NLM Tele-Educational Application for Radiologists to Interpret Mammography

Min Wu, MSc, Yuanshui Zheng, Ph.D, Michael North, MSc, Etta Pisano, MD

University of North Carolina, Chapel Hill, NC

ABSTRACT

The goal of this study was to provide unique tools for an educational program to improve the skills, namely consistency and accuracy, of radiology residents who interpret digital mammograms. The tele-educational tools, created at UNC, will be implemented locally and connected to the National Digital Mammography Archive (NDMA) through the Next Generation Internet (NGI). This application includes an annotation tool, as well as a teaching and testing tool. The annotation tool will allow radiologists to label all imaging findings including the specific location information in mammograms, and make lesion diagnosis based on pathology reports. The teaching tool will allow teachers to demonstrate cases of specific types and diagnoses. Trainees themselves will also be able to use the teaching tool for reviewing of cases of types of their choosing. Our testing tool can test radiology residents' performance in interpreting digital mammograms, and provides them detailed performance test results, such as, sensitivity, specificity, ROC curves, AUC values, etc. A local Oracle database was designed and implemented at UNC to support those tools. We developed a method to map information of cases from the local database to DICOM Structure Reports by using XML techniques.

INTRODUCTION

Breast cancer is second to lung cancer in the cancer fatality rate among U.S. women today[1]. In developed countries, one in eight women up to 85 years of age is diagnosed with breast cancer. Early detection is the best defense and mammography is the best tool to detect early stage breast cancer. The American Cancer Society recommends women to have a 'Baseline Mammogram' done between the ages of 35 – 39 years, every 1 to 2 years ages 40 to 50 and every year after 50.

In 1998, the National Library of Medicine (NLM) funded the National Digital Mammography Archive (NDMA). A consortium of academic radiology departments, led by the University of Pennsylvania, and including the University of Chicago, the University of North Carolina – Chapel Hill, and the Sunnybrook and Women's College Health Sciences Center (University of Toronto), as well as technical research and development partners Y-12 (Oak Ridge, TN), have been working together for several years to test the concept feasibility and to design a plan for creation and implementation of the NDMA project test bed. The tele-educational application, created at UNC, is an important component of the NDMA project. The application developed at UNC includes an annotation tool, as well as a training and testing tool for radiology residents and breast-imaging fellows that utilizes the NDMA.

Reading mammograms is a challenge for radiologists. Currently, most of residency education in breast imaging relies on the use of film teaching files[2]. This is cumbersome at best. The residents generally review the cases after patient care is over for the day. They do not have ready access to similar cases when they are in the midst of a reading session. It is not particularly easy for the attending radiologist to retrieve cases with similar findings and the same pathologic diagnosis for comparison since the file is made of analog images. The cases are often stored according to the patient's name so that they are available for clinical purposes. This makes them difficult to retrieve for other uses. Unless the teaching radiologist remembers a particular patient's name and diagnosis, and what her mammogram showed, he or she would not know that case to show the resident as a companion case to the one being discussed clinically.

In addition, testing of radiology residents to determine professional competence is limited to a single written and oral examination given during the last two years of residency training. The written examination contains questions on all areas of interest for practicing radiologists. The oral examination, for which Dr. Pisano at UNC has served as an examiner since 1997, consists of 6-10 breast-imaging examinations. The breast imaging portion of the American Board of Radiology certification examination is one of 10 subexams given, and was the last subexam given using film instead of softcopy display, having converted to softcopy display in 2001. There is also significant question whether a maximum of 10-20 cases, all of which have radiological findings suitable for discussion, are sufficient to assess professional competence for radiologists who interpret screening mammograms. In a clinical study, the vast majority of properly interpreted examinations are normal.

This paper will discuss the NLM Tele-educational application at UNC, which provides unique tools to improve radiology residency education in breast imaging.

METHODS

Local database and images: A local database in Oracle (company name) was carefully designed and implemented at UNC. The goal of the database application is to maintain the data that we generate, to support the annotation and teaching / testing tools for radiologists to interpret mammography, and to facilitate the cooperation and sharing of information between UNC hospital and NDMA database. We identified four major user views for this database application, which are *annotator, teacher, test designer* and *student* user view. Firstly, we use the centralized approach to merge the requirements for the *annotator* and *teacher (case demo)* view to one data model, because there is a significant overlap between the two views. Then we merge *test designer* and *student* user view to another data model by using the centralized approach. After that, we use the integration approach to merge the two data models together. The data in the database are mainly about breast images, users (annotators, teachers, residents) in UNC, graphic annotation and pathology of lesions in images, testing sets of images, and residents' performance of lesion diagnosis. The database application can perform searches and create reports on those data.

We carefully designed the Entity Relationship (ER) diagrams for each logical data model. For example, *Case, Image, Lesion*, and *GraphicsAnnotation* are four important entities in the data model. There are complex relationships among them. The ER diagram is shown in the figure 1. Each case has 4 images, and each case may have many lesions. Each image may have many lesions, and each lesion is located in two images.

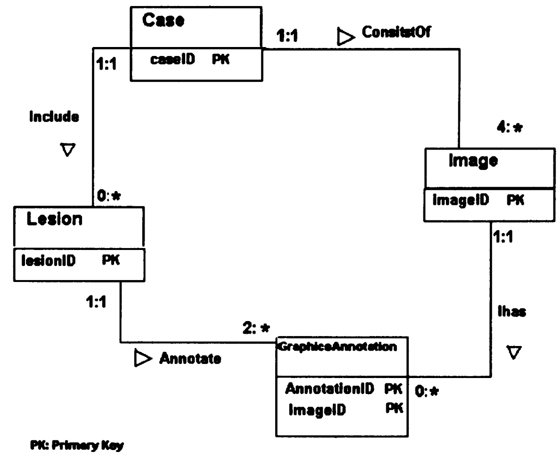

Figure 1. An ER diagram for a part of annotator user view.

In the *Image* entity, we stored 4 unique identifiers (UID) to make it possible to retrieve images from general-purpose DICOM servers, such as are in a PACS. These are SOP Class UID, SOP Instance UID, Series Instance UID and Study Instance UID. These are all present in a DICOM image.

We collected digital mammograms from our clinical site, UNC Hospital, and previous mammography research studies at UNC. All those mammograms selected for the educational application had biopsy information available.

Unfortunately, some of the images with biopsy results were not in DICOM format. We had to add the DICOM headers to those images with a lot of information, such as, patient MRN, etc.

Annotation tool and DICOM structured report: After the cases have been made available in the local UNC database, radiologists can use the web-based tool to annotate cases. All digital mammograms for women who undergo histological evaluation of a palpable or nonpalpable breast lesion will be annotated by the UNC radiologists to confirm the location of the lesion that was biopsied, the findings that were present on the mammogram that correlated with the pathologically-sampled lesion, and the pathological diagnosis.

The NDMA is a DICOM-based archive. All the patient information stored in the NDMA is provided in DICOM Information Objects. DICOM Structured Reporting ("SR") is a powerful and expressive language for representing hierarchically structured clinical information. We developed a method to map the annotation information of cases from the local database to the DICOM Structure Reports by using some XML techniques.

All the processes of data collection and transmission are shown in the figure 2.

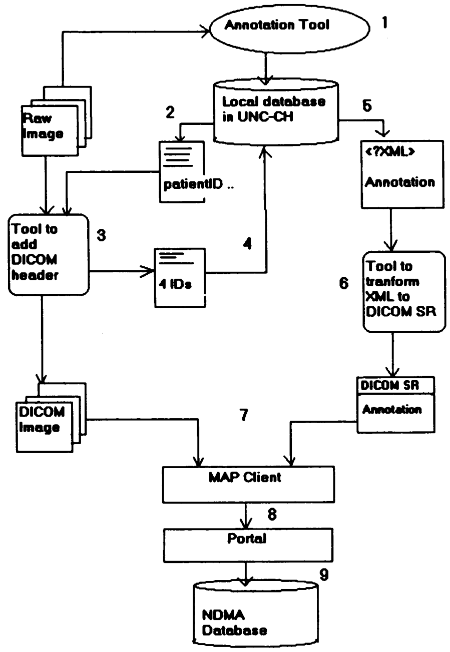

Figure 2. The processes of data collection and transmission

Teaching/Testing tool: At UNC, radiologists and radiology residents will utilize a UNIX workstation with 2 high-resolution monitors. Through the use of the Case Demonstration Mode, either for individualized self-learning or learning with a teacher leading, radiologists can access a large number of pathologically proven digital mammography cases, retrievable by pathologic diagnosis and/or mammographic findings. In addition, the archive can be queried for annotated cases based on BiRads lexicon terms that are included in the annotation.

In addition, the NDMA archive provides digital mammogram cases suitable for the creation of mammography test sets. We defined a "test" with each case being an "item". Test sets will generally consist of 50-100 cases with the full range of mammographic findings. We are still in the process of modifying the rules for selecting cases and presenting them to students.

The trainee can use the test sets in one of two ways, ether with immediate feedback per case, or with feedback only at the end of the entire test set.

Our testing tool uses Receiver Operator Characteristic (ROC) curve methodology to evaluate radiology residents' skills in interpretation of mammography[3].

RESULTS

Annotation tool: The annotation tool for this project is accessible through any computer with web access. The interfaces of the annotation tool are shown in figure 3. After the radiologist's user ID and password are verified, the system will allow the radiologist to choose and view any patient's images from the local database by specifying patient name or Medical Record Number. Radiologists will graphically and textually annotate all areas of interest in all images. Appropriate regions will be electronically circled using a virtual overlay. There are a lot of functional buttons in the annotation interfaces, such as, *undo, Zoom in, Zoom out, etc.* Radiologists can add pathology information using the interfaces, choosing the pathologic diagnoses. Pathologic evaluation includes pathologic information from both large core percutaneous biopsies and open surgical biopsy information, and pathologic information from fine needle aspirating. If a palpable lesion did not undergo biopsy, the radiologist can add information regarding, why it should be considered benign (for example, it has been stable for two years). Indeterminate or insufficient samples of any type will not be entered into the database. Radiologists can input additional information about the lesion before saving the annotated cases and exiting the annotation program.

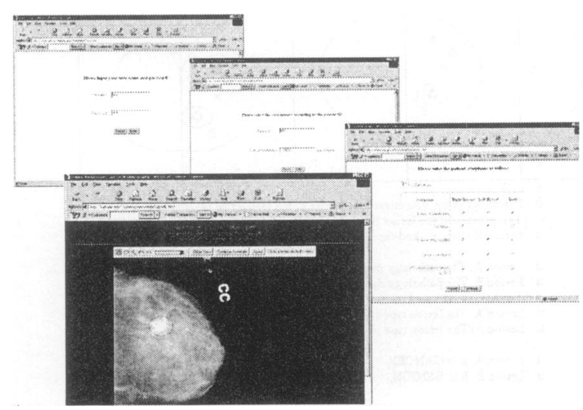

Figure 3. Some interfaces of annotation tool

XML schema of annotation tool for DICOM SR: The annotation information in the relation tables was queried through some object-relational views. By using the XSU utilities of Oracle, the object-relational views were mapped to the XML files.

Both the XML and DICOM SR are hierarchy data models.

Teaching/testing tool: After the radiologist's query for a specific case type, the annotated cases will be transferred from the central NDMA in Philadelphia to the local computer. The raw images appear on the monitors with all the lesions of the type requested circled. The radiologist teacher is able to use a drawing tool to mark on the image to illustrate other points. Residents can interpret the mammograms in a continuous confidence-rating scale, from *definitely not cancer* to *definitely cancer.* An interface of teaching tool is shown in figure 4.

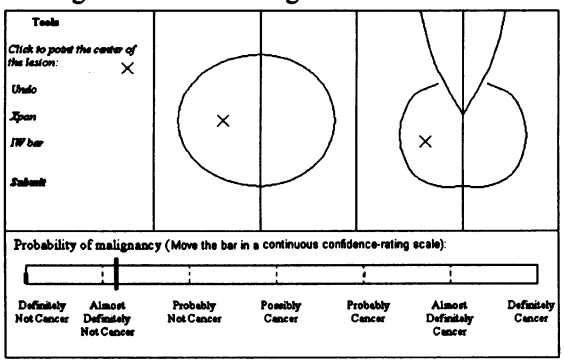

Figure 4. Interface of teaching tool for interpretation

Immediate feedback is then provided, and the interface is shown in figure 5.

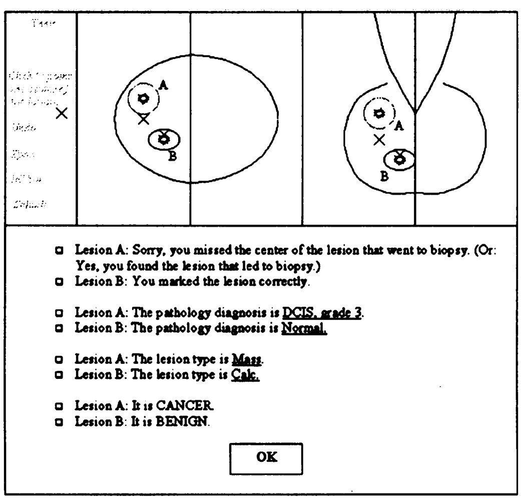

Figure 5. Interface of teaching tool for feedback.

In the testing mode, after and only if the reader completes the entire test set of 50 to 100 cases, performance results from this and prior training sessions will be provided, shown in figure 6.

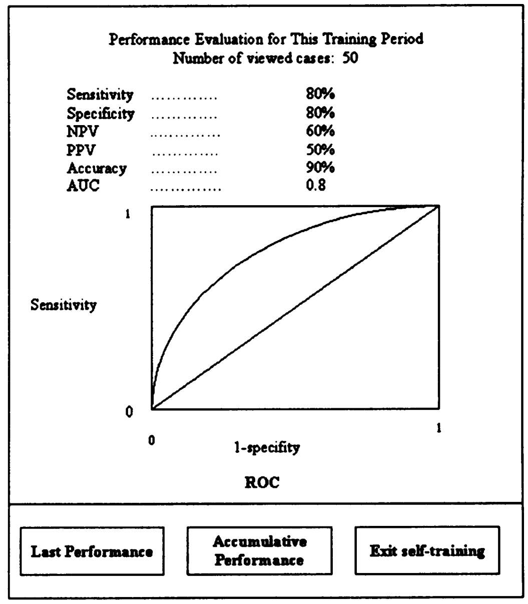

Figure 6. Performance result interface of testing tool

Sensitivity is the probability of detecting a cancer when a cancer exists. High sensitivity is important in order to achieve the maximal detection of cancers at an early stage, where treatment offers an increased potential for cure. Specificity is the probability of correctly identifying negative mammograms when a cancer does not exist. High specificity is also desirable in order to avoid unnecessary biopsies, with their associated financial and emotional costs. The ROC (receiver operating characteristic) curve is a graphic method for depicting the trade-off between the sensitivity and specificity of a test. It's a well-known method, often used by radiologists. The area under the ROC graph (AUC) is used as an index of reader's performance.

DISCUSSION

Our annotation tool is a web-based application. Because radiologists' time is limited, this annotation tool is friendly and relative easily for them to collect all mammogram related information to the archive, including the pathology results. After the radiologist labels the lesion on the computer screen, the computer will automatically remember the location of the lesion. This method provides more accuracy than the regular location methods, using of clock face or quadrant descriptions only.

The DICOM Structured Reporting storage SOP class is a specification, supplement 23 to DICOM[4]. If third party can easily parse our data in DICOM SR, our application can be widely used. We are developing a method to wrap our annotation information on mammograms into DICOM SR by using XML techniques. Both the XML and DICOM SR are hierarchical data models. In our ER diagram of the relational database in the figure 1, you can see a "ring" structure that represents complex relationships. To map data from this relational data model to XML, we have to break the "ring" at a point to create a "tree" structure within XML. So there are some kinds of redundancy in XML, due to the limitation of the data modeling. Currently there is much research in translating DICOM SR to XML[5]. Our application is a good case study for the whole process of collecting clinical data through an annotation tool interfaces, storing data to a relational database, mapping data in relational tables to XML, and translating XML to DICOM SR. There is no other published work on this whole process. It is really an interesting and useful study, not only for us but also for other institutes.

The NDMA resource can be utilized for the training of radiology residents, to provide similar cases for comparison sake, to assist residents in building up their knowledge base by exposing them to large numbers of pathologically proven mammograms.
We believe that the residents' education in breast imaging will be improved through the use of our tool.

We are still working on the rules to create the test sets for the training and testing tool. Our testing tool will use the Receiver Operator Characteristic (ROC) curve methodology to evaluate radiology residents' performance to interpret mammograms. It is really a challenge to create ROC curve results automatically based on the raw data in the database in a short time.
However, if successfully developed in this setting, we would propose their consideration for use by the American Board of Radiology for certification of radiologists for professional competence in Breast Imaging. At least this program could serve as a model for how softcopy breast imaging competency examinations might be conducted in the future. No other such model exists, and we are aware of no other published work on this subject.

The tele-education application at UNC is still an ongoing project, that is, evaluating the predictive validity of our test falls mostly outside the scope of the funded project. Future research could evaluate the ability of test performance to predict performance on the Radiology/mammography board examination. More ambitiously, and ideally, one could evaluate the ability to predict performance of physicians in post-graduate practice.

In short, we hope that through this innovative educational program, the skills of radiology residents who interpret mammograms will be improved, both in consistency and accuracy.

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