Optimization of Contrast-Enhanced Digital Breast Tomosynthesis

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Abstract. Digital breast tomosynthesis (DBT) is a tomographic technique in which individual slices through the breast are reconstructed from x-ray projection images acquired over a limited angular range. In contrast-enhanced DBT (CE-DBT) functional information is observed by administration of an radiographic contrast agent. The uptake of iodine in the breast is very small and causes changes in x-ray transmission that are smaller than 5%. This presents significant technical challenges if quantitative assessment of contrast agent concentration in tissue is desired. We modeled CE-DBT acquisition by simulating x-ray spectra from 40 to 49 kV. Comparison of attenuation data of our simulated and measured spectra were found to agree well. We investigated the effect of patient motion and scatter on iodine uptake. These parameters were evaluated by means of experiments and theoretical modeling.

1 Background

Digital breast tomosynthesis (DBT) is a tomographic technique for imaging the breast morphology at a dose comparable to digital mammography. However, as breast tumor growth and metastasis are accompanied by neoangiogenesis, a functional tomographic imaging technique is desired. Contrast-enhanced digital breast tomosynthesis (CE-DBT) [1] would potentially integrate the benefits of both CE digital mammography [2, 3] and DBT [4-7]; thus, providing both functional information and improved breast cancer morphology by minimizing the superimposition of nonadjacent breast tissues that occurs with projection mammograms. Temporal analysis of contrast enhancement may further help to distinguish benign and malignant lesions.

The uptake of iodine in the breast is very small and thus causes only small changes in x-ray transmission; typically less than 5%. This presents significant technical challenges if quantitative assessment of contrast agent uptake is desired [1]. Technical factors that significantly influence quantitative analysis of CE-DBT exams are exposure reproducibility, linearity of the detector as a function of position, temporal response of the detector, scatter and patient motion. In this paper, we will discuss scatter, and patient motion.

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2 Methods

We have used a modified GE 2000D under IRB approval to gain initial experience in CE-DBT. In the experiments described, we have used temporal subtraction. High energy images are acquired before and after administration of an iodinated contrast agent. Logarithmic subtraction of these images is then performed. The signal intensities (SI) of the resulting images are proportionally to the uptake of iodine.

2.1 Spectrum

To model the acquisition process, x-ray spectra in the range of 40 to 49 kV were simulated by extrapolating Boone's model [8]. We validated our simulations using a least-squares comparison (χ^2 values) between attenuation data from our simulated spectra and attenuation data measured with the GE Senographe 2000D. We used high-purity Al filters to determine the attenuation curves. Minimum χ^2 values were found by adjusting the kV ($kV_{equivalent}$) and adding or subtracting Al ($Al_{equivalent}$) to the simulated spectra. We also compared the half value layers (HVL) and quarter value layers (QVL) of the simulations and the measurements. In this paper, we compare simulated and measured attenuation data from a Mo-target with 1 mm Al filtration, and a Rh-target with 0.27 mm Cu filtration.

2.2 Scatter

We performed CE-DBT without a grid. Scatter, *S*, was estimated by extrapolation of signal intensity measurements under Pb-disks with diameters of 3.9 to 23 mm to a disk of zero diameter. Scatter fractions (SF) were then calculated as the fraction of *S* to the SI value in the open field at the same position, which consist of *S* and primary radiation, *P*. These measurements were repeated as a function of position in 50% glandular-50% adipose breast equivalent phantoms (CIRS, Norfolk, VA), and various breast equivalent thickness. The phantoms were positioned so as to mimic the MLO breast position, including higher order scatter from the chest. A 49 kV spectrum with a 0.27 mm Cu filter was applied.

As part of our clinical CE-DBT trial, we have measured SF in the MLO projection images of 6 patients. Pb-disks 12 mm in diameter were positioned on top of the compression plate while the breast was compressed and a series of projection images was acquired over a 50° arc (as measured at the fulcrum, 20 cm above the breast support). SF were then calculated from the SI measured in the shadows of the Pb-disks, giving *S*, and the SI was also measured at the same position in the previously acquired pre-contrast projection images, thus giving $P + S$. The SF in the clinical data were compared with the SF calculated from the 12 mm Pb-disks in the phantom images. The same mammography unit and spectrum were used as in the phantom measurements.

We modeled the effect of scatter on the quantification of the iodine concentration for various breast thicknesses. We simulated a Senographe 2000D tube operated at 49 kV with a Rh target and 0.27 mm Cu filtration. Our simulation includes the attenuation of the Be-window, Cu-filter, compression plate, air, ICRU-44 breast tissue, and the CsI detector material. We used the SF measured near the center of the breast equivalent phantoms. We calculated the contrast as a function of iodine uptake for the various breast thicknesses and then calculated the error in the iodine concentration estimate due to the scatter.