Developing a Radiology Data Base for Quality Assurance

Peter J. Haug, Margaret Farrell, Joe Frear, Duane Blatter, and Philip R. Frederick

Radiology Information Systems (RIS) are designed to capture and manage the data associated with ordering, executing, reporting, and billing x-ray procedures. The HELP Hospital Information System contains a radiology subsystem that supports these functions. In an effort to enhance quality assurance initiatives, we have created a supplemental data base. This data base contains not only the data traditionally generated by RISs but also data from the hospital system that is relevant to quality assurance. One of the goals associated with this data base is to use techniques from the discipline of Continuous Quality Improvement (CQI) in the radiology department. A focus of our initial efforts has been the time necessary to provide x-ray reports to ordering physicians once the imaging examination has been performed. Efforts to manage the portion of this time interval caused by transcription have resulted in a substantial decrease in the time required for this function. A second goal of this project is to evaluate the quality of x-ray ordering. This objective requires a computerized record of the outcome of the x-ray procedure. Initial analysis of data derived from this data base indicates significant differences in the ordering behavior for computed tomography (CT) examinations among a test group of physicians. A third goal is to do quality assurance on x-ray reports. Experience with pilot systems has shown promising results using a mathematical model of report quality. We hope to leverage these techniques and this quality assurance data base to define a CQI process for medical reports in general and for x-ray reports in particular.

Copyright © 1997 by W.B. Saunders Company

THE HEALTH CARE system in the US has embarked on a period of dramatic change. Not only are prevailing approaches for managing and financing the delivery of care changing. In addition, tools to automate the capture, management, and distribution of clinical information are entering medicine at an unprecedented rate. As the process of care delivery is transformed, new approaches will be required to support measurement of the quality of medical services delivered in this evolving environment. These approaches will themselves require the capture and management of large amounts of information.

In this report, we deal with a group of tools and techniques that have been developed for quality assurance and department management in the realm of radiology. These techniques are borrowed from the fields of Medical Computing and Continuous Quality Improvement (CQI) to provide insights

into three aspects of radiology. The aspects of care focused on are (1) processes within the radiology department; (2) the ordering practices of physicians who use x-ray services, and (3) the quality of the products of the radiology department, most notably the x-ray report.

Central to this developmental effort has been the creation of a quality management data base for radiology. At present, this data base provides services to four hospitals, all a part of Intermountain Health Care (IHC), a large health care organization in Utah. As the tools described below continue to develop, additional hospitals and outpatient settings will be able to take advantage of them.

SETTING

The overall setting for the work described here is the medical computing environment provided by IHC. This environment consists of two principal parts. The first is a hospital information system called the HELP system. The second is a client/server-based environment in which the successor of the HELP system is being developed.

The HELP Hospital Information System (HIS)¹ represents more than 20 years of development and testing. It currently operates on hardware provided by the Tandem Corporation (Cupertino, CA). One or more of its principal software components are installed in seven IHC hospitals. Our test bed for the pilot system described in this report is the HELP system in the LDS Hospital. Here the information system communicates with users and developers through approximately 1,200 terminals and more than 200 printers.

The HELP System consists of an integrated clinical database, a frame-based medical decision system, programs to support hospital and departmental administrative functions, and the tools re-

From Intermountain Health Care and the University of Utah School of Medicine, Salt Lake City, UT.

Supported in part by National Institutes of Health Grant No. HL53427.

Address reprint requests to Peter J. Haug, MD, LDS Hospital, Medical Informatics, 8th Ave and C St, Salt Lake City, UT 84143.

*Copyright © 1997 by W.B. Saunders Company
0897-1889/97/1003-1036\$3.00/0*

quired to maintain and expand these components. The integrated clinical database contains a variety of patient data kept on-line during the patient's stay to allow access by health care professionals at terminals throughout the hospital. These terminals allow the entry of pertinent clinical data into the HELP system by personnel who are involved in patient care.

In the radiology department, a Radiology Information Subsystem (RIS) is embedded in the HELP system. It provides for the order entry, process tracking, charge capture, and film tracking functions necessary to support the delivery of radiological services. In addition, each radiologist has a terminal used for managing his/her dictated reports and as a window onto clinical data bearing on the patients for which he/she provides services.

The second part of IHC's medical computing environment is centered around a group of data base servers using the Oracle relational data base product (Oracle Corp, Redwood Shores, CA). These tools are part of an effort to develop a next generation medical information system. In the context of this project, these servers provide a home for the radiology data base described below.

METHODS

The discipline of CQI has provided a motivating philosophy for data collection and management processes. It is described briefly below. Central to the application of the principals of CQI is the ability to collect and store data that can reflect the quality of the processes managed. This requires a quality assurance data base and techniques to collect the required information. In addition, tools that can summarize the accumulated data and provide appropriate feedback are essential to the quality improvement process. Below we discuss our approach to these various requirements.

CQI

CQI theory is derived from industrial quality control techniques that were developed by Shewart,² working for Western Electric in the 1920s. Deming³ introduced the technique to the Japanese in the early 1950s, and much of Japan's economic success since then has been credited to the successful implementation of these techniques. Crosby⁴ has written extensively about the social implications of the quality control effort, Juran⁵ has edited a large handbook of quality control techniques, and Ishi-

kawa⁶ has described graphic tools for use in quality improvement. Berwick^{7,8} has been the champion of CQI teams and techniques in medicine and has published many reports and a book on the subject.

Central to the use of CQI techniques is the identification and elimination of inappropriate variability in a process and its outcomes. Large variability in outcomes implies that some outcomes are inadequate and need to be reworked.

The general goal of this project is to test tools designed to support quality assurance procedures in a radiology department. The specific focus is to develop an efficient approach to the capture, storage, and evaluation of all data bearing on the quality of x-ray services.

Data Base

Large amounts of information are generated in the HELP RIS as part of the process of delivering radiological services. In addition, a significant portion of the clinical data collected during each patient's hospital stay is captured by the HELP system. This includes a variety of data that can contribute to the evaluation of x-ray services.

As part of this project, we have developed an independent data base in which is stored information relevant to the process of delivering x-ray services. This data repository is a relational data base using the Oracle's data base engine. It is called the Imaging Services Data Warehouse (ISDW).

Data Collection

To acquire the information necessary to pursue the goals outlined above, we have implemented a set of tools within the HELP system that capture salient x-ray data in real time and send it to the relational data base. These tools trap the data as it is in route to the native HELP data base and direct a copy to the ISDW. In addition, we use these tools to intercept other HELP data and send it to the ISDW. Currently, we use them to capture outcome data such as biopsy results, discharge diagnoses, and microbiology results.

Much of the information necessary to evaluate the processes of image acquisition and result dissemination for the radiology department is captured through this interface. However, a subset of the data needed for quality assurance activities is not generally available in the HELP system. This subset has required the development of additional data collection tools.

The added data frequently must come from the radiologists. A typical example is the information necessary for evaluating the appropriateness of radiology ordering behavior. In this case, the goal is to measure the ability of the ordering physician to choose those procedures appropriate to a patient's clinical situation. Two pieces of information are necessary, the reason for each order and the result of interpreting the radiograph. This result can be dichotomized as (1) consistent with the ordering reason or (2) not consistent with the ordering reason.

The HELP RIS captures the first of these data elements at the time of order. The second must be entered by the radiologist. In the past, we have tested various mechanisms to expedite this process including check boxes, bar codes, and computerized questionnaires. Our current implementation uses a simple natural language parsing system.

To use this interface, the radiologist simply appends a brief statement to the end of his report stating whether the results of the examination were or were not consistent with the reason for the procedure. He encodes this observation as "code 1" or "code 2." Once transcription is complete, a program examines the text and extracts and stores this information in the ISDW. It is then available for quality assurance activities.

Measuring X-ray Processes

After relevant data have been stored in the ISDW, they must be summarized in ways useful to groups who need to evaluate the success of the medical processes these data represent. The simplest processes to measure are those that take place exclusively within the radiology department. The quality of the ordering process and of the content of the x-ray reports is a more challenging measurement problem. Below are descriptions of the approaches that we have piloted to provide evaluations for these three areas.

Radiology department processes. The fundamental data necessary to evaluate the efficiency, productivity, and timeliness of processes in the radiology department are captured through the interface from the HELP system. Table 1 is a partial list of the reports produced in the radiology department as part of the quality assurance processes. These reports provide a basis from which to plan changes of each process in the radiology depart-

Table 1. Simple Tables/Graphics Developed for Departmental Management

Exam volume by day of week
Exam volume by radiologist
Exam volume by technician
Exams not confirmed
Exams not confirmed prior to reading
Exams ordered by physician
Exams ordered by physician specialty
Exams ordered/confirmed/reported by ordering physician
Exams per hour of the day
Exams per shift
Exams by department
Exams by hour of the day ordered by ER (MKAY)
Exams by room location
Etc

ment. They also allow measurement of the effectiveness of these changes.

To evaluate the effects over time of some of these interventions, we have used a tool from the discipline of CQI called Statistical Process Control Charts (SPCCs). SPCCs provide a graphical way of assessing the variability of processes that occur in the radiology department. Figure 1 is a sample of a SPCC intended to measure the time required for transcription of x-ray reports.

The data for this chart comes from an analysis of 62,196 transcriptions done in 1996. The chart shows the mean time from completion of dictation to completion of transcription for the whole data set (the center line). For each month, a range is shown that represents three standard deviations from the global mean. This range is demarcated by the upper and lower control limits (UCL and LCL). These represent the range of values within which the mean time for that month could fall and still be entirely due to random (unassignable) variation. Values outside of this range are considered to represent assignable variation (ie, variation that can be attributed to a global change in the transcription process). In this example, a new transcription service and a new transcription process were introduced on May 1st. The effect of this change is clearly demonstrated.

Ordering practices. The evaluation of ordering practices is also facilitated by the ISDW. As part of the data collected by the RIS, the ordering physician and the reason for each examination are captured. The other relevant piece of information is the outcome of the x-ray examination.

Above we described the mechanism used to capture the radiologist's evaluation of the consis-

Fig 1. An example of an SPCC for the time required to transcribe a radiology report. The effect of an intervention in May (changing transcription services) is clearly seen.

tency of each examination's results with the reason given by the ordering physician. This simple indicator can be used to generate a measure of the success by the ordering physician in identifying patients who might benefit from a specific type of radiological procedure.

An example comes from the emergency department. Here we have been piloting these tools in an effort to determine their place in a quality assurance program. The focus is on computerized tomography (CT) of the head. In this context, we have evaluated the frequency of head CT scans ordered per 10-hour shift. Initial analysis using SPCCs suggest that a subset of physicians fall outside the control limits for the ordering process. This observation has triggered a further analysis of CT ordering behavior in this setting.

We have been trying to refine the interpretation of this information by gathering additional information from the ordering physician. By capturing the reason for the test, we can evaluate the ordering process for specific subsets of patients. This will

allow a much more useful form of feedback to be given to the ordering physician.

X-ray result quality. The final area in which the availability of the ISDW can assist in quality assurance initiatives is in the principal product of the x-ray department, the x-ray report. The combination of data captured in the radiology department along with information from other HELP sources can facilitate measurement of the success of this report as a diagnostic aid. Below we review previous work that indicates how this data might be combined with data from the hospital information system to provide an evaluation of the overall quality of x-ray reports. We are currently extending the techniques described to create a new group of measurement tools focused on variability in the recording of specific radiological findings. These should permit much more focused feedback to be directed to the radiologists who produce these x-ray reports.

There are two categories of information that occur in a radiology report. The first is descriptive

data that summarizes the abnormalities seen in the image. In this category fall such findings as *hazy parenchymal opacities* seen on the chest x-ray and *microcalcifications* observed in a mammogram. The second category of information reported is the interpretation of these descriptive findings. The conclusion that the patient may have *pneumonia* or *breast neoplasms* are examples of these interpretations.

For this second type of data, the HELP data base can often supply directly comparable information. Verification of pneumonia or breast neoplasm can be extracted from the discharge diagnoses and biopsy results encoded there. However, for the descriptive data found in radiographic reports, other clinical data may be only indirectly related to these findings. The hazy parenchymal opacities mentioned above may, in fact, represent other illnesses besides pneumonia.

An example of a system that evaluates descriptive findings comes from research into the information content of chest x-ray reports. The goal of this project was to develop a technique for measuring the quality of x-ray reporting without requiring the review of radiographs by multiple radiologists. This is in contradistinction to typical approaches for evaluating the accuracy of radiologists. Typically, audit procedures in the radiology department require multiple readings of a select set of x-rays.⁹⁻¹³

The technique developed as part of this project was based on a simple premise. Each examination is a test of the radiologist's accuracy. Instead of comparing the abnormalities reported to a standard formulated through multiple readings, the description in the report is evaluated in comparison to the patient's overall diagnostic outcome. In the case of chest x-rays, the standard used was the list of final diagnoses attached to the patient's record at the time of discharge. The report generated by the radiologist is successful to the extent that it supports the diagnoses process.

There is not a one to one relationship between the descriptive findings and discharge diagnoses. Therefore, to assess the consistency of the x-ray findings with the final diagnoses, the system required a diagnostic model. In this study, a probabilistic model of pulmonary diagnosis was used to link the findings to the discharge diagnoses.

A variety of algorithms can be used to evaluate the strength of the association between findings represented in the x-ray report and the final diagno-

sis. We have demonstrated the success of a modified version of Shannon Information Content.¹⁴ This algorithm has been able to discriminate among members of a group of physicians reading chest x-rays. Our evidence comes from two studies. In the first study, we used expert system technologies to demonstrate discrimination in a controlled experiment.¹⁵ In this experiment, five x-ray readers (radiologists and pulmonary physicians) read an identical set of films. The assessment, driven by diagnostic logic gave results consistent with the differing expertise of the readers and consistent, as well, with the results of a more standard audit procedure.

In a second study of this technique, we tested a group of radiologists as they did their daily work. Each chest x-ray was reported only once as a part of the radiologist's daily work. The goal of this study was to determine the algorithm's ability to measure the quality of x-ray reporting in the uncontrolled setting of a typical radiology practice.

As part of this experiment, 651 reports generated by a group of radiologists were compared with the patients' discharge diagnoses using an information content algorithm. The radiologists were grouped according to whether they had additional (postresidency) training in chest radiology. The "trained" radiologists produced 11% more information than the "untrained" radiologists (0.664 bits as opposed to 0.589 bits, significant at $P < .005$).

The approach used successfully discriminates these groups. However, it is an overall measure. We are actively attempting to extend these results to allow discrimination of accuracy at the level of individual findings. To accomplish this, we have routed discharge diagnoses and biopsy results from the HELP system into the ISDW. We are exploring alternatives that would allow capture of both the descriptive and the interpretive data that is contained in x-ray reports. If these goals can be accomplished we should be able to extend quality assurance initiatives to the x-ray report itself.

DISCUSSION

In this report, we have described an approach to quality assurance focused on the discipline of CQI. CQI encompasses a variety of techniques for identifying areas with suboptimal quality and for communicating relevant measurements of related processes to those responsible. Here we have

focused on the issue of data collection and the measurement of process outcomes.

Central to CQI is the ability to measure the results of each process whose quality we seek to improve. We have interpreted this observation to mandate the creation of a data base bearing on the processes in the radiology department. This data base is referred to as the ISDW.

To develop this data repository we have begun by diverting information collected by the HELP RIS into an Oracle data base. We are augmenting this data with other information collected by the HELP system. Diagnostic, laboratory, and biopsy data have been our first targets.

The most difficult data to capture in a computer

usable form has been the information embedded in the x-ray reports. This data is essential to quality assessment for several of the processes associated with the ordering, executing, and resulting of an x-ray examination. Above we describe our efforts to use natural language parsing techniques to encode this data.

The efforts described here are a part of the overall push to understand and evaluate processes that contribute to the delivery of medical care. The goal, better and more cost effective health care, is a central focus in the evolving discipline of medical computing. The use of data bases to enhance the ability to measure all aspects of care delivery is a central theme in this effort.

REFERENCES

1. Kuperman GJ, Gardner RM, Pryor TA: HELP: A Dynamic Hospital Information System. New York, NY, Springer-Verlag, 1991
2. Shewart WA: Economic control of quality of manufactured product. Washington DC: Creepress, The George Washington University; 1986 (reprinted from Van Nostran, 1931, and the American Society of Quality Control, 1980)
3. Deming WE: Out of the crisis. Cambridge, MA: MIT and The Cambridge University Press, 1986
4. Crosby PB: Quality is free: The art of making quality certain. New York, NY, American Library, 1980
5. Juran JM: Quality Control Handbook 3rd ed. New York, NY, McGraw-Hill, 1979
6. Ishikawa K: Guide to quality control. White Plains, NY, Kraus International Publications, 1982
7. Berwick DM: Continuous improvement as an ideal in health care. *N Engl J Med* 320:53-56, 1988
8. Berwick DM, Godfrey AB, Roessner J: Curing Health Care: New Strategies for Quality Improvement. San Francisco, CA, Jossey-Bass 1991
9. Herman PG, Gerson DE, Hessel SJ, et al: Disagreements in chest roentgen interpretation. *Chest* 68:278-282, 1975
10. Rhea JT, Potsaid MS, DeLuca SA: Errors of interpretation as elicited by a quality audit of an emergency radiology facility. *Radiology* 132:277-280, 1979
11. Yerushalmy J: Reliability of chest radiology in the diagnosis of pulmonary lesions. *Am J Surg* 89:231-240, 1955
12. Baines CJ, McFarlane DV, Wall C: Audit procedures in the national breast screening study: Mammography interpretation. *J Can Assoc Radiol* 37:256-260, 1986
13. Koran LM: The reliability of clinical methods, data, and judgments (second of two parts). *N Engl J Med* 293:695-701, 1975
14. Shannon CE, Weaver W: The mathematical theory of communication. Urbana, IL, University of Illinois Press, Chicago, 1949
15. Haug PJ, Clayton PD, Tocino I, et al: Chest Radiography: A Tool for the Audit of Report Quality. *Radiology* 180:271-276, 1991