Comparison of Breast Percent Density Estimated from Digital Mammograms and Central Reconstructed Tomosynthesis Slice Images

Predrag R. Bakic[1], Despina Kontos[1], Andrea B. Troxel[2], and Andrew Maidment[1]

[1] University of Pennsylvania, Dept. Radiology, 3400 Spruce St., 19104 Philadelphia, PA
{Predrag.Bakic,Despina.Kontos,Andrew.Maidment}@uphs.upenn
[2] University of Pennsylvania, Dept. Biostatistics and Epidemiology,
632 Blockley Hall – 423 Guardian Drive, Philadelphia, PA 19104-6021
ATroxel@mail.med.upenn.edu

Abstract. We analyzed breast percent density (PD) estimated from 35 women with existing or recently detected abnormalities. Analyzed were digital mammograms (DM) and the central digital breast tomosynthesis (DBT) reconstructed slices. PD was estimated from the breast contralateral to cancer. We have examined the effect of modifying the DBT reconstruction filter on the accuracy of dense tissue segmentation; we selected the filter that effectively reduced image intensity overshoot near the breast edge, which interfered with segmentation. The Pearson correlation coefficient between PD estimates from DM and the central reconstructed DBT slices was r = 0.90. The corresponding quadratic-weighted kappa coefficient was κ = 0.78, indicating substantial agreement. The observed results are comparable with the agreement between PD estimates from DM and the central DBT projection images (r = 0.89 and κ = 0.74). This suggests that PD is robust to variations in acquisition conditions.

Keywords: Breast percent density, digital breast tomosynthesis, filtered back-projection, Pearson correlation, Kappa statistics.

1 Introduction

Breast percent density (PD) is an independent risk factor of breast cancer [1]. Studies have shown that women with very dense breasts, as measured mammographically, have a 4- to 6-fold increase in breast cancer relative risk, compared to women with the least dense breasts [2]. Mammographic percent density (PD_M) is defined as the fractional area of mammographic dense tissue. PD_M is limited to 2D analysis of density, it cannot portray the volumetric distribution of dense tissue within the breast.

Digital Breast Tomosynthesis (DBT) is an x-ray imaging modality, providing volumetric visualization of the breast tissue. Early clinical trials with DBT suggest this technique is associated with improved sensitivity and specificity relative to projection mammography [3], which makes DBT a viable candidate to replace mammography as the standard modality for early cancer detection.

Breast density can be estimated in DBT images using several approaches. Two-dimensional PD can be estimated from DBT projection images or from individual

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reconstructed breast slices; three-dimensional PD can be estimated from reconstructed breast volume. We have previously shown that PD estimates from the central DBT projection and the corresponding PD_M yield high correlation (Pearson coefficient r=0.90) [4]. PD estimates from various projections did not vary significantly; their standard deviation computed over all projections was 1-7%.

Our intention has been to systematically validate the degree of consistency between PD estimates from DBT obtained using different approaches, as well as their relationship with the corresponding PD_M. In this paper we present the analysis of PD estimates from the central reconstructed DBT slice (PD_{CRT}). In our previous PD analysis of DBT reconstructed images, we observed the effect of reconstruction artifacts on dense tissue segmentation [5]. In this paper, we have examined the effect of modifying the filter used in DBT reconstruction, in order to improve the accuracy of dense tissue segmentation.

2 Material and Methods

DBT image data were retrospectively collected from a clinical multimodality imaging study in our department (NIH R01 CA85484-01A2). In the study, bilateral DBT, digital mammography (DM), MRI, ultrasound, and PET of the same women were performed the same day.

Imaging was performed with a GE Senographe 2000D FFDM system (General Electric Medical Systems, Milwaukee, WI) modified to allow DBT. The breast was positioned in the MLO position and immobilized with light compression (4 to 6 daN). The breast support table did not contain an anti-scatter grid. Each DBT image data set consists of nine projection images acquired in 6.25-degree increments over a 50 degree arc. The pixel pitch is 100 μm. The radiation dose for each tomosynthesis data set was similar to the mean glandular dose used for a standard 2-view mammographic exam. A custom filtered backprojection method was used to reconstruct DBT tomographic planes in 1 mm increments with 0.22 mm in-plane resolution. A volume of interest of $20.5 \times 20.5 \times T$ cm^3 was reconstructed, where T was equal to the thickness of the breast as measured by the compression device and recorded in the source image DICOM header.

The study included 51 women (mean age 52 years, range 31-80 years). For PD analysis, we selected 35 women (mean age 50 years, range 31-78). Sixteen women were excluded due to the existence or suspicion of bilateral cancer, or due to incomplete visualization of the breast tissue which precluded the breast density estimation.

PD was estimated using Cumulus 4.0 software [6], which is considered as gold standard in quantitative analysis of PD. Cumulus is based on manual segmentation of pectoral muscle region and interactive thresholding of breast outline and dense tissue in 2D, mammographic, breast images; the software has been validated in many PD studies, *e.g.* [7].

The modulation transfer function (MTF) of the reconstruction filter, shown in Figure 1, was defined using a piecewise linear function. Filters with similar MTF have been used for DBT reconstruction in the literature [8], [9].

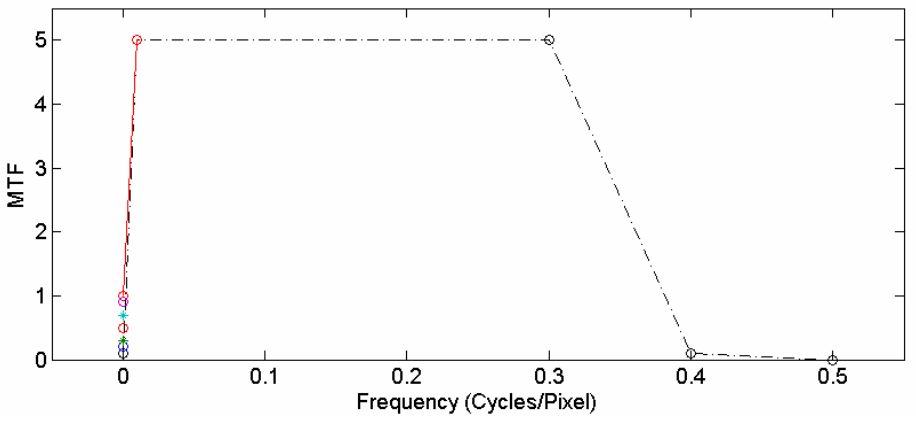

Fig. 1. We have examined the effect of modifying the slope of the low frequency MTF portion, on the segmentation of the dense tissue regions by thresholding. The slope has been modified by changing successively MTF(0) from 0.1 to 1.0, in the piecewise linear definition of the filter.

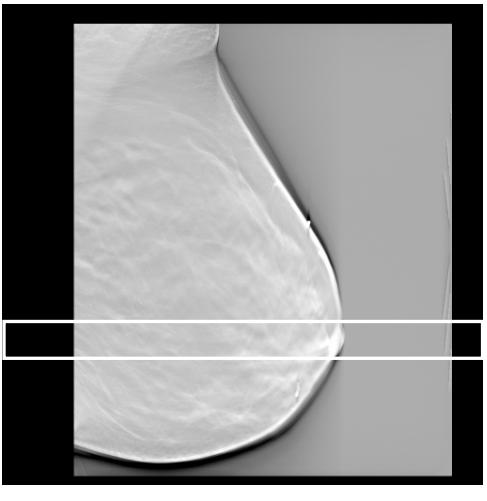

Fig. 2. Example of the central reconstructed DBT slice for a clinical case used in our study. We analyzed the effect of modifying reconstruction filter by computing the intensity profile in reconstructed images. The image profile was defined as the sequence of mean pixel values computed along a 50-pixel wide horizontal band (white line) passing through the nipple.

We have examined the effect of modifying the low frequency MTF portion of the filter. Filtered backprojection algorithms usually suppress the low frequency portion of the MTF to optimize visibility of small detail, *e.g.*, microcalcifications. Strong suppression of the low frequencies portion, however, causes the overshoot near the breast edge, and also a trend of gradually decreasing intensities, from the nipple towards the chest wall. This spatial trend gets superimposed with the underlying

anatomical profile, and interferes with the thresholding based segmentation of dense tissue regions. We modified the slope of the low frequency MTF portion by changing MTF(0) in the piecewise linear definition of the filter (see Figure 1). The effect of MTF modification was assessed by computing the intensity profile in reconstructed images. We defined the image profile as the sequence of mean pixel values computed along a 50-pixel wide horizontal band passing through the nipple (see Figure 2). For the analysis of PD_{CRT} we selected the MTF which provided an approximately uniform image profile.

Statistical comparison between the PD_{DM} and from the PD_{CRT} has been performed by computing Pearson correlation coefficient and kappa statistics. Pearson correlation coefficient, r, is defined as:

$$r = \frac{\sum (PD_M \cdot PD_{CRT})}{\sqrt{\left(\sum PD_M^2\right) \cdot \left(\sum PD_{CRT}^2\right)}}. \tag{1}$$

PD can also be quantified using categorical scale. The most frequently used approach is Boyd's 6-class categorization, defined as [9]: (i) PD = 0%; (ii) 0% < PD ≤ 10%; (iii) 10% < PD ≤ 25%; (iv) 25% < PD ≤ 50%; (v) 50% < PD ≤ 75%; and (vi) PD ≤ 75%. We analyzed agreement between PD_M and PD_{CRT} on a categorical scale using kappa statistics. The kappa coefficient, κ, describes the agreement between categorical results of paired diagnostic ratings, taking into account only agreement beyond chance [10]:

$$\kappa = \frac{P_0 - P_C}{1 - P_C}, \tag{2}$$

where P_0 and P_C represent the proportion of observed agreement and the proportion of agreement expected by chance, respectively. When the rating results are presented by a multicategory ordinal scale, the proportions of agreements are usually weighted to reflect different degree of disagreement between larger and smaller rating differences; in this study we used quadratic weights [10],

$$w_Q = 1 - \left(\frac{\Delta_C}{N_C - 1}\right)^2, \tag{3}$$

where Δ_C represents a difference between the categories assigned in paired rating, and N_C is the number of categories used. In case of Boyd's 6-class categorization, $w_Q = 1$ for no disagreement, and $w_Q = 0.96$, 0.84, 0.64, 0.36, or 0, for disagreements by $\Delta_C =$ 1, 2, 3, 4, or 5 categories, respectively.

3 Results

Figure 3 shows the image profiles computed on the central reconstructed slice from Figure 2, corresponding to MTF(0) values of 0.1, 0.2, 0.3, 0.5, 0.7, 0.9, and 1.0. For PD_{CRT} analysis we selected the reconstruction filter with MTF(0)=0.5. Figure 4 shows

results of dense tissue segmentation by thresholding using Cumulus, in a mammogram and the central slices of the same breast, reconstructed using filters with MTF(0)=0.5 and 0.1. The corresponding PD estimates are PD_M=48%, and PD_{CRT}=46% (for MTF(0)=0.5) and PD_{CRT}= 38% (for MTF(0)=0.1).

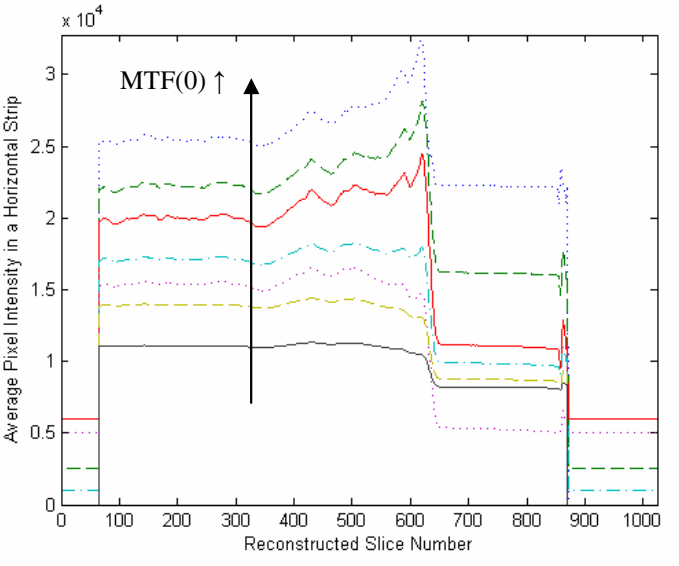

Fig. 3. Image profiles for the central reconstructed slice shown in Figure 2, corresponding to MTF(0) of 0.1, 0.2, 0.3, 0.5, 0.7, 0.9, and 1.0 (top to bottom)

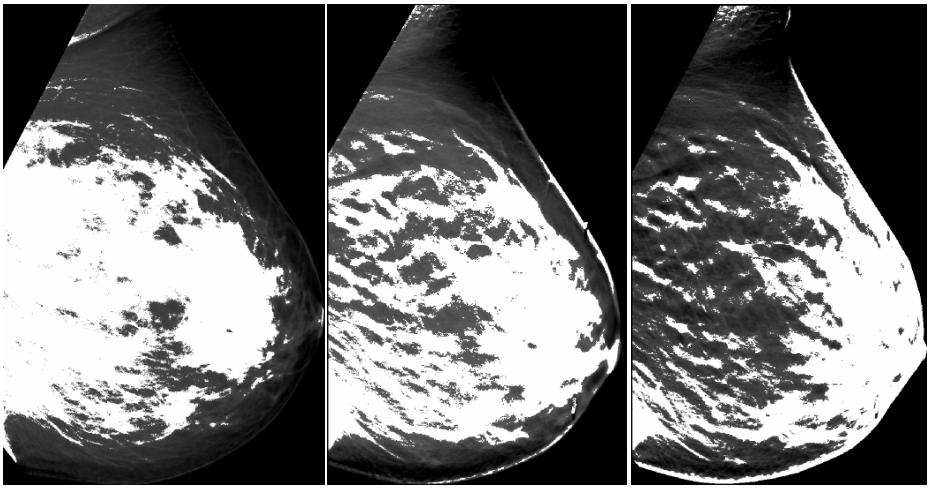

Fig. 4. Examples of dense tissue segmented by thresholding using Cumulus in a mammogram (left) and the central DBT slices, reconstructed using filters with MTF(0)=0.5 (center), and MTF(0)=0.1 (right). The corresponding PD estimates are 48%, 46%, and 38%, respectively.

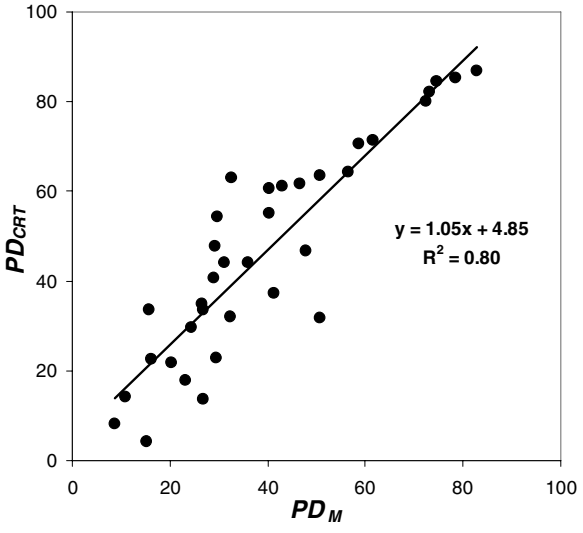

Fig. 5. Scatter plot of PD_M and PD_{CRT}; and the corresponding linear regression

Fig. 5 shows the scatter plot of PD_M and PD_{CRT} and the corresponding linear regressions. The Pearson correlation coefficient between PD_M and PD_{CRT} was 0.90, and the corresponding kappa coefficient 0.78, indicating substantial agreement [12].

4 Discussion

We selected the filter with low frequency slope of the MTF defined by MTF(0)=0.5 for the reconstruction of DBT images used in PD analysis. The selected filter effectively reduced the overshoot near the breast edge, thus providing an approximately uniform image profile. Figure 3 shows that the filters with MTF(0)>0.5 produced overshoot in the image profiles near the breast edge. On the other hand, the filters with MTF(0)<0.5 produces undershoot near the breast edge.

The results of dense tissue segmentation, shown in Figure 4, illustrate the effects of filter modification. The dense tissue region segmented in the image reconstructed using the filter with MTF(0)=0.5 shows higher spatial correlation with the dense tissue segmented from the mammogram of the same breast, compared with the image reconstructed using the filter with MTF(0)=0.1.

The filter with MTF(0)=0.1 was designed for reconstruction of DBT images used in a study of different clinical imaging modalities, as it provided good visibility of breast tumors and microcalcifications [11]. Our current results indicate that the reconstruction filter optimized for clinical detection of breast cancer is not necessarily optimal for accurate segmentation of dense tissue. To fully evaluate the effect of image reconstruction of PD analysis of the reconstructed DBT images, we plan to analyze reconstructed images of physical phantoms of different thickness, and both with and without simulated anatomical noise.

The observed agreement between PD_M and PD_{CRT} is comparable with the agreement between PD_M and the PD estimated from the DBT projections (r = 0.89 and κ = 0.74). Our current results indicate similar performance in PD estimation from mammograms, the central DBT source projections, and the central DBT reconstructed images, suggesting that PD is robust to variations in acquisition conditions. A larger study is needed to fully evaluate the effects of image acquisition on PD estimation and its the relationship with breast cancer risk.

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