I – Introduction

Breast cancer is the most frequently diagnosed cancer in women. Early detection of breast cancer can increase the survival rate and treatment options. Although mammography has played a significant role in reducing breast cancer mortality, the accuracy of mammography is limited, especially in women with dense breasts. Positron emission tomography (PET) imaging has played a significant and evolving role in the staging, follow-up and management of metastatic breast cancer. However, current PET has low sensitivity to detect micrometastases and small tumor-infiltrated lymph nodes.

Here we intend to use penalized maximum likelihood (PML) reconstruction method to improve the detectability of small breast tumors. In a previous work [1], we have shown that PML image reconstruction can improve lesion detection at a fixed location by designing a shift-invariant quadratic penalty function. This paper extends this method to design a shift-variant penalty method for detecting lesions at unknown locations, which is more relevant to clinical applications where we do not know the lesion location a priori.

We conducted computer-based Monte Carlo simulations to compare the optimized shift-variant penalty with a conventional penalty for detecting a breast lesion. Lesion detectability was assessed by a channelized Hotelling observer and human observer. The results show a statistically significant improvement in lesion detectability by the proposed penalty function compared to the conventional penalty function.

II – Method

a) PML reconstruction and lesion detection

For PET image reconstruction, the PML solution can be found as

\[ \tilde{x}(p) = \arg \max_{x} \log \mathbb{P}(y | x) - \beta \mathcal{R}(x), \]

where \( \log \mathbb{P}(y | x) \) is the log-likelihood function of the measured sinogram data \( y \) given the unknown tracer distribution \( x \), \( \beta \) is the weighting factor for the shift-variant penalty function, and \( \mathcal{R}(x) \) is the quadratic penalty function.

\[ \mathcal{R}(x) = \sum_{i=1}^{N} \sum_{j=1}^{N} g_{ij}(x_{i} - x_{j})^{2}, \]

where \( g_{ij} \) is the weighting factor for the pairwise penalty function.

To measure lesion detectability, we use the channelized Hotelling observer (CHO) [2] because many studies have shown that CHOs have good correlation with human performance. The detection performance can be measured by the SNR of the CHO

\[ \text{SNR}_{\text{CHO}} = \frac{U^{*}K^{-1}U}{U^{*}K_{0}U}, \]

where \( U \) is the frequency selective channels and \( K \) is the covariance of the output channels.

Using the theoretical approximation derived in [3], the lesion detectability of PML reconstruction at a fixed location can be approximated by

\[ \text{SNR}_{\text{PML}} \approx \sum_{i=1}^{N} \left| \frac{U_{i}^{*}K_{0}U_{i}}{\lambda_{i}} \right|^{-1} \sum_{j=1}^{N} \left| \frac{U_{i}^{*}K_{0}U_{j}}{\lambda_{j}} \right|^{-1} \]

\[ K = \sum_{i=1}^{N} \left( \frac{1}{\lambda_{i} + \mu_{i}} \right) U_{i}^{*}K_{0}U_{i}, \]

\[ \text{SNR}_{\text{CHO}} = \frac{U^{*}(K^{*}K^{-1} - K_{0})U}{U^{*}K_{0}U}. \]

In the previous work [1], the lesion detectability was evaluated at a fixed position and the weighting factors were kept spatially invariant, i.e., \( g_{ij} \) is only a function of \( j - i \). For detecting lesions at unknown locations, here we calculate the weighting factors \( g_{ij} \) for every pixel and then form a symmetric shift-variant matrix \( K \) by

\[ g_{ij} = \frac{1}{\lambda_{i} + \mu_{i}} \]

Performing the optimization in equation (5) for every pixel is time-consuming. To reduce the computation cost, we only compute the optimum weights on a coarse grid and then assign the values of \( g_{ij} \) to other pixels using the nearest neighbor interpolation. We found that \( g_{ij} \) varies slowly as we move from one pixel to its neighbors, so this interpolation method works well. The number of pixels on the coarse grid was determined experimentally.

III – Simulation Results

We simulated a 2D GE DST clinical scanner. The digital phantom (Fig. 1(a)) was created based on a patient PET/CT scan, where there was a histologically verified tumor in the breast. We simulated a detection of a small tumor in the contralateral breast, as currently PET imaging of breast cancer is often used to detect distant metastases for staging purposes. To evaluate the proposed method for detecting a tumor at unknown positions, a left breast with a diameter of 3 mm and contrast of 5:1 was inserted at three different locations (indicated by the purple “o” marks in Fig. 1(a)) in the glandular tissue.

References


IV – Conclusion

We have developed a method to design a quadratic penalty function in PML image reconstruction for lesion detection at a unknown location. The results of the computer simulations and human observer show that the proposed method can significantly improve the lesion detectability over the conventional quadratic penalty function. Currently we are extending this model to fully 3D PET data and plan to evaluate it using real patient data.