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Model predictions for the wide-angle x-ray scatter signals of healthy and malignant breast duct biopsies

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. Wide-angle x-ray scatter (WAXS) could potentially be used to diagnose ductal carcinoma (DCIS) in breast biopsies. The regions of interest were assumed to consist of fibroglandular tissue and epithelial cells and the model assumed that biopsies with DCIS would have a higher concentration of the latter. The scat-

malignant tissue (9.0%) while the differences between malignant and fibrocystic change tissue were considered not significant (3.4%).

Primary x-ray beams incident on breast biopsies cause trace elements to emit secondary x-rays with unique wavelengths.[18] Geraki et al.[19] used a synchrotron x-ray fluorescence study and found statistical increases in concentrations of iron, copper, zinc, and potassium in malignant breast tissue. Pereira et al.[20] also observed increases in zinc and iron.

Several groups[21–41] are devising x-ray diffraction methods to detect cancers in breast biopsies. There are two regimes of interest: small-angle x-ray scatter (SAXS) (x <

in the healthy duct is invaded by epithelial cells in the carcinoma in situ duct. A central [illegible] μm diameter void was left in the malignant duct. A DCIS biopsy can be considered to have more epithelial cells. Since 71.4% of the mass of a typical cell is due to water, a malignant biopsy could have higher water content because of this. As explained later in Sec. 2.1.3, WAXS scatter predictions from breast duct biopsies will require $d\mu/d\Omega$ of fibroglandular tissue and of epithelial cells. The $d\mu/d\Omega$ for fibroglandular tissue was available from literature, whereas those for epithelial cells were not. Although the $d\mu/d\Omega$ of epithelial cells will be measured using the WAXS methods described in Refs. 42 and 43, here a model was devised.

2.1.2 [illegible]

An epithelial cell of [illegible] μm diameter was assumed. Grover et al.[49] measured the density of a single cell using Archimede methods to be [illegible] g/cm³. The epithelial cell of mass 4.524 ng was simplified by looking at all of its constituents as a combination of five basic categories: water, lipids, nucleic acids, proteins, and carbohydrates. The fractional weights (w) were those estimated by Watson[50] for a typical active human cell and are shown in Table 1 along with corresponding masses. Let the DNA, RNA, proteins, and carbohydrates be collectively referred to as the other part of the epithelial cell (OTCell). The fractional volumes ν also shown in Table 1 for each group were estimated using densities [illegible] g/cm³ for water and [illegible] g/cm³ for fat. As a result, the OTCell's density was estimated to be

for compounds using data for elements from Hubbell et al.[52] Compositions for breast tissue were those measured by Poletti et al.[40] Figure 5(a) shows $d\mu/d\Omega$ at $\theta =$ for fibroglandular and the epithelial cell. The energies E185eldewere-262.84(cenuli762420.718Tms)-16251379.85l1.02430TD2 deg those indicated on the top energy axis. The epithelial cells are predicted to have a higher $d\mu/d\Omega$ than fib for ($\leq x <$) (region 1) and $x >$ (region 3), whereas in region 2, the opposite occurred. Due to the IAM use at low x for the OTCell, the $d\mu/d\Omega$ for the epithelial cell has a slow monotonic increase as $x \rightarrow$. Although the scatter data for both fib and the epithelial cells for $x <$ were questionable, the range was included in the study. The main findings would not change if one was to exclude the range since regions 2 and 3 would provide sufficient contrast.

For the calculations of the scatter signals, μ values shown in Fig. 5(b) were used. The μ data for breast tissue were taken from Ref. 1, water and OTCell μ were obtained using the mixture rule and cross-section data from Plechaty et al.,[56] and the μ for the epithelial cell was estimated by

$$\mu_{\quad}(E) = \nu \quad \mu \quad (E) + \nu \quad \mu \quad (E) + \nu \quad \mu \quad (E) + \nu \quad \mu \quad (E):$$

2.3

For the simulations, a 2-mm diameter nondiverging 110-kV 2.5-mm Al filtered[57] beam entered the shaft of a seven gauge needle to interact with the duct biopsy which ranged from $d =$ - to 20-mm thick. The distance between the bottom of the biopsy and a flat matrix of CZT detector pixels was fixed at 40 cm. Figure 6, a scatter geometry schematic, will aid in describing how the calculations of N on the detector plane were computed. Since the single scatter field is circular symmetric about the rule

$$\blacktriangleright = \int_{t}^{\infty} g\ (S)\ S; \qquad \text{(illegible)}$$

$$\sim\ = \int_{-\infty}^{t} g\ (S)\ S: \qquad \text{(illegible)}$$

Furthermore, if the S and S values among the biopsy configu-

biopsies (M-diamonds) were higher than those of healthy ones (H-triangles), whereas the opposite occurred in region 2 (i.e., H-squares > circles). The number of points satisfying the conditions is indicated in each panel by the numbers in the first two parentheses (e.g., for the 2-mm biopsy, 29 points where M-diamonds > -triangles and 3 points where H-squares > -circles). From these data, the S and S signals shown in Fig. 8 were obtained. The error bars are shown yet they were smaller than the symbols. None of the signals between malignant and healthy overlap for a、 uncertainty. Note for d >、 l l , both S S become negative.

represent the values of x for defining the three regions that were shown in Fig. 5(a). The mean of the angles used in the calculations of N for the malignant biopsy were [illegible] (inner ring) and [illegible] (outer). There are differences between the healthy and malignant biopsy cases for this particular annulus. However, to increase the diagnostic signals, the data from all annuli were similarly calculated and then binned in terms of x, as was done in Sec. 3.1.

The Gaussian distributions shown in Figs. 11(a)–11(c) are all the same and correspond to the predictions of S and S distributions for the 8-mm-thick biopsies. The values of x used in the calculations were those corresponding to the 8-mm-thick biopsy in Fig. 7. The decision threshold shown was as before the mean of both values. The arrows in panels (a) and (b), respectively, correspond to malignant and healthy signals for other biopsy thicknesses, whereas in (c), they represent the malignant signals of 8-mm-thick biopsies with different malignant epithelial cell layer thicknesses. For generating all signals denoted by arrows, the same values of

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