Final Report
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MAMMOGRAPHIC IMAGING STUDIES USING THE MONTE CARLO IMAGE
SIMULATION-DIFFERENTIAL SAMPLING (MCMIS-DS) CODE
Department of Energy
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ABSTRACT

This report summarizes the highlights of the research performed under the 1-year NEER grant from the Department of Energy. The primary goal of this study was to investigate the effects of certain design changes in the Fisher Senoscan^{TM} mammography system and in the degree of breast compression on the discernability of microcalcifications in calcification clusters often observed in mammograms with tumor lesions. The most important design change that one can contemplate in a digital mammography system to improve resolution of calcifications is the reduction of pixel dimensions of the digital detector. Breast compression is painful to the patient and is thought to be a deterrent to women to get routine mammographic screening. Calcification clusters often serve as markers (indicators) of breast cancer.

For this study, we designed a computational phantom of microcalc clusters consisting of a large set of calc pairs. The MCMIS code was used to generate simulated digital images of the phantom embedded at the center of a simulated breast as a function of the degree of compression of the breast and detector pixel size. The results indicate only marginal improvement in resolution and contrast by decreasing the pixel size from 100 micron squares to 25 micron squares. Also, compression of the breast does not appear to very significantly affect the discernability of the cluster patterns, presumably because the contribution of scattered photons to the image in the slotted source/detector geometry that is used in the Senoscan is quite small, only of the order of a few percent.

We also have attempted to study the visualization of individual spiculations (fibrils emanating from tumors). Because the width of spiculations are typically only of the order of a few cell widths, even with a 25 micron detector, they were not be individually visible. Although the results of our pixel size study are somewhat negative, it is deemed useful for the system designers since it eliminates the need to develop very high resolution detectors. The breast compression study is encouraging in that there is only a slight loss of resolution resulting from significantly decrease breast compression. Also, larger breast thickness appears to degrade the image only slightly.

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The error rate (false negatives) in mammographic screening for women over 50 is about 10% and for those between 40 and 50 the rate is about 25%. The major reason for this error is that small tumors embedded in the normal heterogeneous architecture (parenchial tissue) of the breast prevents detection of the tumor because the density difference between normal glandular tissue and tumor is only about 2%. In such cases an indication of malignancy may be the appearance of microcalcification clusters. Individual calcifications are present in most breasts but about 50-70% of those with tumors show clusters of microcalcifications. Discernability of these clusters as individual calcifications can be useful in mammographic screening. Since they are calcium deposits (oxalates, mainly) their contrast in x-ray mammography is significantly better than for tumor tissue (higher density and atomic number). It is well established that cluster patterns can not be made clearly visible with the current technology of 100 micron size digital detector pixels. The question is whether or not lowering the pixel size to 50 or 25 microns help with this problem. 50 micron detectors are now commercially available but 25 microns are available only in certain research labs.

Another important problem stems from the need to compress the breast to get uniform thickness when doing mammography. It is quite a painful process to women which makes them refrain from getting routine screening. It is conjectured that for any new imaging system to become viable, it must be able to take images with much less compression of the breast, preferably just enough to immobilize the breast. Lack of compression means more x-ray scattering which can blur the images and also the non-uniform thickness particularly towards the nipple can generate artifacts in the images. So we decided to investigate the visibility of microcalcifications in less compressed breasts. Unfortunately the shape of the breast is not easily amenable to studying the change of compression directly. Therefore we decided to simply look at the breast thickness as the variable. Soft tissue being non-compressible (no change in density, only thickness) we argue that this procedure gives a first-order indication of the effects of reduced compression.

To do these studies, we designed a computational phantom that could be embedded in the breast model and used in simulations of images using the MCMIS code. The phantom consists of pairs of different size microcalcifications, each one in a pair separated by a given distance. One member of each pair is 400 microns in diameter the other one varies between 50 and 400 microns in increments of 50. The separation distance within a pair varies from 25 microns to 200 microns in increments of 25. The breast tissue consisted of 50% glandular tissue and 50% fatty tissue typical of menopausal women. The phantom size was 1.0 cm x 1.5 cm x 0.04 cm. The overall area of the breast on the compression plate was 16 cm x 20 cm and the breast thickness was varied from 4 cm to 7 cm. The phantom was embedded in the dead center of the breast and therefore was unaffected by the edge effects of the breast.

The pixel size was changed from 100 microns to 50 microns to 25 microns. Current technology for mammography uses either 100 microns or 50 microns. 25 micron detectors are available only in a few research labs and not yet used commercially. Also the detector price sharply rises with decreasing pixel size.

The large set of computational images were examined qualitatively and showed expected results: better discernability of individual calcifications within the cluster pairs when the pixel size decreases, the pair separation distance increases, when the diameter of the second calc in a pair increases and when the breast thickness decreases. Much effort was devoted to

quantifying the resolution and contrast of the pair images in a consistent manner. After many unsuccessful attempts, we have been able to devise a method that showed the following:

- Only about 5%-10% increase in resolution is achieved by decreasing the pixel size from 100 microns to 25 microns. Although a negative result, this tells that the additional expense of going to 25 microns detector yield only marginal utility.
- Increasing breast thickness (to a first-order approximating lower compression) lead to only a slight decrease in contrast, contrary to intuition. The reason appears to be that in the Senoscan with the slot collimation for the source and a line detector scanning across the breast, virtually most of the scattered x-ray contribution to the image is eliminated. This is a positive result showing that less compression may be feasible although it needs to be checked experimentally.
- Clear visibility of calcs less than 75 microns was not possible in any of the images, showing that image processing methods might have to be used to see small calcifications.

We also attempted to simulate spiculations emanating from a tumor. The spiculations were cylinders with diameter varying from 10 microns to 200 microns (an unrealistic size in practice) and separated by given distances as in the case of the calcification phantom. The spiculation density and composition were assumed to be that of the tumor since they are thought to be consisting of malignant cells. Individuals spiculations were visible only when they were larger than 75 microns in diameter. In most cases, the spiculation bunch appeared as a hazy region around the tumor, not in conflict with what is observed in practice.

Publications:

G.B. Zeigler, D.E. Peplow and K, Verghese, "Simulation of Microcalcification Clusters in Digital Mammography", Trans. Amer. Nucl. Soc., **83**, 514-515 (2000).

A journal article for publication in *Physics of Medicine and Biology* is in preparation.

Research Students:

Gary B. Zeigler, "M.S. degree in progress. Expected graduation date: May 2002.

Thesis Title: "An Investigation of the Discernability of Microcalcification Cluster Patterns in Breast Tissue"

Christopher McElroy, Undergraduate research student.

Project: "Simulation of Spiculations in Breast Tumors". Expected graduation date: December, 2002.

Future Work:

Perhaps the most exciting part of the two NEER grant covering a little over three years is the prospect for expansion and collaboration with other research groups. The PI is currently engaged in a major project investigating the potential for doing x-ray tomography using synchrotron radiation and "diffraction enhanced imaging (DEI)". DEI is able to produce images of unparalleled quality for breast tissue samples through the use of appropriate x-ray optics and a Bragg analyzer with a narrow rocking curve analyzing the

transmitted photons. It virtually eliminates all scattered photons and produces two types of images, one of which has outstanding boundary definition for tumors. The PI currently has a graduate student working with him to investigate the potential for doing DEI tomography. The experimental work is carried out at NSLS at Brookhaven National Lab.

Also, it is clear that to bring the very high quality of DEI images into clinical use, we have to devise a high intensity, monoenergetic x-ray source. The PI, a colleague from NCSU nuclear engineering, and a group from IIT, Chicago are designing such a source. We are close to building a prototype which will be interface with the x-ray optics from IIT to make preliminary measurement. If successful, we propose to apply for a large grant from the National Institutes of Health (from NIBIB).

Lastly, it must be mentioned that the PI retired from service recently but plans to devote at least half time to imaging research.