Quality-of-Service Improvements From Coupling a Digital Chest Unit With Integrated Speech Recognition, Information, and Picture Archiving and Communications Systems

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Speech recognition reporting for chest examinations was introduced and tightly integrated with a Radiology Information System (RIS) and a Picture Archiving and Communications System (PACS). A feature of this integration was the unique one-to-one coupling of the workstation displayed case and the reporting via speech recognition for that *and only that* particular examination and patient. The utility of the resulting, wholly integrated electronic environment was then compared with that of the previous analog chest unit and dedicated wet processor, with reporting of hard copy examinations by direct dictation to a typist. Improvements in quality of service in comparison to the previous work environment include (1) immediate release of the patient, (2) decreased rate of repeat radiographs, (3) improved image quality, (4) decreased time for the examination to be available for interpretation, (5) automatic hanging of current and previous images, (6) ad-hoc availability of images, (7) capability of the radiologist to immediately review and correct the transcribed report, (8) decreased time for clinicians to view results, and (9) increased capacity of examinations per room.

KEY WORDS: chest imaging, RIS, PACS, speech recognition, selenium, image quality, workflow.

MAYO CLINIC SCOTTSDALE performs 180,000 x-ray examinations per year, 25,000 of which are chest examinations. The chest examination is a high-volume procedure. A mean of 100 patients is done per day in the chest room (peak volume of over 180 per day). The film cost for these studies comprised 30% of total film costs before the conversion to digital methods. The work imposes significant network (and production) "loads."

This workload presents an enormous challenge for efficient throughput of patients, their studies, and their reports, for either an analog or a digital system. Chest x-ray studies are technically challenging, including high spatial resolution, wide dynamic range, and disease processes that demand low-contrast detection as well. Any digital device must challenge the dedicated film-screen system for chest imaging that had been in use.[1,2] Chest reports often are short and structured and often refer to a previous examination. Approximately 30% of chest examinations have prior comparison images, and 10% have more than one. As predicted by Bauman,[3] demands on primary care physicians necessitate quick turnaround of examination results; thus, the immediate availability of a commonly ordered examination (such as chest radiography) would have a favorable impact on clinical service. A "digital" system could have an immediate economic impact.

The chest studies are now performed on a Thoravision unit (Philips, Best, Netherlands), a large-area (17 × 19 in) digital imaging device. The Thoravision is interfaced to the Radiology Information System (RIS). Our RIS is a Mayo-developed one called the Mayo Radiology Information Management System (Mayo RIMS).[4] The Mayo RIMS contains all radiology reports since it became operational in November 1995. The chest studies are automatically passed to the PACS following quality control. The PACS (General Electric Medical Systems; Milwaukee, WI) is interfaced with the Mayo RIMS.

Speech recognition was first used for reporting in ultrasound and computed tomography. Subsequently, it was extended to chest reports (IBM Medspeak/Radiology, Armonk, NY). Because of the high-volume throughput in the chest area and the typically tight scheduling of physician visits for patients soon after their radiographic study, it was necessary to have an interface between the softcopy images displayed on the workstation and the report file in the Mayo RIMS for a particular patient and study. The time constraints were so tight that separate entry of an accession number or patient/examination information to identify the case to be reported was not acceptable. This problem was solved with an interface that guaranteed synchronicity of the images and the patient's report file for that

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case (Digital Dictate; NCC, Scottsdale, AZ). "Speaking" the report puts the information into the right file in the Mayo RIMS for the study under review.

This specially integrated group of digital systems has seemed very useful. This study compares it with the previous hard-copy chest examinations with direct dictation to an on-line transcriptionist.

MATERIALS AND METHODS

Radiographic Chest Unit

The previous system was a Picker dedicated chest with a bulk film loader and a coupled wet processor. The highest number of examinations possible with that system was about 120 per 8-hour day. Insight screens (Kodak, Rochester, NY) and Kodak film were used.

The digital chest unit that replaced it is a Thoravision. The Thoravision uses a selenium coating on a 50-cm-diameter drum to provide for direct capture of phototimed x-rays (150 kVp). After exposure, the drum is rotated and the resultant generated electrical field is read out and digitized, giving pixels of a nominal 2K × 2K with 14 bits and 916,384 shades of grey).[5] The detector area provides a maximum of 43 × 49 cm (17 × 19 inches), so large patients are accommodated easily. Patients needing 17 × 14-in examinations are automatically sized (the previous chest unit required the patient to be repositioned with the wall bucky). Collimation is independently controlled top and bottom, thus operator setup is simplified, and the tube crane does not require adjustment to make small collimation changes. Readout is automatic after exposure and is displayed in 20 seconds at the control booth in low resolution (1K × 1K) to give an immediate indication to the technologist of the need to repeat the exposure. Patients are permitted to go to their next appointment after this in-room check.

The Integrated Electronic Environment

The wholly integrated electronic environment now in use, which this study compares with the previous automated analog methodology, has five essential elements: the digital chest unit, the RIS, the PACS, the speech-recognition engine and programs, and the special interfacing of that system to the RIS. An interface to the electronic medical record also is operational but is not essential for the purpose of this study.

The Radiology Information System is the Mayo-developed Radiology Information Management System. The Mayo RIMS is interfaced to an electronic medical record system (IDX, Burlington, VT). The PACS System in use is a centralized image storage and distribution system marketed by GE Medical Systems (Milwaukee, WI). It uses a high-speed proprietary fiber connection arranged in a star topology to provide high-speed access to the central short-term storage (STS) server. Our facility has 3 such stars. An ATM OC-3 WAN connects the hospital to the clinic, so images are available electronically throughout the practice.[6]

Reports were created directly using the Medspeak/Radiology product (IBM, Armonk, NY), a 16,000-word continuous speech-recognition engine. Special interfacing of Medspeak to the Mayo RIMS was done via a GUI interface product (Digital Dictate, NCC, Scottsdale, AZ).

Workflow Using the Integrated Electronic System

The technologist selects the patient from the modality worklist, performs the examination, and 20 seconds later reviews the image locally before dismissing the patient. Posteroanterior and lateral images are automatically forwarded to the PACS with the patient demographics. The arrival of the chest examination at the PACS causes a new name to be added to the list of examinations to be quality controlled (QC), which validates the examination with the Mayo RIMS order, flip-rotates the image, window-level; these are performed by the technologist. The chest examination is then available (in about 20 seconds, because the database is updated at this frequency for new examinations) to the radiologist for image interpretation, as the QC process alters the examination status to be on the "Unread" list. Examinations are displayed according to a hanging protocol and are interpreted with a continuous speech-recognition system that has been interfaced with the Mayo RIMS. Previous chest examinations are retrieved from long-term archives up to 30 hours before the scheduled examination. Any comparison images and the current study are displayed for soft-copy viewing within 3 seconds in an autohang protocol on a 4-monitor high-brightness high-resolution interpretation workstation following selection of the patient from the worklist. The Mayo RIMS interface with the PACS automatically triggers the proper screen selection for the Mayo RIMS workstation (this is a separate workstation) so that the patient selected by the radiologists in the PACS for the interpretation is the exact same patient in the dialog box for transcription. Preset windows are available for viewing bone and mediastinum in addition to the default window (soft tissue) presentation. The Mayo RIMS sheet shows the previous studies on the patient; thus, the presence of a chest computed tomogram (CT) for example, would notify the radiologist to select that comparison examination for viewing. Ideally, the CT would be part of the autohang configuration. Five radiologists use the computer speech-recognition system for dictation of chest interpretations. The interpretation is placed into the Mayo RIMS by speaking the report for processing by the Medspeak Speech Recognition engine. This has been reported to have 97% accuracy.[7] The radiologist selects the patient and, using the microphone (Philips Speech, Model 6174), gives the command "Begin Dictation!," which opens the dictation dialog box. The report is spoken, most commonly without regard to text being generated. The command "Stop Dictation!" completes the session. The text is reviewed for accuracy and corrected if necessary. In experience with more than 10,000 chest examinations the accuracy is about 95% for a radiologist who has used the system for 6 months.[8] The report is finalized in Digital Dictate, which closes a patient's session and adds the report to the radiologist's speech profile, thereby improving future accuracy. Reports are immediately reviewed and finalized at the RIMS workstation, which automatically tells the PACS database to remove the patient's name from the "Unread Worklist" in PACS. The dictated report and images are available immediately at all RIMS and PACS clinical review stations throughout Mayo Clinic Scottsdale.

Viewing of results by clinical physicians, including any previous results, is possible in any of the 25 workstations located outside the radiology department, including the hospital, which is about 12 miles from the clinic. Reports without images are available at all personal computers throughout the institution.

Data Collection Procedure

Two studies were performed during the busiest part of the morning (9:30 to 10:30 AM) during a busy month (March) in Scottsdale. The mean time for more than 100 patients was measured, including: the time the patient was physically in the chest examination room, the time of electronic examination transfer to QC, the duration of QC, the time of transfer to the radiologist's diagnostic workstation, the mean time of displaying a 2-image chest examination, and the mean time of the radiologists' interpretation, which included computer speech recognition and finalization of the report. Wheelchair patients and interruptions of examination flow (ie, clinical consultations with the radiologists) were not included.

RESULTS

Image Quality Considerations

Improvements in x-ray detective quantum efficiency (DQE) and image processing exist with the change that had taken place.[9] These authors reported that for objects of 2.0 mm to 11.1 mm, the detectability of Thoravision is twice that of the film-screen system they used for comparison.

Figure 1 compares Insight film-screens with the properties of selenium (Thoravision) and shows a decided advantage for capturing x-rays with selenium.[5] Improvements are to be expected in the detection of low-contrast objects, as seen at comparable low-frequency values of the DQE curve. Further, the dynamic range of selenium is greater, thereby providing contrast detection with processing for regions of both low and high exposures, as compared with Insight screens. Importantly, having the data in an electronic form allows for image enhancement.

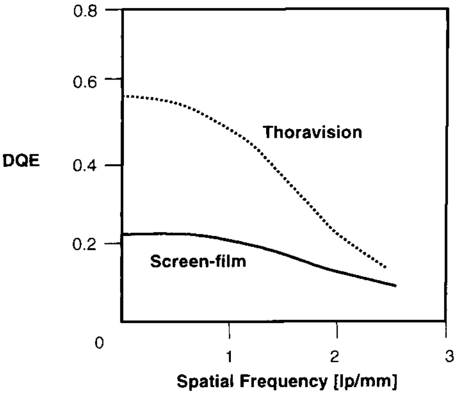

Fig 1. Comparison of detective quantum efficiency (DQE) for film screen compared with selenium, as used in Thoravision.[5,14] DQE allows comparison of a detector's overall efficiency in capturing x-rays and how that detector adds noise to the image. The reader is cautioned that DQE varies with kVp as well as with exposure. Curves are used to depict the physical basis for image quality improvement with selenium.

We chose an automatic processing algorithm using a 3 × 3-cm kernel (Fig 2) resulting in a selected soft-tissue enhancement. Automatic processing allows for placement of the maximal data enhancement to occur predictably at the juncture in the pixel histogram where the pixel values representing the lung soft tissues are found. In comparison, the manual radiographic technique previously used would not necessarily accentuate the lung soft-tissue contrast. It would depend on the exposure at the location of interest—an uncertain method that places demands on the technologist to accurately and consistently measure the patient and to select the correct technique. The image processing used at our facility differs in that it has a large enhancement for the soft-tissue component of the lung. An actual patient enhancement of the soft tissue of the lung is shown in Fig 3. A full discussion of the processing of the Thoravision is provided in reference 10. Although no formal clinical comparison is offered herein, the experience of radiologists who have interpreted more than 50,000 similar selenium chest examinations[11] shows that the digital studies using soft-tissue enhancement are "strongly" preferred over the film-screen technology used previously. Pathological lung tissue generally causes increased (but just slightly so) attenuation. A contrast enhancement such as this exploits this phenomenon.

The greater dynamic range of selenium is more forgiving of under exposure and overexposure than is film-screen. This, in addition to the use of phototiming, has resulted in improvements of quality, as measured by our repeat rate for chest examinations, which decreased from 2.1% to 0.4%.

Utilization Study

Clinical viewing of images and reports, including any previous results, was possible at any of the 25 workstations located outside the radiology department, including the hospital, as quickly as 10 minutes from the time the patient received the first exposure of the examination. The results of the time study measurements (Table 1) show that the average time to interpret a chest examination was 2 minutes 20 seconds using PACS and voice recognition. The reported value shows the time as measured from the point the radiologist receives the

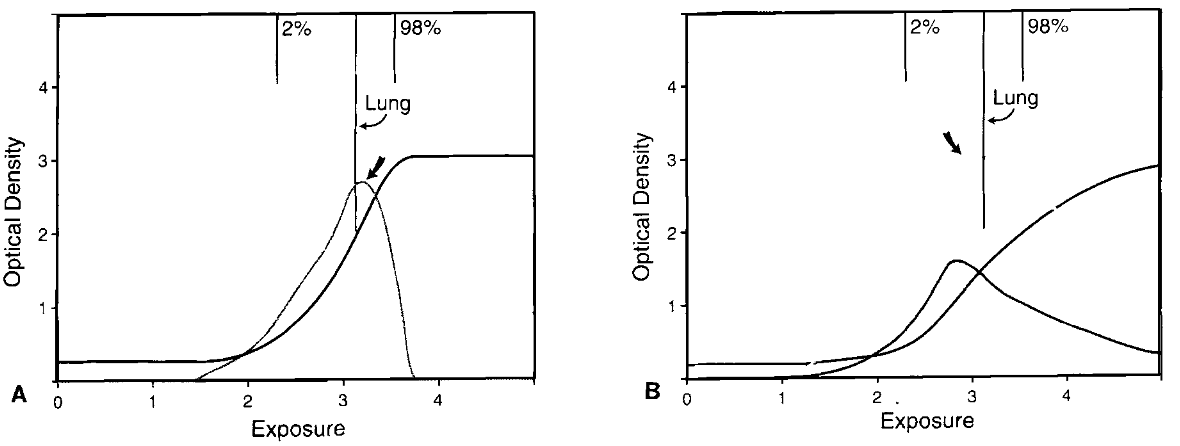

Fig 2. Kodak Insight HC compared with the processing used in this study with Thoravision. (A) Curve A is the typical H and D plot of exposure versus optical density. Curve B is a differential of Curve A. The vertical axis is relative scale of contrast when looking at Curve B. Curve B shows maximal contrast when objects in the image are exposed to radiation in quantities just over 3 (relative units), which produces an optical density of about 2 on film. This peak contrast would be applied to any sized object, but only over a relatively narrow range of exposures in the image. At the top, the 2% and 98% lines mark the histogram percentile points in this image, and "Lung" is the pixel value (exposure) computed from the histogram data for this patient to best represent the region of lung. Notice that the peak contrast (unlabeled arrow in Curve B) lies just *beyond* the lung density (regions of high x-ray penetration). (B) Curve A is the equivalent of the H and D curve but with Thoravision. An automatic processing mode we use forces the minimal pixel values to be OD 0.2, with an OD of 3.0 assigned for maximal pixel values, were these images to be printed on film. Every patient has a slightly different Curve A, because of differences in the histograms. Curve B is again the differential of Curve A. Curve C depicts one example of contrast enhancement applied to Curve B that is possible with processing digital data, which is not possible with conventional film-screen. It is the one used routinely at our facility. Maximal contrast in the image occurs to pixel values having slightly *lower* values (arrow in Curve C) than the computed average value in the lung region. Assuming disease processes cause slightly *more* attenuation than normal lung tissue, the application of maximal contrast to these pixel values maximizes conspicuity of subtle disease, being limited only by DQE of the system. Importantly, the processing provides enhancement for small- to mid-sized objects (2 mm to 10 mm), and does so over a wider range of exposures than depicted in Fig 2A.

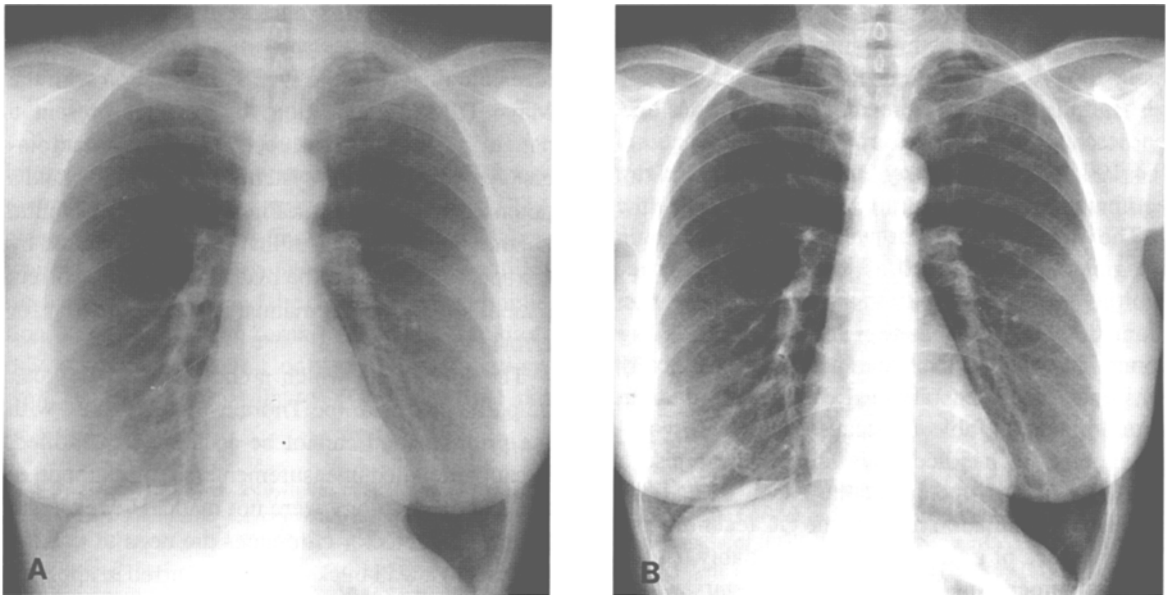

Fig 3. Chest image processed with Insight HC (left) and the technique described above. The data used in Fig 2 are from these images. Note the improved contrast and conspicuity of soft tissue details in the lung field in Fig 3B.

addition to the worklist sheet until the examination is finalized in RIMS. As mentioned, these times exclude any interruptions (telephone calls, live consultations) and also assume that the report is finalized immediately after a review of the computer-generated text; that is, the electronic signing of the reports is not a "batch process."

Gay et al[12] suggested the application of Little's law[13] to perform an evaluation of workflow. From the determination of the average time required to perform the entire process, as well the average times of the subprocesses, the determination of bottlenecks can be made from inspection of the data. This can be an aid in resource allocation. We chose to include certain aspects of the movement of the patient just before the chest examination as well. This showed that patients were always available, and the lack of patients was not a cause of throughput delays. Little's law states that the mean number (of patients or examination results) in the system equals the mean throughput rate multiplied by the mean time in the system (reference 12). If the examination results are to be optimally available for the clinician, the mean time for patient throughput must equal the examination result's throughput. That is, the images and reports must be immediately available. We measured the mean time of the patient in the department to be 15 minutes (if just a chest x-ray was being done). Doing 150 patients (and reports) in 1 room per day averages 10 minutes for each report (when averaged for the day). When the chest service comprises 1 room, 1 imaging technologist, and 1 radiologist, Littles analysis allows for computation of whether the

Table 1. Staff and Equipment Resources for Chest Imaging

Step	No. Image Tech	No. Chest Unit	No. QC Tech	No. Radiologist	Average Time (min)	Task Per Minute
Patient is called, dressed, and seated	–	–	–	–	4.5	–
Chest room occupancy time	.5	1	–	–	2.3*	.43
Examination available for QC	–	–	1	–	1.8	.55
QC review	–	–	1	–	0.2	5.0
RIMS sheet given to radiologist	–	–	1	–	2.0	.05
Read, voice dictate, sign report	–	–	–	1	2.3	0.43

*Room occupancy approaches 50% for 100 patients per 8-hour day. Serial processing of images (1 chest examination room, 1 QC technologist, and 1 radiologist) can be impacted negatively by any interruption of workflow. Examples include unavailability of patients, technologist "batch" performance of QC, and radiologist-physician consultations.

ing errors and to provide a user-mandated substitution would be helpful.

CONCLUSION

The results of the measurements made of the integrated digital chest modality show that improvements in quality of service were substantial. The patient was dismissed more quickly, with less waiting. Images were superior in quality to those obtained previously, and the rate of repeat examination was reduced. The turnaround times in radiology for patients having only chest examinations were as short as 15 minutes (from the time the patient entered the chest x-ray room until the patient was dressed and leaving the department). The speed with which the report and images are available to the clinical service (the examination throughput) improved by up to 12-fold, from a minimum of 2 hours to a minimum of 10 minutes with the possibility of further improvements. The five essential components in this integrated service were a digital chest unit, PACS, RIS, computer speech recognition, and application software integrating RIS with computer speech recognition. A key finding of this study was that significant improvements can occur only in an *integrated* electronic environment.

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