A proposed method for the detection of breast tissue artifacts in cardiac SPECT:

Preliminary search for a breast attenuation footprint in projection data

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This paper presents the results of a preliminary investigation into a method for detection of breast tissue artifacts in myocardial perfusion SPECT scans by searching for a characteristic breast attenuation footprint in projection image data. As the first portion of a larger investigation of this problem, this study involved using a simplified computer model to calculate the effect of breast tissue attenuation on the signal strength received by the gamma detector. Simulations for a crude model of the myocardium were performed with breast tissue and with a perfusion defect. It was found that four centimetres of breast tissue can decrease detected signal levels at certain projection angles by over a factor of two. Breast attenuation was found to introduce two changes in the morphology of a signal strength versus projection angle curve. The angle of least attenuation was shifted further to the right side of the body, and the curve's full width-half maximum was decreased by as much as a third. In contrast, a perfusion defect was found to decrease the amplitude of the signal strength versus projection angle curve, but leave the curve's morphology unchanged. Because breast attenuation and perfusion defects alter the signal strength versus projection angle curves in different ways, it is proposed that breast attenuation can be detected by searching for a characteristic breast attenuation signature in acquired projection data. More detailed studies are currently being carried out to determine whether the proposed method is practicable.

Myocardial perfusion imaging using SPECT (Single Photon Emission Computed Tomography) is used clinically to diagnose coronary artery disease. However, myocardial SPECT images are distorted by non-uniform tissue attenuation which can impair the accuracy of the technique(1). In particular, breast tissue can cause artifacts overlying the anterior wall of the left ventricle that are difficult to distinguish from scar tissue(2). These artifacts are highly dependent on breast size(3), and vary considerably from patient to patient.

Several methods have been proposed for dealing with breast tissue artifacts. Most nuclear medicine departments currently take a qualitative approach, in which the radiologist compares SPECT images to other patient studies to determine the extent of breast attenuation. This is difficult, as it is subjective and therefore affected by variability in the observer. Another approach is to correct for non-uniform tissue attenuation using iterative reconstruction algorithms and attenuation maps(4). The attenuation map used may be generated in several ways. Because of variations in patient anatomy, average attenuation maps are likely not useful. Attenuation maps based on transmission measurements can significantly improve the accuracy of cardiac SPECT(5), but require expensive hardware that may be out of reach of most nuclear medicine departments. In addition, a significant amount of extra imaging time is required. Another method for generating an attenuation map involves the injection of Technetium-99m (99mTc) macroaggregated albumin following the standard Thallium-201 or 99mTc-sestamibi delayed images(6). An additional SPECT acquisition is performed

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in order to obtain contours for lung tissue and for the body outline. A simplified attenuation map is generated based on these contours. While this method of generating an attenuation map yields results that are perhaps not as accurate as the transmission method, it requires less additional imaging time and no additional hardware. Both methods require additional radiation exposure.

To date, no method of detection of breast attenuation artifacts has made use of *a priori* information contained in projection data. This paper is a preliminary investigation of a method for detecting breast tissue artifacts by searching existing projection image data for a breast tissue attenuation footprint. The hypothesis is that image count density from the region of the myocardium in the projection set changes in a characteristic way if breast tissue is present. A method using existing data could be implemented entirely in software, and so would require no additional equipment or imaging time. In addition, patient exposure to radiation would be minimized. This paper presents the results of computer simulations that were performed to determine whether a suitable breast attenuation footprint exists in projection data that would make breast attenuation artifact detection possible entirely in software.

METHODS

In order to determine the signature of breast attenuation in projection image data, a computer program was written in MATLAB(7) to simulate breast tissue attenuation in a simplified computer model. These simulations gave a first order description of the breast attenuation problem.

The computer model used was a two-dimensional transverse section through the torso, and consisted of three ellipses (Fig. 1). The first ellipse represented the torso, measuring 36 cm (long axis) by 23 cm (short axis). The other two ellipses were placed over the first ellipse, and represented breast tissue. The torso, breasts, and myocardium were assumed to be uniform linear attenuators, with a 0.15 cm^{-1} linear attenuation coefficient[8]. That is the linear attenuation coefficient for 99mTc photons in soft tissue. This value was chosen because 99mTc is the perfusion agent of choice when imaging patients with large amounts of soft tissue(9). Because the object of the study was to prove the concept, the model was intentionally oversimplified. If no breast attenuation footprint can be found in the simplest case, it is unlikely that one could be found with more complicated effects present. As a result, background activity and additional anatomic effects, such as those due to the lungs, were ignored. In addition, no attempt was made to simulate more complex phenomena such as scatter and detector non-linearities.

The myocardium was crudely simulated by a square of eleven point sources by eleven point sources,

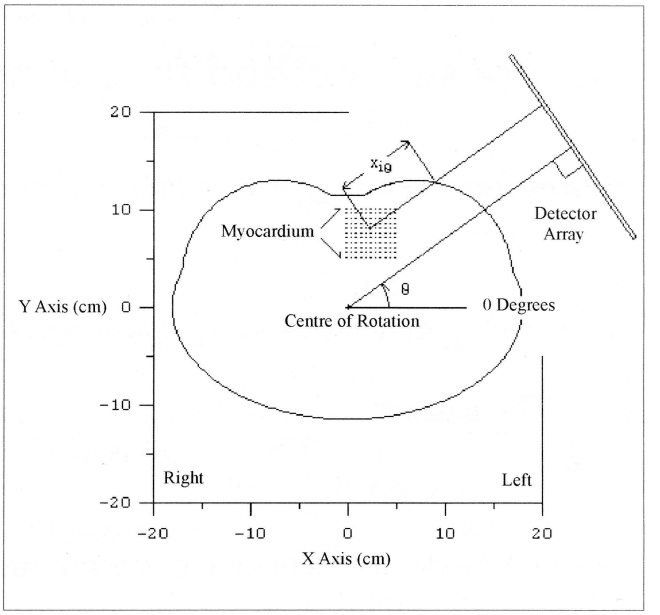

Figure 1- Computer Model: *This figure shows the 2D computer model of a female torso that was used in the simulations. The myocardium is simulated as a collection of 121 point radiation sources. This figure shows breast tissue, but no perfusion defect. It also demonstrates the attenuating distance for a particular point source and projection angle.*

each spaced 0.5 mm apart, each emitting radiation of unit intensity. The square was positioned such that its medial border matched the model's anatomical midline and its inferior border was positioned 5 cm superior to the center of the model. In addition, a perfusion defect was simulated by removing the center 9 point sources of the square, such that the perfusion defect measured three point sources by three point sources.

The computer program determined the body contour specified by the ellipse parameters, and for each point source of the myocardium, calculated the detector's received signal intensity at one degree intervals over 360 degrees of rotation. The component of received signal intensity for each individual source depended on the path length (in centimeters) within the attenuating tissue "x", according to the formula

$$I = I_0 \exp(-\mu x),$$

in which "μ" is the linear attenuation coefficient and I_0 is the intensity of the radiation source. For each projection angle, the received signal intensity results were summed and normalized by the number of sources (121). In this way, the program generated characteristic attenuation curves, plotting the detector's received signal intensity versus projection angle. The curves represent the calculated signal at each projection angle, and were used to measure changes in signal level as breast tissue is increased or decreased. More rigorously, the curve was defined by:

$$F(\theta) = \sum_i \{\exp(-\mu x_{i\theta}) / 121\}$$

where μ and x are as above, i is an index over the collection of point sources, and ø is the projection angle.

Four simulations were performed: 1) with neither breast tissue nor perfusion defects, 2) with breast tissue and no perfusion defect, 3) with no breast tissue but with a perfusion defect, and 4) with both breast tissue and a perfusion defect (Fig. 2). Breast parameters were chosen such that the maximal breast tissue thickness was 4 cm, a value seen in some Myocardial Perfusion SPECT subjects in the Nuclear Medicine Department at the Victoria General Hospital.

Signal strength versus projection angle curves were generated with and without the breast tissue for both the myocardium without the perfusion defect and the myocardium with the perfusion defect. The simulation with neither breast tissue nor a perfusion defect present set the baseline signal levels to which the other simulations were compared.

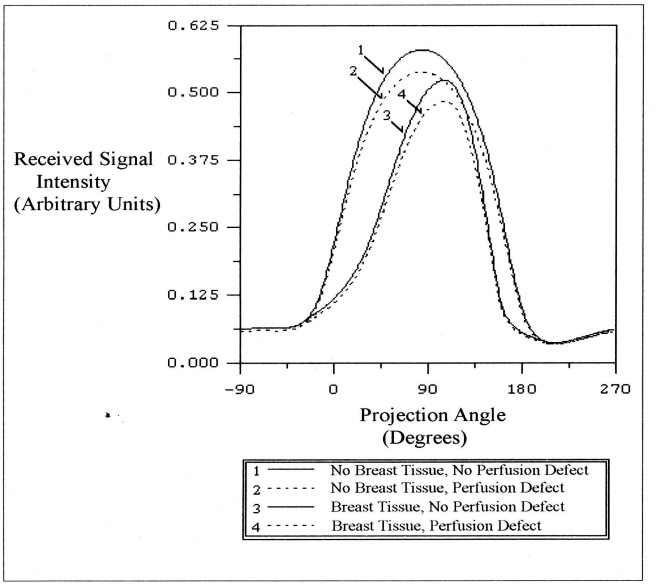

Figure 2 - Simulation Results: *This plot shows the signal strength versus projection angle curves for each of the simulations that were run. Breast attenuation alters the curve morphology, while perfusion defects affect only curve amplitude.*

RESULTS

It was observed that the presence of breast tissue increased the tissue attenuation over a range of projection angles. Breast tissue 4 cm thick decreased the signal level compared to that with no breast tissue present by as much as a factor of two at peak attenuation. There were two changes in the morphology of the signal strength versus projection angle curve as breast tissue was added. First of all, the breast tissue caused the angle of least attenuation (the maximum point on the curve) to undergo a positive phase shift. This corresponds to a shift towards the right side of the body. Second, the full width-half maximum of the curve was significantly reduced; a reduction by one third was observed with four centimeters of breast tissue.

In contrast, the only effect of the addition of a perfusion defect was to decrease the amplitude of signal strength versus projection angle curve. Unlike breast attenuation, a perfusion defect did not alter the morphology of the curve. This result is the predictable consequence of the fact that the amount of radiation emitted by the source at each projection angle is constant. Because the curve represents the strength of the signal received by the detector, the only effect decreasing the source strength is to decrease the amplitude of the curve; its overall morphology is unchanged.

DISCUSSION

The results of the computer simulations showed that breast attenuation and perfusion defects affect signal strength versus projection angle curves in very different ways. Breast attenuation altered the morphology of signal strength versus projection angle curves, while perfusion defects did not. This fact suggests that it may be possible to detect breast attenuation artifacts by analyzing the raw projection image data. If a rigorous characterization of the effects of breast attenuation could be developed, software routines could search the projection images for the characteristic signal strength versus projection angle curve properties. In this way, breast attenuation defects may be detectable by using only software and existing SPECT data. While this technique may not correct for the attenuation, accurate detection of breast attenuation artifacts may increase the sensitivity and specificity of myocardial perfusion SPECT without the added trouble of generating an attenuation map.

This technique could be made more robust by additionally comparing adjacent slices. It is anticipated that, since breast tissue thickness changes in a smooth way between slices, the morphological effects of breast tissue attenuation on the signal strength versus projection angle curves will also change smoothly between slices. This would imply that the signal strength versus projection angle curves for two adjacent transverse slices will be related in a predictable way. In contrast, a perfusion defect may have more abrupt borders. As a result, adjacent transverse slices may not share similar curve amplitudes. Comparing information from adjacent slices could help determine whether breast attenuation or a perfusion defect is present.

The largest drawback to the simulations described above is that the model is oversimplified. This was intentional, as the model was only intended to prove the concept. Additional factors that modulate gamma signal levels include addition anatomical factors, such as the lungs, scatter, detector non-linearities, background radiation, and noise. Lung tissue, because it has a much smaller linear attenuation coefficient than breast tissue,

will dramatically alter the shape of signal strength versus projection angle curves. In particular, new peaks in the curve will be introduced at angles corresponding to the lateral aspects of the torso. These new peaks may make it difficult, if not impossible, to detect the phase shift of the peak observed in the computer simulations described above. Other anatomical structures will further complicate the curves. In addition, scatter, background radiation, and noise may impair resolution sufficiently to make it very difficult to detect the amplitude and morphology differences previously observed. A series of more sophisticated computer simulations is currently being carried out, and a series of chest phantom studies is currently planned to determine whether a breast attenuation signature can be reliably detected in actual SPECT data, and whether it can be used to accurately discriminate between breast attenuation artifacts and perfusion defects.

CONCLUSION

The computer simulations performed with a simplified two dimensional model of the torso show that commonly encountered amounts of breast attenuation can decrease detected signal levels by over a factor of two. Breast attenuation was found to introduce two changes in the morphology of a signal strength versus projection angle curve. The angle of least attenuation, corresponding to the maximum point of the curve, was shifted towards the right side of the body, and the full width-half maximum of the curve was decreased by as much as one third. A perfusion defect was found to decrease the amplitude of the signal received by the detector, but was found to leave the shape of the signal strength versus projection angle curve unchanged. Because perfusion defects and breast tissue attenuation affect signals received by the gamma detector in different ways, it is believed that the two phenomena can be differentiated by examining projection images of SPECT myocardial perfusion scans for characteristic footprints of the two phenomena. By identifying artifacts caused by breast attenuation using existing data, it may be possible to increase the accuracy of SPECT myocardial perfusion scans without additional equipment or imaging procedures. Additional studies are currently being done to investigate this problem further.

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