X-Ray Spectra for Breast CT

Dedicated breast CT is an emerging technology that may significantly reduce the problem of superposition of tissue structures that occurs in conventional mammography and is known to reduce the diagnostic performance of that modality. The feasibility of breast CT has been tested by several groups, but there is no consensus as to the optimal energy spectrum.

Simulation

Results of calculations with mono-energetic photons of the fluence required to obtain a fixed value of CNR are shown in Fig. 1. The data are presented as plots of fluence as a function of photon energy for several phantom thicknesses. These plots show that the optimal energy increases with phantom thickness, and that the sharpness of the maximum decreases with thickness. For the 16 cm and thicker phantoms, for instance, the fluence increases very slowly, indicating that a range of spectra might provide similar performance, thus permitting exposure conditions to be based on other considerations such as tube loading.

Calculations with realistic spectra are shown in Figs. 2 and 3. Calculations were done to computationally estimate the following quantities: dose efficiency vs. tube voltage for a range of filter thicknesses, Fig. 2, and the tube power as a function of dose efficiency, Fig. 3. The filter thickness \( t = 0 \) represents no added filtration. Dose was calculated as the difference between incident fluence and transmitted fluence. Monte Carlo simulation will be used to obtain a more accurate measure of dose for future work.

Figure 2 shows that, between 45 and 60 kVp, dose efficiency is nearly constant beyond a filter thickness of 0.23 mm. The higher dose efficiency values for lower tube voltages occur in a region where the K-edge of the filter (43.6 keV for Nd) is above the upper limit of the spectrum, so the filter is simply a conventional beam-hardening filter. Operation in this range is prohibitive due both to anode heating and filament emission limits. Therefore, an optimization scheme that accepts lower than optimal dose efficiency but has reasonable power requirements is preferable.

The points on the curves in Fig. 3 are for increasing filter thickness, and refer to the optimal tube voltage for that thickness taken from Fig. 2. A rapid increase in the required power is clearly seen beyond the fourth data point which corresponds to a filter thickness of 0.23 mm. Since the results from Fig. 2 show that there is no added benefit to using a filter thickness greater than 0.3 mm, a filter thickness around 0.3 mm represents a practical upper limit.

Experiment

Given these results, we will obtain experimental data using filters of 0.1 to 0.3 mm over the range of 45-60 kVp to validate the computational results. Preliminary data for each filter were collected to show the feasibility of the proposed experimental approach. 300 images spanning 360 degrees were collected and reconstructed using the Feldkamp filtered back-projection algorithm. Air kerma measurements were taken at the center and periphery of the phantom for each filter using a Radcal 9010 radiation monitor and a 10X5-3CT ionization chamber.

Dose efficiency was calculated as \( \text{CNR}^2 / \text{dose} \), where dose was calculated as the average of the center and periphery air kerma. Given the possibility of an optimal spectrum with a low tube voltage, other dose metrics such as peak skin dose will also be investigated to account for the non-homogenous dose distribution.

Results

Preliminary results using four lanthanide filters and a copper filter of 0.1 mm thickness are shown in Figure 4. The data were collected using a 60 kVp tube voltage and 6.3 mAs per image. Neodymium yielded the highest dose efficiency value. However, the differences between the filters are within our current estimate of experimental uncertainty. More experiments at various tube voltages and filter thicknesses will be performed to determine the optimal energy spectrum.
Figure 1: Fluence to obtain a fixed CNR for various phantom thicknesses

Figure 2: Dose Efficiency vs. Tube Voltage

Figure 3: PCNR vs DE for various phantom sizes and filter thicknesses

Figure 4: Experimentally determined DE for a glandular contrast

References