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GRANT NUMBER DAMD17-94-J-4371

TITLE: Computer Aided Breast Cancer Diagnosis

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REPORT DATE: October 1998

TYPE OF REPORT: Annual

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

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DTIC QUALITY INSPECTED 4

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE October 1998	3. REPORT TYPE AND DATES COVERED Annual (23 Sep 97 - 22 Sep 98)	
4. TITLE AND SUBTITLE Computer Aided Breast Cancer Diagnosis			5. FUNDING NUMBERS DAMD17-94-J-4371	
6. AUTHOR(S) Carey E. Floyd, Ph.D.				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Duke University Durham, North Carolina 27710			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Commander U.S. Army Medical Research and Materiel Command Fort Detrick, Frederick, MD 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)				
14. SUBJECT TERMS Mammography, Radiology, Computer-Aided Diagnosis, Neural Networks, Malignancy Prediction, Artificial Intelligence, Breast Cancer			15. NUMBER OF PAGES 14	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

FOREWORD

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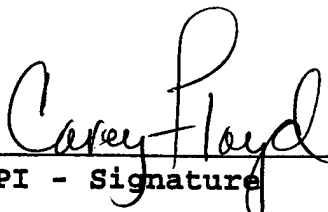
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Computer Aided Breast Cancer Diagnosis
PI: Carey E. Floyd Jr.

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The long range goal of this project is to improve the accuracy and consistency of breast cancer diagnosis by developing a Computer Aided Diagnosis (CAD) system for early prediction of breast cancer from patients' mammographic findings and medical history. Specifically, this system will predict the malignancy of non-palpable lesions that are examined with diagnostic mammography and are considered for biopsy. The goal is to improve the specificity of diagnosis with little loss of sensitivity thus significantly improving the positive predictive value of breast biopsy.

Toward this goal, we have developed an artificial neural network (ANN) to predict biopsy outcome from mammographic and history findings. In the first four years of the grant we have 1) developed a user interface for acquiring mammographic findings, 2) acquired 700 cases using the standardized BI-RADSTM reporting system, 3) trained and evaluated several ANN predictive models, 4) conducted a small prospective study, 5) examined the inter- and intra-observer variability of the reporting lexicon, 6) investigated reducing the number of active input features, and 7) examined the sensitivity of the system to the techniques used for sampling the data.

What follows is a point by point assessment of the progress for each task in the original statement of work:

Statement of Work

Task 1, Develop an ANN to predict biopsy outcome from mammographic and history findings.

Years 1-4

Development will start with the successful preliminary backpropagation network.

The significant improvements needed include: 1) larger set of clinical cases to better represent the general patient population, 2) higher specificity while maintaining >98% sensitivity. The preliminary work will be extended as follows.

Year 1

1.1) Expand the number of input features, both mammographic and medical history.

The ANN will be implemented on a workstation (SUN SPARC) to allow the size

of the network to be enlarged. This will allow more medical history and radiological features to be included.

These tasks were all achieved in year one.

Year 2-4

1.2) Develop a time-series ANN to examine current as well as previous exams.

Note: this aim was dropped in response to the decreased budget as negotiated with BC Baker in a revised statement of work in August 1994 .

1.3) Evaluate other ANN architectures which have been demonstrated to be appropriate for pattern classification.

Achieved in year 2.

Year 3-4

2) Evaluate the improvement in radiologists' diagnostic performance when the computer diagnostic aid is provided.

Year 3

2.1) Install the trained network on the Mammography Database server to perform on-line prediction as the radiologists input the features.

Achieved in year 2.

Year 3-4

2.2) Test the hypothesis that use of the network prediction by radiologists will increase diagnostic accuracy (prediction of biopsy results).

Not yet achieved. Begun in year 3.

In summary, all of aim 1 has been achieved and previously reported. All that remains is to finish the evaluation of the improvement in radiologists' performance when the system is used. This work was slightly delayed by a change in directorship of the division of mammography and by a change of management in the radiology informatics group. The only real difficulty was a result of the change in the informatics

system. A workaround has been initiated and the evaluation is scheduled for the spring of 1999.

This report describes a computer aid to predict the malignancy of non-palpable lesions that are examined with diagnostic mammography and are considered for biopsy. The goal is to improve the specificity of diagnosis with little loss of sensitivity thus significantly improving the positive predictive value of breast biopsy. An artificial neural network (ANN) is described to assist radiologists in the differentiation of benign from malignant lesions. Inputs to the ANN were derived from the patient's history and the radiologist's description of lesion morphology following the ACR Breast Imaging Reporting and Data System (BI-RADSTM). The output of the neural network is the likelihood of malignancy. Evaluation of the system on 500 cases demonstrates that 22% of the benign biopsies could be avoided without missing a malignancy. At this threshold, the positive predictive value (PPV) of biopsy would be improved from 35% to 41%. With a less conservative approach, 41% of the benign biopsies could be avoided while still performing biopsies on 98% of the malignancies. At this threshold, the positive predictive value (PPV) of biopsy would be improved from 35% to 47%.

1. INTRODUCTION

The lifetime risk of developing breast cancer has increased to one woman in eight ¹. While screening mammography can decrease the mortality due to breast cancer by 30%^{2,3}, improvements in the diagnosis are still needed. Although mammography is a sensitive tool for detecting breast cancer, the positive predictive value (PPV) is low ⁴⁻⁶. Several factors contribute to this, including similarity in the radiographic appearance of benign and malignant breast lesions ⁶ as well as an overall conservative approach of physicians ⁷. Only 10-34% of women who have biopsy for mammographically suspicious nonpalpable lesions have a malignancy by histologic diagnosis⁵. Currently, more than a million biopsies are performed each year ⁸. Due to the present low PPV of mammography, hundreds of thousands of women undergoing biopsy for a benign finding are unnecessarily subjected to the discomfort, expense, potential complications, change in cosmetic appearance, and anxiety that can accompany breast biopsy ^{5,9-11}.

The long range goal of this project is to improve the accuracy and consistency of breast cancer diagnosis by developing a Computer Aided Diagnosis (CAD) system for early prediction of breast cancer from patients' mammographic findings and medical history. Specifically, this system will predict the malignancy of non-palpable lesions that are examined with diagnostic mammography and are considered for biopsy. The

goal is to improve the specificity of diagnosis with little loss of sensitivity thus significantly improving the positive predictive value of breast biopsy.

Toward this goal, here we describe the development of an artificial neural network (ANN) to assist radiologists in the differentiation of benign from malignant lesions. Inputs to the ANN were derived from the patient's history and the radiologist's description of lesion morphology following the ACR Breast Imaging Reporting and Data System (BI-RADSTM). The output of the neural network is the likelihood of malignancy.

Artificial neural networks are a form of artificial intelligence analogous to layers of biological neurons. These networks can be trained to "learn" essential information from a set of data. The structure of an ANN is a set of processing units (nodes) arranged in rows. Input nodes are interconnected by simple calculations with an internal layer of hidden nodes and a single output node. Rather than having a fixed algorithmic approach to a classification problem, an ANN is sequentially presented with a set of supervised training cases — input data paired with the correct output. The ANN modifies its behavior ("trains") by adjusting the strength or "weights" of the connections until its own output converges to the known correct output. The information "learned" by the ANN is stored in the weight the network gives to connections between nodes.

2. METHODS

The ANN for prediction of breast malignancy was constructed as a three layer feed-forward network with a backpropagation training algorithm. The layers consist of an input layer with 18 input nodes, one hidden layer with 10 nodes, and an output layer with one output node. Each input node corresponds to either a radiologist's description of a feature of the lesion or information from the patient's medical or family history.

A total of 500 lesions were identified on mammograms of those women undergoing needle localization for nonpalpable breast lesions that went on to open excisional biopsy and pathological diagnosis. Each mammographic study was acquired using film-screen technique on dedicated mammography equipment. No case was included in the study if either of the reviewing radiologists had prior knowledge of the biopsy results or if the suspicious area was not definitely identified. Of the 500 lesions evaluated, there were 232 masses alone, 192 suspicious calcifications, and 29 combinations of masses and associated microcalcifications. The remaining 47 lesions included architectural distortion, regions of asymmetric breast density, areas of focal asymmetric density, and areas of asymmetric breast tissue. Patients ranged in age from 24 to 86 years with an average age of 55 years. At biopsy, 326 (65%) of the lesions were found to be benign while 174 (35%) were malignant. This PPV of 35% is somewhat greater than that described in prior studies.

Each set of training films was reviewed prospectively by one of two radiologists whose primary clinical responsibilities are the interpretation of mammograms and the evaluation of breast lesions and who are familiar with the definitions of the BI-RADSTM descriptors. At least two views of the breast with the suspicious lesion were provided to the participating radiologists; a cranio-caudal and mediolateral-oblique view were available in all cases. Other views including true lateral, magnification

views, and spot compression views as well as comparisons with the opposite breast were provided for evaluation when available. In order to avoid biasing the radiologist's description of the lesion, films from prior studies and the patient's history were initially withheld while the reviewing radiologist chose descriptors for each lesion. The radiologist described each lesion using the BI-RADSTM lexicon by completing a checklist that included all possible BI-RADSTM descriptors. The reviewing radiologist selected only a single descriptor from each category. Each reader was blinded to the biopsy results while reviewing the films.

There were 18 inputs to the ANN. Ten of the inputs were morphologic features assigned to the mammographic image of the lesion by a radiologist. Eight of the inputs were from the patient's personal and family history. These data were from a survey form completed by the patient at the time of the exam. Each input is information routinely collected using the ACR BI-RADSTM standardized lexicon.

Three of the features, calcification distribution, number and description, apply to microcalcifications and calcifications associated with masses. Four of the features apply only to masses: mass margin, shape, density, and size.

The patient's history provides the other 8 inputs. These include the patient's age, history of prior breast cancer, history of prior ipsilateral benign biopsy, family history of breast cancer, menstrual status, and use of estrogen or progesterone therapy. All mammographic features and patient history findings were assigned a numerical value scaled so that each input ranged from zero to one. The scaling of the inputs was selected after discussion with experienced mammographers and a review of the literature concerning the BI-RADSTM descriptors.

3. RESULTS

The classification performance of the model is shown below in Figs. 1 and 2 as histograms of the benign and malignant cases binned by the ANN model output. If a threshold is set between two bins, the cases to the left of the threshold will be called benign while the cases to the right will be called malignant. The shaded bars represent the benign cases and the solid bars represent the malignant cases. In fig. 1, the model shows good behavior for the benign cases as seen by the predominant grouping to the left. Performance for the malignant cases is not as dramatic but still results in a good separation of the two classes. It is evident that setting a threshold at around 0.1 will save over 100 benign biopsies while missing few malignancies. To examine this region further, the histogram is expanded in fig. 2 to show the region between model outputs of 0 and 0.1. In this region now we see that a threshold can be set to save some benign biopsies while missing no malignancies. The performance of the network as the decision threshold is varied is shown in Table 1.

It is common to report the performance of classification models using Receiver Operating Characteristic plots as shown in Fig. 3. In addition, it is common to show fitted ROC curves based on a normal model of the histograms. From examination of the histogram in Figs. 1 and 2, it is evident that while the malignant cases could be represented by a normal distribution, the benign cases could not. Indeed, when fitted using a normal model, the left hand region of the histograms is poorly fit. This is unfortunate since this is the high sensitivity region that is of most interest for cancer diagnosis models. For this reason, we show the ROC curve computed from the data

case by case in Fig. 3. The sensitivity, Specificity, and positive predictive value are shown for one threshold. The area Az is computed from Newton's method.

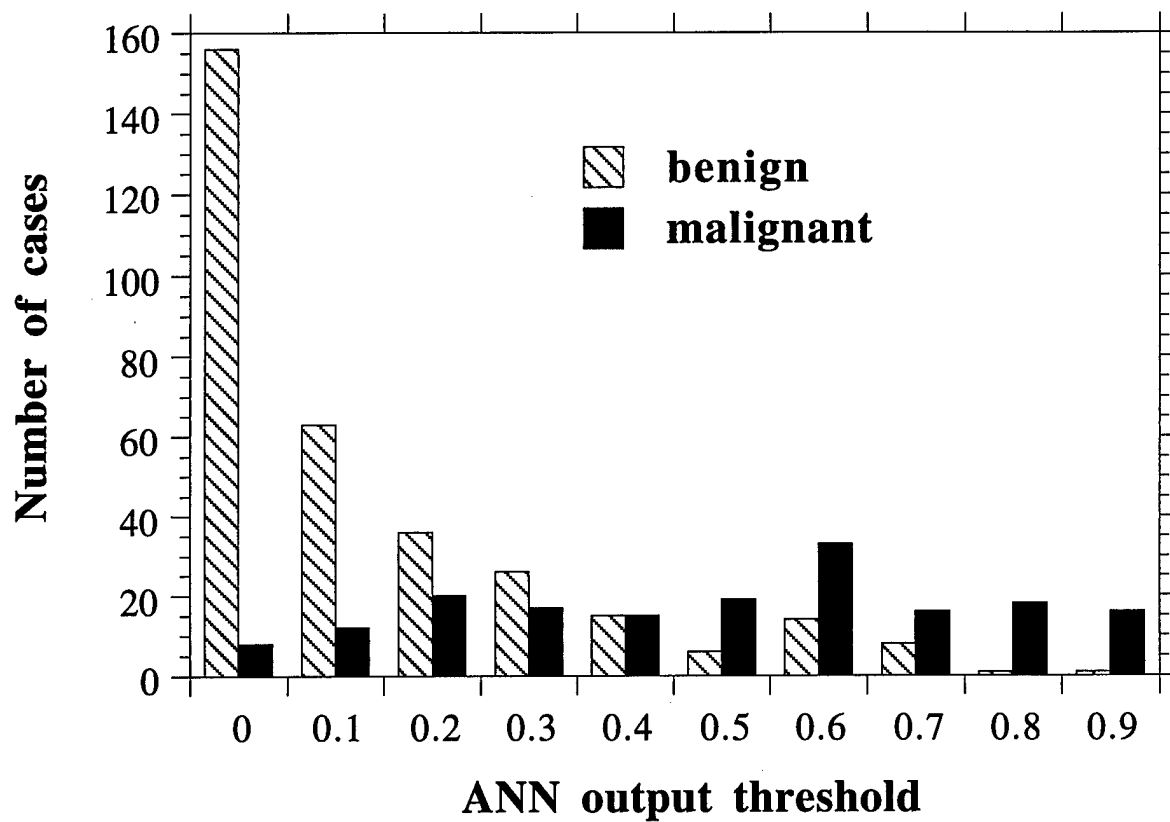


Fig. 1. Histogram of cases binned by ANN model output.

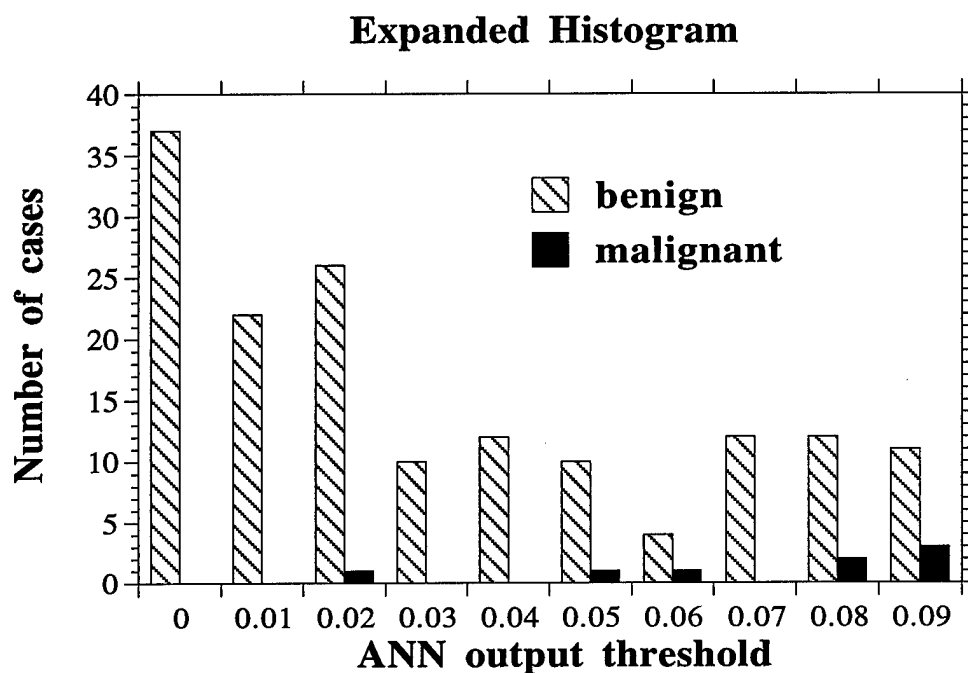


Fig. 2. Histogram expanded to emphasize the region between 0 and 0.1.

Table 1

Performance of the trained neural network

Sensitivity	Specificity	Performance: Sparing Benign Biopsies			ANN Output Threshold
		Positive Predictive Value	Malignancies Missed	Benign Biopsies Spared	
100	0	35	0	0	0.000
100	22	41	0	72	0.025
98	41	47	4	133	0.081
95	52	51	9	168	0.119
90	64	57	17	208	0.175
85	69	59	26	225	0.216

For the decision to biopsy, another important way to visualize the model performance is to plot the number of benign biopsies that would be saved or avoided along with the number of malignancies that would be missed as a function of the decision threshold. These are plotted in Fig. 4. The solid line represents the number of benign biopsies that would be saved while the dashed curve represents the number of malignancies that would be missed as the threshold is varied.

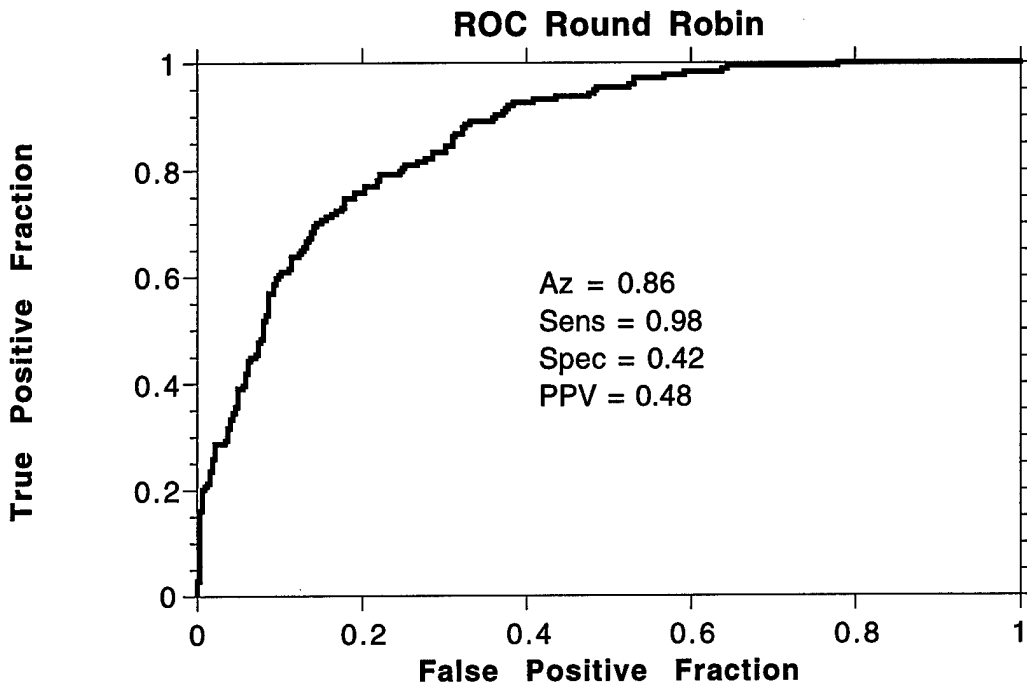


Fig. 3. Receiver Operating Characteristic plotted from the data case by case.

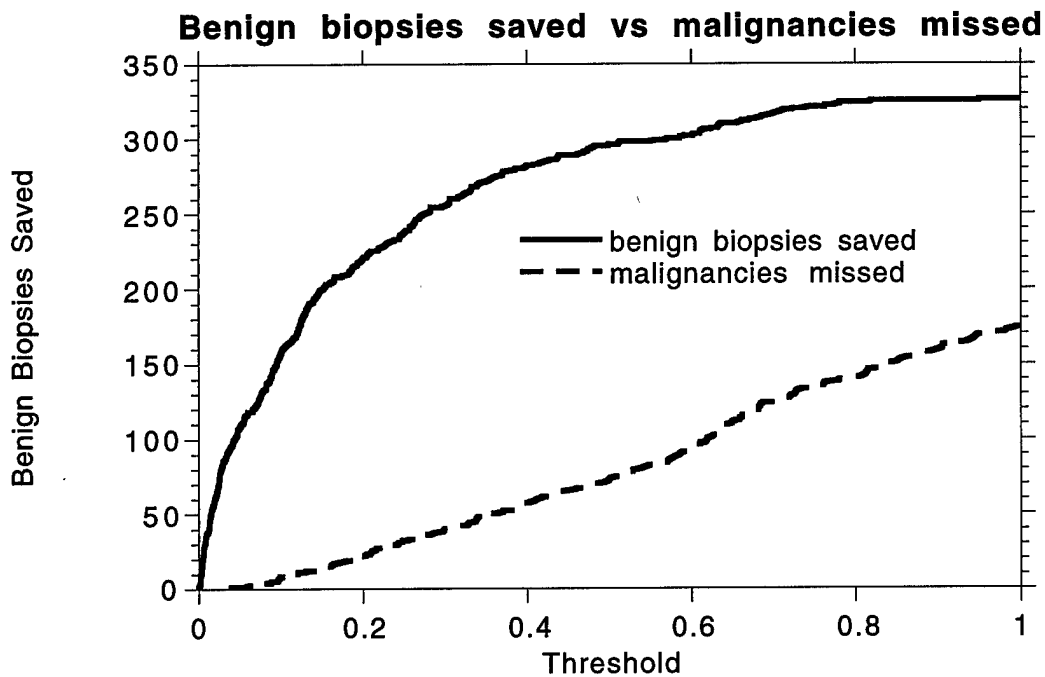


Fig. 4. The number of benign biopsies that would be saved or avoided along with the number of malignancies that would be missed as a function of the decision threshold

4. DISCUSSION

Previous work includes rule-based systems¹², neural network approaches by others¹³, and ourselves¹⁴⁻¹⁷, and recent work using Bayesian networks¹⁵. One of the most important aspects of the problem has not been addressed in this work. This is the relative cost of saving a benign biopsy compared with the cost of missing a malignancy. This is critical to selecting an operating point for the decision threshold. If the costs are equal, then a threshold of 0.8 will be optimal. The costs are not equal and clearly the cost of missing a malignancy is greater than the cost of performing a benign biopsy. If the cost of missing a malignancy is infinite and the cost of a biopsy is zero, then the decision level should be set at 0.25 (from table 1) and the system would still save 22% of the benign biopsies. The cost analysis must include "quality of life" measures which are difficult to estimate and measure. Further, the cost is dependent on the proposed treatment strategies. If all cases that are called benign by this system are followed closely, then the cost of missing a malignancy at this stage will be less than if the patient is simply returned to the screening pool. Cost analysis for this project is underway. Other future work will include clinical trials and evaluation of the place for such a computer decision aid in the diagnosis and treatment plan for breast cancer patients.

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