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GRANT NO: DAMD17-94-J-4338

TITLE: A Digital Breast Imaging Teaching File

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REPORT DATE: October 1995

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for public release;
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19951215 007

DTIC QUALITY INSPECTED 1

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1995

3. REPORT TYPE AND DATES COVERED
Annual 15 Sep 94 - 14 Sep 95

4. TITLE AND SUBTITLE
A Digital Breast Imaging Teaching File

5. FUNDING NUMBERS
DAMD17-94-J-4338

6. AUTHOR(S)
Edward Sickles/Ronald Arenson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of California, San Francisco
San Francisco, California 94143-0962

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Because of inefficient utilization of current mammography teaching facilities and existing deficiencies in training resources for radiologists, there is a need to supplement or replace the traditional film-based method of training. The purpose of this research is to develop a digital breast imaging teaching file (DBITF) as an interactive training tool for learning and continuing education for radiologists. Two hypotheses are being investigated: (1) a comprehensive DBITF can be designed and implemented using current technology, and (2) this DBITF's interactive response-driven type of instruction is more effective than the traditional "show and tell" type of instruction used with film-based teaching files. To test these hypotheses, our current film-based breast imaging teaching file, which contains over 1,000 pathologically proved state-of-the-art imaging cases, is being converted to digital format. Current technologies in high resolution film digitization, high resolution soft-copy image display, relational database architecture, and computer-aided instruction models are being used to create a DBITF containing these cases. The effectiveness of using the DBITF to teach breast imaging interpretation will be compared with traditional passive film-based teaching. As a result of this research, we expect to develop a comprehensive DBITF as a national resource, which should be superior to other methods of teaching.

14. SUBJECT TERMS
Mammography, breast imaging, digital radiography, computer-aided instruction, education, teaching file. breast cancer

15. NUMBER OF PAGES
10

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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*U.S.GPO:1993-0-358-779

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Edward A. Nickles MD 9-27-95

PI - Signature Date

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INTRODUCTION

Breast cancer is the fourth most common cause of death among women in the United States [1]. There is no known means of preventing the disease, and available therapy has been of very limited success in reducing the national mortality rate over the past 60 years. Current attempts at controlling breast cancer concentrate on early detection by means of mass screening, using clinical breast examination and periodic mammography, because ample evidence is now available to indicate that such screening indeed can be effective in lowering the death rate [2-13]. Cases judged abnormal at screening are further evaluated with breast ultrasonography, percutaneous-needle and/or needle-localization biopsy, and occasionally breast CT and breast MRI.

Extensive mammography quality assurance procedures have been developed over the past several years, and now are mandated by the U.S. Mammography Quality Standards Act. However, these procedures for the most part cover mammography equipment, imaging parameters, and image processing. They have not yet addressed the issue of image interpretation in a meaningful way.

Breast imaging interpretation is taught using a variety of approaches. During radiology residency and fellowship one-on-one instruction is used widely, but this is not feasible for post-graduate training (required for all radiologists practicing mammography), due to the overwhelming mismatch in numbers of teachers and students. As a result, continuing education primarily involves group instruction, using medical journals, books, lectures, workshops, and videotapes. A particularly effective teaching approach for both residency and post-graduate training involves individual review of selected case material, including original radiographs, sonograms, and supporting text material that indicates eventual clinical diagnosis. This material is traditionally presented in the format of film-based teaching files.

However, current teaching files, because they involve conventional film images, can be viewed by no more than a few users at a time. Because it is impossible to present the imaging work-up of each case on an image-by-image basis (one cannot anticipate all the work-up options that might be selected by an individual user), the display of film cases is limited to sequential descriptions of imaging findings, interpretations, and pathologic diagnoses.

Digitally stored and displayed teaching file images, on the other hand, can be viewed by large numbers of users simultaneously, at different workstations (even at distant sites), in the precise sequence in which the images were obtained. With carefully structured questions, each user can be prompted to respond by making his/her own observations, assessments, and work-up decisions just as if the patient were being examined at that time. This effectively replaces a "show and tell" teaching experience with the interactive, response-driven type of instruction that currently must be taught in person.

Additional advantages of a digitally-based teaching file are: (1) the user does not have to sort through all the films in each case in order to view them in the proper sequence; (2) the user is not burdened with the request to replace film images in the same sequence in which they were presented; (3) images and supporting text material cannot be misfiled, damaged, lost, or stolen; (4) digital images are much more amenable to post-acquisition enhancement (enlargement, contrast and density windowing, filtering techniques [edge enhancement, unsharp masking, etc]) than are film images (enlargement by use of a magnifying lens); (5) digital images can be duplicated easily and relatively inexpensively without loss of image quality; (6) digital images can be viewed in various user-selected sequences (organized by mammographic finding, organized by pathologic diagnosis, organized by degree of difficulty of interpretation, organized by complexity of work-up, organized by use of specific work-up examinations); (7) user progress through the teaching file can be linked to providing correct answers for key questions; and (8) user progress through the teaching file can be documented by these correct answers, thereby permitting Category I credit for continuing medical education to be awarded automatically on an hour-for-hour basis.

This funded research is designed to investigate the effectiveness of an interactive computer-based digital breast imaging teaching file (DBITF) compared to that of an established and widely used conventional-film teaching file (CFTF) in providing initial and continuing medical education in breast imaging. Two hypotheses will be investigated: (1) A totally digital-based breast imaging teaching file can be designed an implemented with current technology; and (2) This DBITF's interactive response-driven type of instruction is a more effective teaching approach than the traditional passive "show and tell" type of instruction used with the CFTF. We believe that the DBITF will succeed primarily because it has the advantage of more closely approximating the real-life work-up of patients, since the user is presented with images in the sequence originally obtained and then is prompted to respond to his/her own observations and arrive at work-up decisions as if the patient were being examined at that time.

BODY

Six tasks were outlined in the Statement of Work within our grant proposal. Two minor modifications in our original plan were made. (1) We undertook an initial pilot study evaluation of the DBITF in Year 1 rather than waiting until Year 2, to provide an early indication of effectiveness and user acceptance of the DBITF. This also will permit us to incorporate user suggestions for improved DBITF performance even earlier in the process of DBITF creation. (2) We chose not to restrict case selection to those already entered into the CFTF as of the end of Year 1. This will permit us to include in the DBITF even more current case material and discussion of as yet unrealized concepts and advances in breast imaging. As a result, during Year 1 we have selected only a representative sample of CFTF cases for inclusion into the DBITF, rather than all 1,000 cases planned for ultimate inclusion. The remainder of the Statement of Work for Year 1 has been accomplished as initially proposed.

Task 1. Select cases from the current CFTF for inclusion into the DBITF. We have selected 750 cases, based on inclusion of the full spectrum of mammographic findings, work-up approaches, and disease entities now encountered in breast imaging practice. Case selection includes the choice of images, collection of medical-related data, and formulation of questions/answers for interactive response-based instruction. Since many selected cases represent variations in appearance of similar mammographic findings, and since the work-up approaches for some mammographic findings are limited to relatively few choices, many of the DBITF test questions will have similar (at times identical) wording. Note that we have chosen to leave 250 cases for later selection, in the expectation that these cases will involve more up-to-date imaging techniques and work-up approaches than are currently available. Depending on the extent to which further advances are actually achieved, it may be necessary to include even more than 250 "new" cases, at the expense of discarding some already selected cases.

Task 2. Convert the CFTF to digital format. We have completed the digitization of selected film mammograms and other breast images (sonograms), so as to be compatible with our DBITF format. So far, we have not included cases involving breast CT and MRI (or the full potential of breast ultrasonography), since the clinical roles of these modalities are still in flux. Related medical data (text) has also been incorporated into the DBITF format described in our initial grant proposal.

Task 3. Image display. We have completed the development of a two-monitor 2K digital image display workstation (hardware and software), and have tested its use on a variety of subjects [14]. Refinements in software were based primarily on the suggestions of our initial test subjects, in order to maximize ease of use.

A Sun 4/470 platform is used, running SunOS 4.1.3. The workstation has 64 MB of system memory. Attached to the workstation is a parallel transfer disk, capable of storing 7-22 GB of digitized mammograms, and restoring these graphic files to be displayed very rapidly. Indeed, the four standard views of an initial mammography examination (MLO + CC views of right and left breast) are recalled from disk and displayed on paired monitors in less than 5 seconds. Using an average image size of 7.5 MB, this indicates a combined transfer-display rate of at least 5 MB/sec. The two gray-scale monitors used in the system have a display resolution of 2048 pixels by 2560 scan lines in portrait mode on their 21-inch (diagonal) screens, with 10-bit resolution.

Image processing is performed by dedicated hardware (Pixar, Inc), enabling an extensive library of image processing routines to be called upon for region of interest (ROI) investigations. Specifically, these include filtered edge detection, contrast enhancement, highlighted calcifications, and relief map simulation. In addition, images can easily be manipulated on the screen using real-time window and level controls and ROI magnification.

The only major limitation we have encountered so far in our digital image display system is a reduced ability to demonstrate at standard resolution (two paired images per monitor) the most subtle mammographic microcalcifications seen on conventional film mammograms. We encountered this limitation when digitizing film mammograms scanned with either 50-micron or 100-micron sampling pitch (using the specially designed Abe Sekkei laser film scanner described in our grant proposal). This has caused us to exclude, at least for the time being, cases involving very subtle microcalcifications as the sole mammographic finding on initial four-view examination. We plan to include examples of this type of case in Year 2 or Year 3 of the project, if hardware improvements permit detection at standard resolution using the DBITF workstation. During Year 2, we plan to move the DBITF workstation from its current location in the UCSF Informatics

Laboratory to the UCSF Mammography Reading Room, where residents, fellows, visiting radiologists, and UCSF staff radiologists work on a daily basis.

Task 4. Database design and implementation. We have completed preliminary work on designing the architecture of the teaching file database system and the computer-aided instruction model, exactly as outlined in our grant proposal. In this format, we have assembled a series of 20 DBITF cases, including 125 images and 155 interactive query-and-instruction questions. The bulk of this work, aided by feedback from initial test subjects, involved the development of a fast, robust, reliable, and user-friendly interface. The 20 cases also formed the basis for the pilot study of DBITF effectiveness described below.

Much work remains to be done. We have yet to implement our proposed design requiring the user to place an arrow over each lesion to be identified, an important aspect of response-driven instruction, since only in this manner can the DBITF reliably test the user's ability to perceive abnormalities. Plans call for completion of this and all remaining elements of database design/execution in Year 2.

Task 5. Evaluation. Although our initial grant proposal called for this activity to begin in Year 2, for reasons stated previously we have already completed a pilot test of DBITF effectiveness and user acceptance.

This pilot study involved 18 of the 20 cases fully integrated into the DBITF, with test subjects using both DBITF and CFTF materials [15]. We studied 24 test subjects (radiology residents, fellows, and general diagnostic radiologists from UCSF and a neighbor institution), who were randomly assigned to start with either the DBITF or the CFTF. Each subject was given a pre-test and post-test, involving questions about breast imaging and breast cancer pertinent to the case material. Subjects then completed the other teaching file, to serve as a comparison. The time required to complete each teaching file was recorded. A questionnaire was then administered asking subjects to rate on a scale of 1 to 10 the ease of use, level of enjoyment, and value as a learning tool for both the DBITF and CFTF. Subjects also were asked to indicate whether they would be more willing to use the DBITF or CFTF in the future, and which teaching file they would recommend to a colleague.

The mean time to complete the 18 cases in each teaching file was 1.5 hours. The group taking the post-test after completing the DBITF demonstrated a higher mean improvement (from pre-test) in scores, compared to the group that initially evaluated the CFTF, but results were not statistically significant. However, significantly higher ratings ($p < .01$) for the DBITF were recorded regarding ease of use, enjoyment, and value as a learning tool. 22 of 24 (92%) subjects favored using the DBITF over the CFTF in the future, and 23 of 24 (96%) subjects favored recommending the DBITF to a colleague. These preliminary results suggest that the DBITF will be an effective approach to teach breast imaging interpretation, and that it promises to be even more readily accepted by radiologists than conventional film-based teaching files.

The bulk of our planned evaluations will take place in Years 2 and 3 of the project, as initially proposed. These evaluations will guide us in revising the numerous interactive response-driven test questions that we have already developed, and that we will continue to develop, in order to maximize the teaching effectiveness of our case material.

Task 6. Dissemination of the DBITF. As indicated in our initial grant proposal, this is planned for the last two months in Year 3.

CONCLUSIONS

Work on this project is proceeding on schedule, with few unanticipated problems. After completion of only 1 year of this 3-year project, we have already demonstrated a modicum of success in developing, on a very small scale, a comprehensive digital-based breast imaging teaching file. By the end of the project, we expect to have developed a comprehensive and full-featured DBITF as a national resource, which should be a highly effective means of teaching breast imaging interpretation.

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