitized in the radiology department, then transmitted, stored and retrieved at the nurses' station in the MICU. This unit was easy to install, required minimal user training, and has been in continuous use for 1 year with negligible down time. The details of this system are provided in this report. © 1990 by W.B. Saunders Company.

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AT OUR INSTITUTION, providing clinicians with timely access to radiographic studies ordered from the intensive care units (ICU) has proven to be a difficult problem. We began to search for an electronic-imaging system in an attempt to improve clinician access to portable examinations, and reduce unauthorized film removal from Radiology to the ICUs.

In the fall of 1987, we became a beta test site for the DuPont Clinical Review System (CRS). This report details the technical features and installation of the system, and the responses of our clinicians to the CRS.

HARDWARE, USER INTERFACE, AND SYSTEM FEATURES

The DuPont (Wilmington, DE) CRS is composed of three units: a laser digitizer, a server, and an image display station. The laser digitizer (Fig 1) digitizes a 14 × 17-in field at 1,680 × 2,048 pixels (2K), and stores either the full resolution or a 840 × 1,024-pixel (1K) data set. In either case, all films are digitized to 12 bits of contrast resolution, ie, 4,096 shades of grey. Smaller radiographs can be accommodated, but are still digitized on the 14 × 17-in format. The digitizer is controlled by the adjacent server module. The server (Fig 1) is composed of a

keyboard, monochrome text monitor, 80,286-based central processing unit (CPU), and an 80-Mbyte hard disc.

Digitized images are immediately stored on the server's hard disc until they are automatically transmitted to the display station. The display station (Fig 2) is composed of two high-resolution, 1,280 × 1,024 viewing monitors, a trackball, three control buttons, a CPU, and a 160-Mbyte hard disc. Significantly, there is no user keyboard. The CPU is identical to the server module (an 80,286-based system running under the disk-operating system) with the addition of two 2,048 × 2,084 × 12-bit image display buffers. Three buses are used in the CPU: a PC-AT-control bus, a 32-bit image-processing bus, and an image-display bus. The digitized images are transferred automatically from the server to the display station over coaxial cable using a modified Ethernet protocol.

The 1K (840 × 1,024) images are displayed at full resolution, and take approximately seven seconds to load from the display station's hard disc. On the other hand, the 2K (1,640 × 2,048) images are subsampled and are displayed at 1K resolution. When the 2K images are magnified, they are displayed at full resolution. The 2K images take approximately 28 seconds to load from the hard disc. A display station can be configured to accept either 1K or 2K images, but not both formats simultaneously.

Operation of the system is simple for both radiology and the clinicians. At the server, a default text screen prompts the technician for the patient's name and medical-record number. An extra text field is available for additional information. After entering this information, the technician is prompted to place the film in the digitizer. After six seconds, the film is digitized and automatically returned upon completion of image storage to the server. Transmission of the image to the display station occurs automatically, in the background, and is transparent to the technician or the clinician.

The user interface of the display station represents a radical departure from most current teleradiology systems (Fig 2). The monitors are

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Fig 1. Laser digitizer attached to server module.

divided into a $1,024 \times 1,024$ -pixel region for displaying images, with an adjacent $256 \times 1,024$ -pixel information section for displaying text and graphics. In the information section, a series of icons represent the basic functions of the system. Using a trackball and control buttons mounted on the top surface of the station, a cursor is used to select the desired system functions.

To examine a radiograph of a specific patient, the cursor is placed over the file folder icon, which represents the system directory. After clicking the select button, a list of patients is displayed on the entire monitor. The list can be easily sorted by patient name, medical record, or date of examination. Using the trackball, a specific examination can be selected and displayed on the monitor. If the patient had a prior examination, that radiograph is automatically displayed on the other monitor. Any examination can be displayed on either monitor.

Window and level functions are controlled by "thumb-wheel" controls. The image can also be magnified by clicking the appropriate icon. In the magnified mode, the trackball allows the user to "roam" around the various portions of the image. The hard disc can store about 140 "1K" images and about 35 "2K" images. When the disk is full,

the oldest images are deleted automatically. Images can also be deleted manually, or can be marked to prevent deletion.

THE INSTALLATION

Installation of the CRS was uneventful. The digitizer and server were installed immediately adjacent to the daylight film processor, which is used for portable exams. The two units occupy about 20 sqft of floor space. The display station was installed in the MICU nursing station, and required about 20 sqft of floor space. Very little remodeling of existing space was required. The most difficult part was having the hospital engineering department install the network coaxial cable (500 ft of Ethernet "Thick-Net" cable) in an expeditious fashion. Installation of the CRS required one day. On the next day, the clinicians began to use the system.

CLINICAL RESPONSE

The response of the clinical users was favorable from the first day of operation. The unit has enjoyed immediate and constant use. Despite relatively brief training, the icon-based user interface proved very easy to understand and master for nurses, medical students, residents, and at-

Fig 2. Display station.

tending physicians. No formal training sessions are required to teach the new residents and fellows who rotate through the MICU on a monthly basis.

Physicians enjoyed having much-quicker access to radiologic images. In addition, film loss to the MICU has ceased to be a problem for radiology. The MICU team still reviews the conventional radiographs in the radiology department with a radiologist during their daily radiology rounds.

After six weeks of operation, a formal survey was conducted in order to better quantitate user response. Twenty-eight responses were collected (Table 1). The survey emphasized that the clinicians were generally satisfied with the unit. In addition, several problem areas were identified. First, the level and contrast controls were considered difficult to operate. Specifically, the thumb-

wheel controls had a peculiar response characteristic that confused clinicians. These controls have undergone several revisions, and are now more intuitive to use.

Second, the handling of portable films exposed "sideways" (long axis of film horizontal) was considered less than desirable because the system initially displayed these images with the long axis vertical. Although the images could be properly rotated, the clinicians resented having to rotate virtually every image they reviewed. Recently, a new feature was added that allows each display station to be programmed for the preferred image orientation, eliminating the need to rotate most images.

Third, the users also wanted to be able to use the roam feature without zooming first. This was incorporated, allowing the ability to zoom an image at any time and also providing an addi-

Table 1. Clinical user Questionnaire

Question	Yes	No	NR*
1. Did you feel comfortable using this image display unit?	28	0	0
2. Are you happy with:			
Number of monitors?	28	0	0
Screen size?	25	3	0
Ease of image selection?	24	4	0
Speed of image display?	21	7	0
3. Do the current icons provide the needed viewing options?	24	3	1
4. Are the icons intuitive?	25	0	3
5. Did you use the zoom feature?	25	3	0
6. Was the zoom feature helpful?	20	1	7
7. What was your impression of the window/level controls	13	2	13
8. Do you need to go back to original image as displayed?	22	2	4
9. Is the "system status window" in the lower right corner adequate?	22	1	5
10. Has the system improved patient care?	17	2	9

*No response.

tional level of magnification, which can be helpful on traditionally small images, such as neonatal exams.

Some users considered image quality (at $840 \times 1,024 \times 12$ bits) inadequate for very subtle abnormalities (ie, small pneumothorax), although adequate for most routine portable indications (tube and catheter placement, obvious change in pulmonary status). However, other users have been equally insistent that image quality is completely adequate.

Finally, although the clinicians greatly appreciated the convenience the system offered, it was not documented that patient care had actually improved.

DISCUSSION

At the Shands Teaching Hospital of the University of Florida, 40% of all inpatient radiologic examinations are portable, which accounts for 50,000 portable exams per year. The portable exams are usually obtained in six ICUs scattered throughout the institution. None of these ICUs is close to the radiology department.

Unfortunately, clinicians do not have timely access to portable radiographs obtained in acute care situations because it may take as long as 10 minutes to get to radiology, and several more minutes to find the radiograph. Furthermore, attending clinicians and residents who are directly supervising a critically ill patient often cannot leave the immediate area.

Not surprisingly, a junior resident or medical student is often sent to radiology to retrieve the radiograph before any radiologist or radiology

resident has had an opportunity to review the examination. The films taken from the radiology department are often removed without proper signout, and are subsequently lost without an official interpretation.

The most-striking feature of the CRS is its ease of use, which we attribute to the icon-based interface. After the initial group of users was trained, we have not had to conduct any further training sessions. The system is "user supported": the new fellows, residents, and medical students who rotate through the MICU every month are taught to use the system by the attending physicians, unit nurses, and knowledgeable housestaff. We were also impressed by the ease of installation. Despite being a beta test unit, the system was installed in one day, and was fully operational the next. Down-time has been negligible.

The call-up time for image display is very acceptable because the images are stored locally after being transmitted automatically from the server to the display station. Previous systems using telephone lines were relatively slow for data transmission.¹⁻⁷ Systems like the CRS are more expensive because of the higher quality of display monitors, large local storage requirements, and the use of a dedicated coax line for image transmission.

Some further improvements in the CRS were indicated and have been recently implemented. The system installed needed to support multiple read stations, attached to one server module, so that other ICUs could be covered with one digitizer. This feature has been incorporated at our site, with two ICUs currently operational and

two additional ICUs and a read station in our image processing lab being placed into operation. Close attention is being given to image-movement traffic and elimination of potential bottlenecks.

In addition, the digitizer needed to recognize smaller film formats—an important feature for our Pediatric and Neonatal ICUs. This has been recently addressed by incorporating the ability to program the server module for the desired resolution level (“840 × 1,024” or “1,680 × 2,048” over a 14 × 17-in field) for each reading station. This ensures that reading stations in pediatric

and neonatal ICUs are provided with images of the required resolution.

Finally, in the authors’ opinion, radiology reports should accompany the images. An interface with the CRS and the study hospital information system that would accomplish this function is currently in the design phase.

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