

DUAL-ENERGY DIVIDING METHOD OF THE EARLY DETECTION OF MICROCALCIFICATIONS IN MAMMOGRAPHY

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In spite of the fact that mammography is a 40-year-old technique and is currently the best imaging method for detection of early breast cancer in asymptomatic women, the errors of first and second kinds are too high.

The soft tissue and cancerous tissue are very similar, but their atomic number differs. The cancers exhibit a higher effective atomic number than the normal tissue. The aim of this study was to improve early detection of microcalcifications, which are the earliest indicators of breast cancer, and to get a better definition (sharpness) of the cancer boundary on the base of visualization of an effective number distribution.

Dual-energy subtraction mammography may provide information regarding the product of the atomic number, density and thickness of the breast tissue. Dual-energy subtraction mammography is based on weighted subtraction of the logarithm of the low-energy image from that of the high-energy image. The paper presents the dual-energy dividing mammography which is based on dividing of the logarithms of the low-energy image by the high-energy image. That ratio depends upon only an effective atomic number and does not depend on the density and thickness of the breast.

The study shows that the visualization of that ratio improves the detection of microcalcifications and improves the sharpness of the breast image (soft normal tissue and cancer).

1. Introduction

Traditional X-ray mammography visualizes the distribution of the photon number which is registered by a detector or film pixel. The number of counted photons is determined as

$$N = \gamma N_0 (e^{-\mu_p \rho d} + s - a) \quad , \quad (1)$$

where N_0 is initial photon number generated by X-ray tube which comes through the elementary part of the breast, μ_p is the mass attenuation coefficients (the sum of mass scattering and mass absorption coefficients), which is determined by an effective atomic number and X-ray energy, ρ is the density of the elementary part of the breast, d is the thickness of the breast, s is the part of photons scattered by the neighboring parts of the mammary gland and by the mammography equipment (table, screen etc), a is the portion of photons absorbed by the mammography equipment, γ is the portion of photons that reached and interacted with the detector or the film.

The portion of photons absorbed by the mammography equipment is practically homogeneous and can be accounted for. However the portion of photons scattered by the mammary gland and recorded by the detector (or film) is heterogeneous and depends on the density of the breast tissue located close to the section of the breast being examined. Higher breast tissue density results in more photon scattering.

A special honeycomb collimator allows decreasing the amount of photons scattered under a large angle, but photons scattered under a small angle are counted by the detector (films, scintillators etc.). This reduces the sharpness of the image and makes it practically impossible to identify areas of the breast with insignificant variations in the density.

A cancer with microcalcifications exhibits a higher effective atomic number than normal breast tissue and although the cancerous tissue and the soft tissue are very similar, their atomic number differs.

The effective atomic number can be identified by dual-energy mammography [1-4] or by detecting transmission and scattered radiation [5].

In the dual-energy image, weighted subtraction of the logarithm of the low-energy image from that of the high-energy image is proportional to the product of the atomic number, density and thickness of the breast tissue [1-4].

However, as we show, division of the same logarithms can be more useful in diagnosing malignant growths because it depends only on the effective atomic number [6-8].

2. Method

Despite the fact that the effective atomic number of the breast elements varies from 5.5 (cholesterol) to 12-14 (microcalcifications), the real range of effective atomic number variation is narrower and varies from approximately 6.5 to 7.5. It is explained by a small concentration of anomalies in the breast.

Let us denote the division and subtraction of the mass absorption coefficients as:

$$\alpha = \mu_{\rho}^L - \mu_{\rho}^H \text{ and } \beta = \frac{\mu_{\rho}^L}{\mu_{\rho}^H} \quad (2)$$

where $\mu_{\rho}^L, \mu_{\rho}^H$ are the mass coefficients of absorption for low and high energy, correspondently.

Figure 1 presents the dependence of these coefficients (division and the subtraction of the mass coefficients) for energy 40 and 20 keV from the effective atomic number (Z) [19].

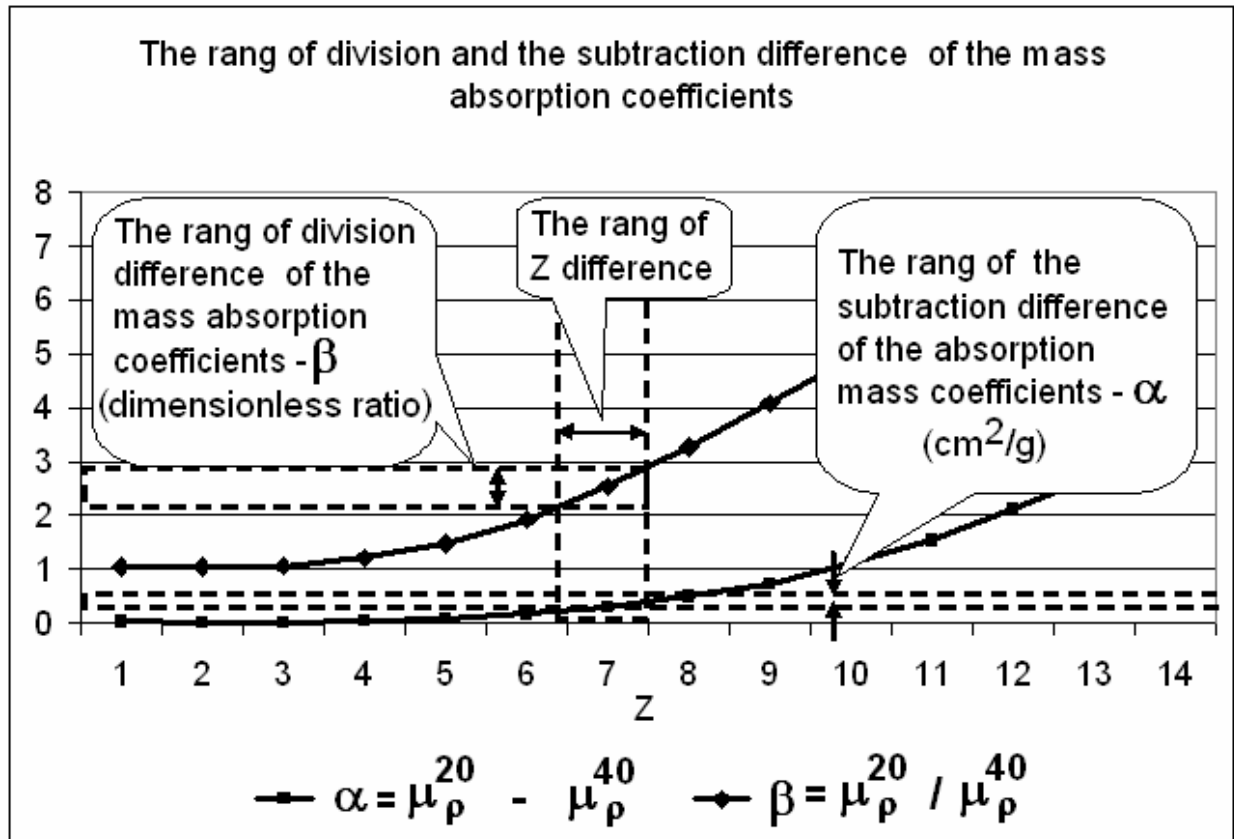


Figure 1. The rang of the division and the subtraction difference of the mass absorption coefficients

Despite the fact that photoelectric absorption coefficients depend on the fourth power of the atomic number, the division and subtraction are practically in direct proportion to the atomic number (Z) where $6 < Z < 8$.

The subtraction of the logarithms is proportional to the product of the effective atomic number, density and thickness

$$\ln \frac{N_0^L}{N^L} - \ln \frac{N_0^H}{N^H} = \rho d (k_\alpha Z + a_\alpha) \quad (3)$$

but division of the logarithms is proportional only to the effective atomic number

$$\frac{\ln \frac{N_0^L}{N^L}}{\ln \frac{N_0^H}{N^H}} = k_\beta Z + a_\beta$$

where – L,H - indices correspond to low and high energy, $k_\alpha, a_\alpha, k_\beta, a_\beta$ - coefficients

$$\ln \frac{N_0^L}{N^L} - \ln \frac{N_0^H}{N^H} = \rho d (k_\alpha Z + a_\alpha) \quad (4)$$

The product of average density and thickness can be calculated as

$$\rho d = \frac{(\ln \frac{N_0^L}{N^L} - \ln \frac{N_0^H}{N^H})}{\frac{k_\alpha}{k_\beta} \left(\frac{\ln \frac{N_0^L}{N^L}}{\ln \frac{N_0^H}{N^H}} - a_\beta \right) + a_\alpha} \quad (5)$$

As a rule, on most part, the thickness of the breast tissue is constant during mammography checkup. Hence, that expression allows us to extract the real density distribution.

This is why these two methods do not compete but rather supplement each other. Subtraction and division of the logarithms give three additional images: the effective atomic number, the density and the product of the two.

3. Experiments and Visualization

Figure 2 show the traditional mammogram of the mammary gland with malignant growth and visualizations of the effective atomic number. As can be seen, the boundary of cancerous growth is sharper on the image of the distribution of the effective atomic number then on the traditional mammogram. There is more contrast between the normal tissue and the malignant growth.

Figure 3 shows the traditional mammograms of the cancerous and healthy sections of the breast together with their visualizations. The effective atomic number, density and their product were calculated according to formulas 2, 3, and 4. Despite the fact that all images are similar, traditional mammograms have less sharpness and contrast then the visualizations. Microcalcifications can be seen more easily on these visualizations then on the traditional mammograms.

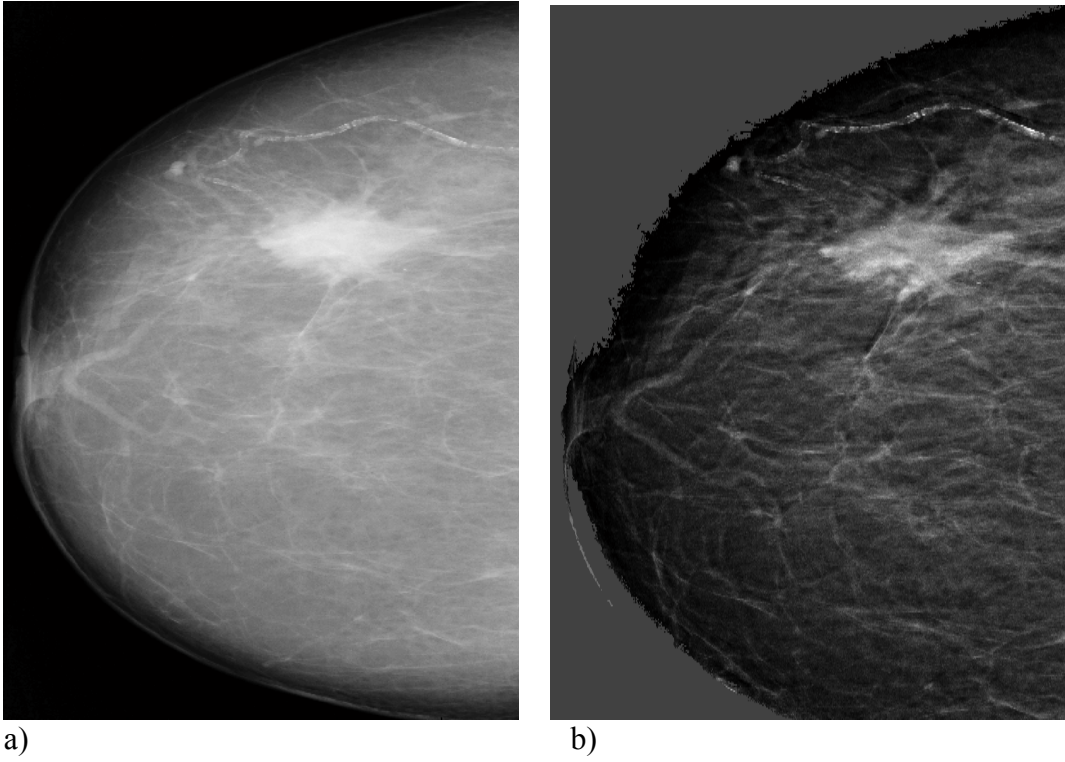


Figure 2. (a) Traditional mammogram (b) Reconstructed Z-distribution

In spite of the small range of the effective atomic number its visualization allows us to get a sharper image with more contrast. The visualization of the atomic number distribution can be improved by non-traditional methods of imaging processing.

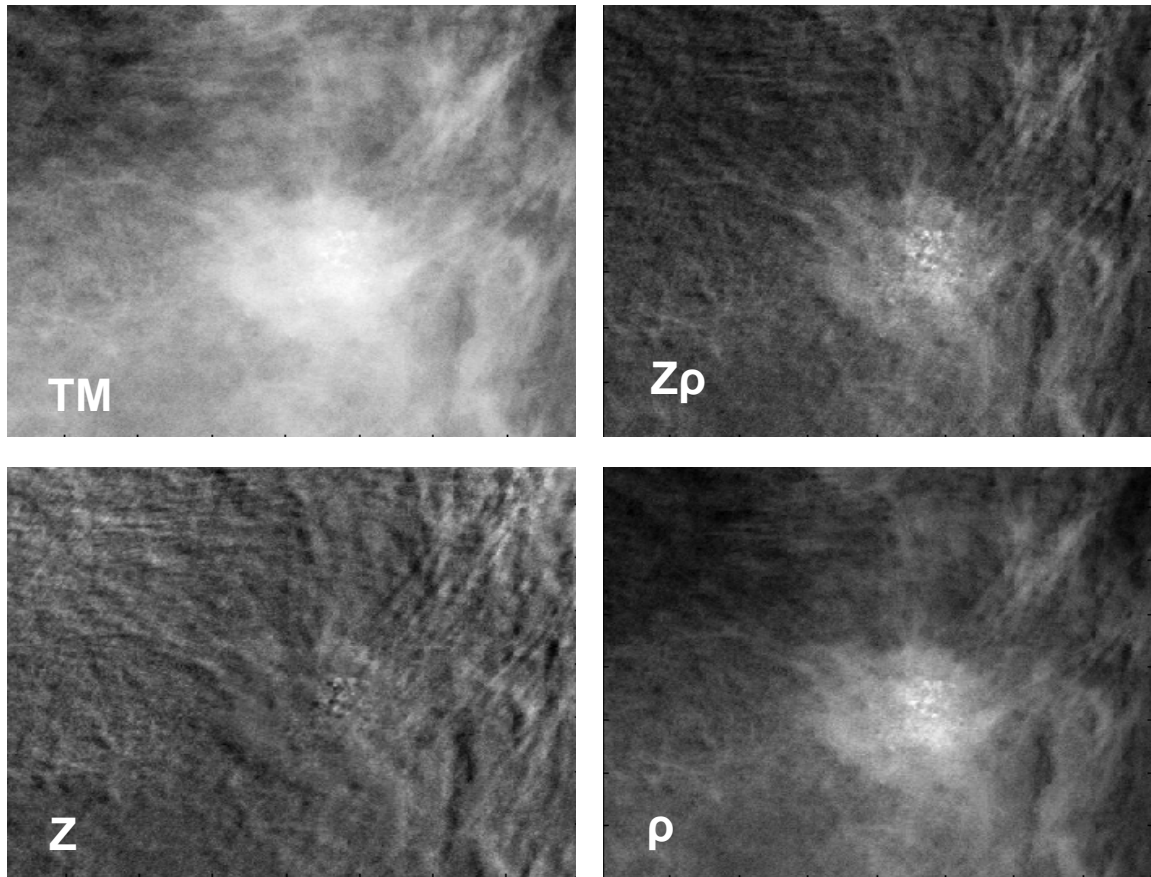
Decreasing high energy can increase image sensitivity to the effective atomic number during its calculation. This can be accomplished by artificially increasing the initial photon number N_0^H . This corresponds to increasing the linear attenuation coefficient that is interpreted as an increase to the effective atomic number.

Such decreases in high energy give the opportunity to identify microcalcifications at early stages when they are very small and practically invisible on traditional mammograms. This can be achieved by decreasing high energy during reconstruction only in the area with the potential tumor, where the number of counted photons is minimal. These images which visualizing the coefficient β (Z-distribution) are practically invariant to density.

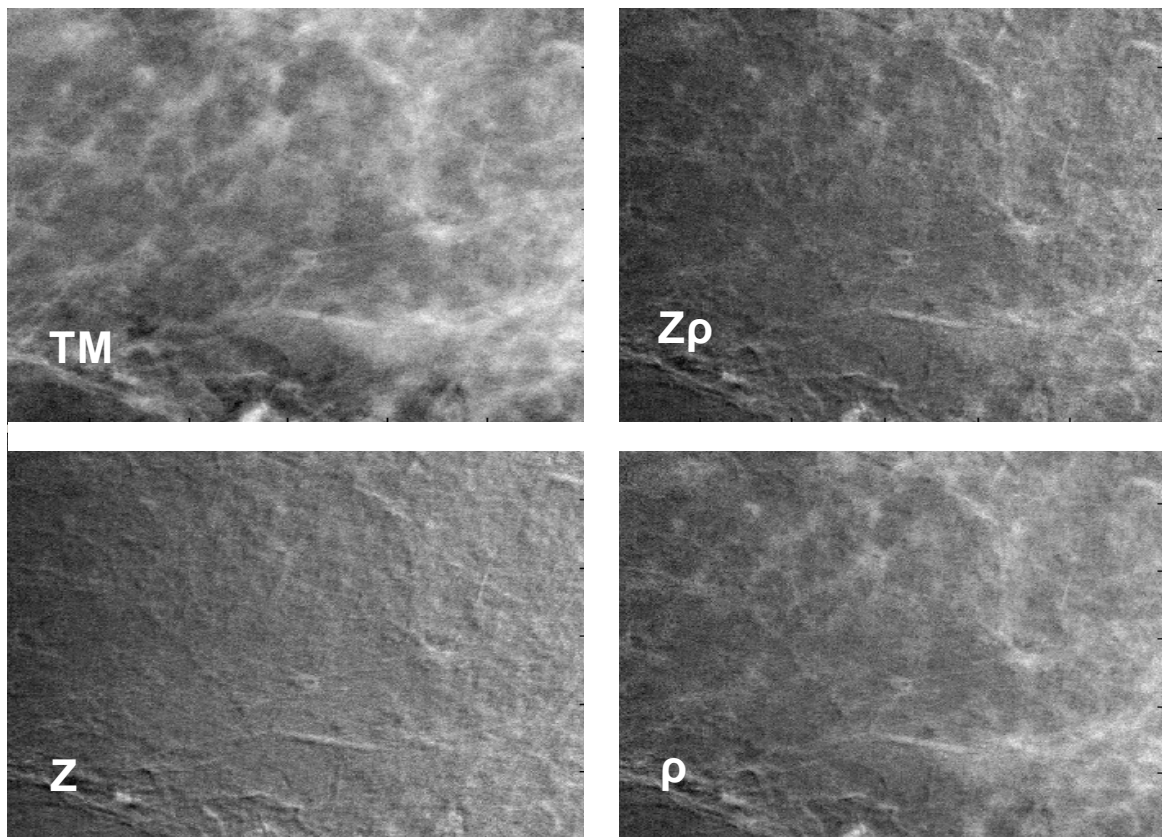
Such non-linear transformations of counted photon numbers improve sensitivity to the effective atomic number and contrast of the effective atomic number distribution solely in the area where we have maximum X-ray attenuation. Microcalcifications smaller than 50 microns cannot be seen at the Z-mammogram. But if microcalcifications are grouped into colonies they can be identified on Z-distribution visualizations with amplified sensitivity to the atomic number.

Figure 4a presents an area with microcalcification in the centre of the malignant growth. More microcalcifications are seen at this visualization than at the traditional mammogram (Figure 3a, TM).

Additionally, such non-linear transformation gives the best line of the cancerous growth boundary (Figure 4b). There are practically no atomic number variations in the healthy section of the breast.



a)



b)

Figure 3. (a) Cancer with microcalcifications (b) Healthy section of the breast

TM - Traditional mammogram

$Z\rho$ - Visualization of the product of the effective atomic number and density

Z - Visualization of effective atomic number,

P - Visualization of the density.

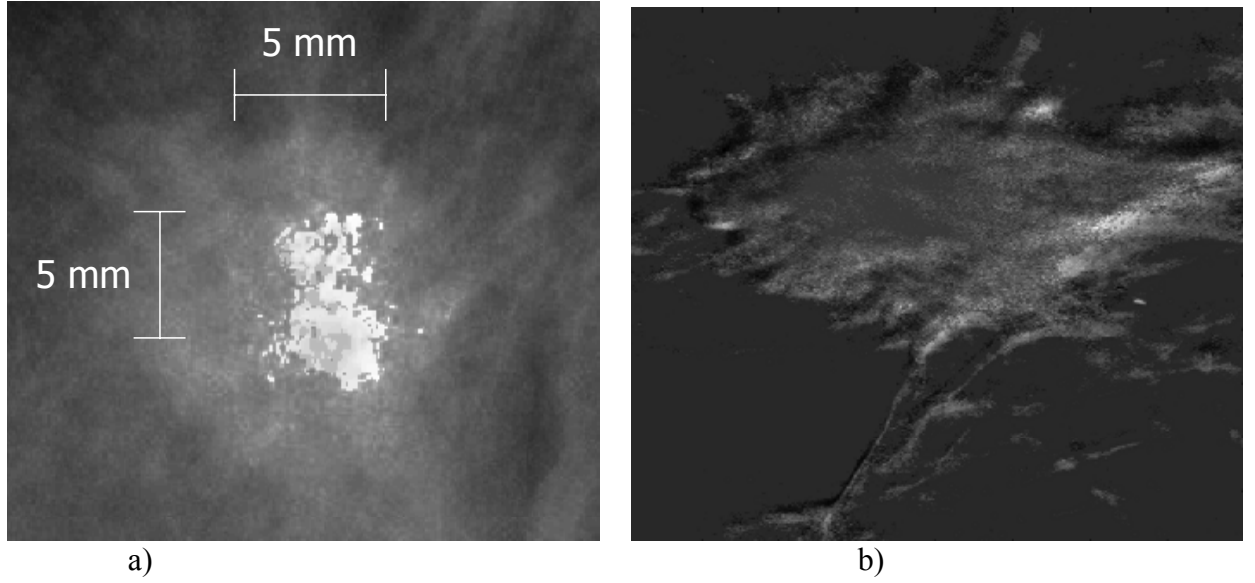
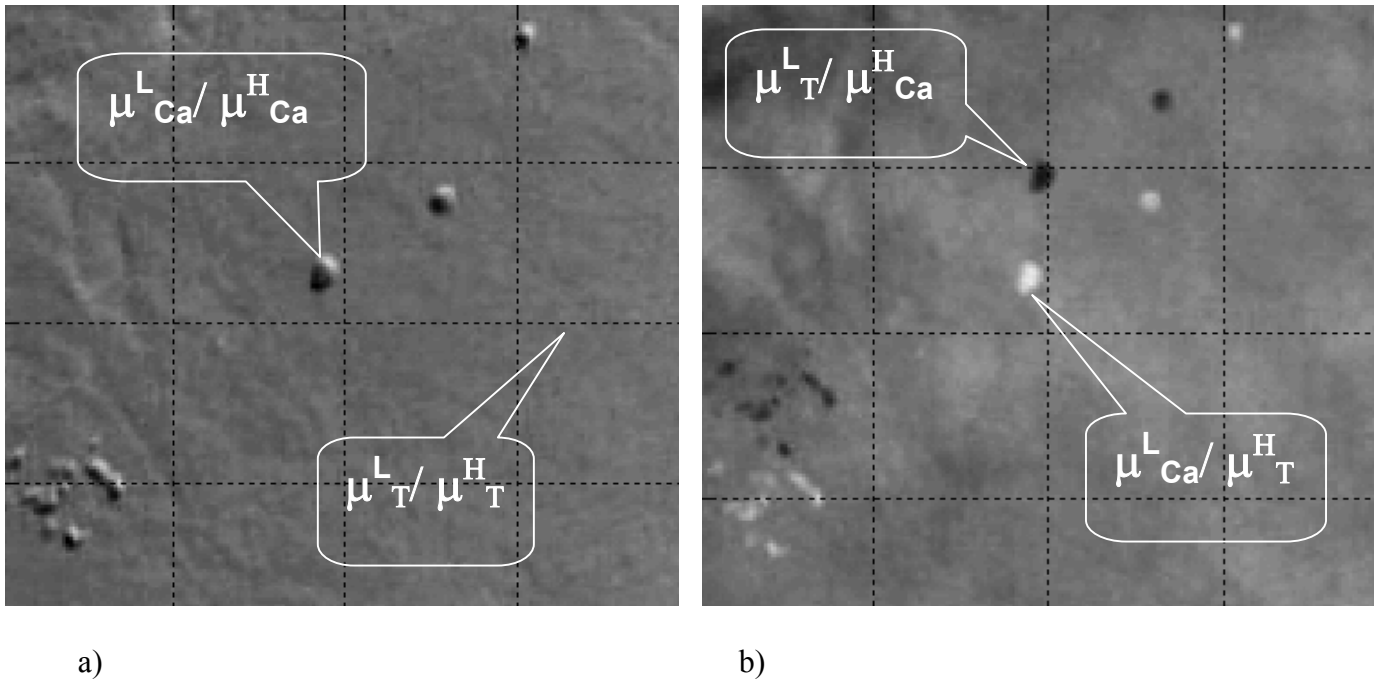


Figure 4. Non-linear visualization of the effective atomic number in the breast
(a) Visualization of cancerous growth boundary with microcalcifications
(b) Visualization of cancerous growth boundary without microcalcifications



a)
Figure 5. Z-distribution
(a) Without initial image shift
(b) With initial image shift

Two images at high and low photon energy should coincide during reconstruction. However, it is not possible to consistently achieve this as the breast may move during measurement. This is why microcalcifications are best examined in three-dimensional form. Such artifacts are typical of all visualizations of Z-distributions (Figures 2, 3, 4). But, if coincidence between high and low energy captures is destroyed, microcalcifications can still be identified in the double image, as microcalcifications appear darker or lighter than the healthy section of the breast tissue.

This is the basis for another method of imaging processing.

Figure 5 presents the Z-distribution reconstructed with (a) and without (b) initial image shift (along x -axis – 5 pixels and y -axis – 40 pixels).

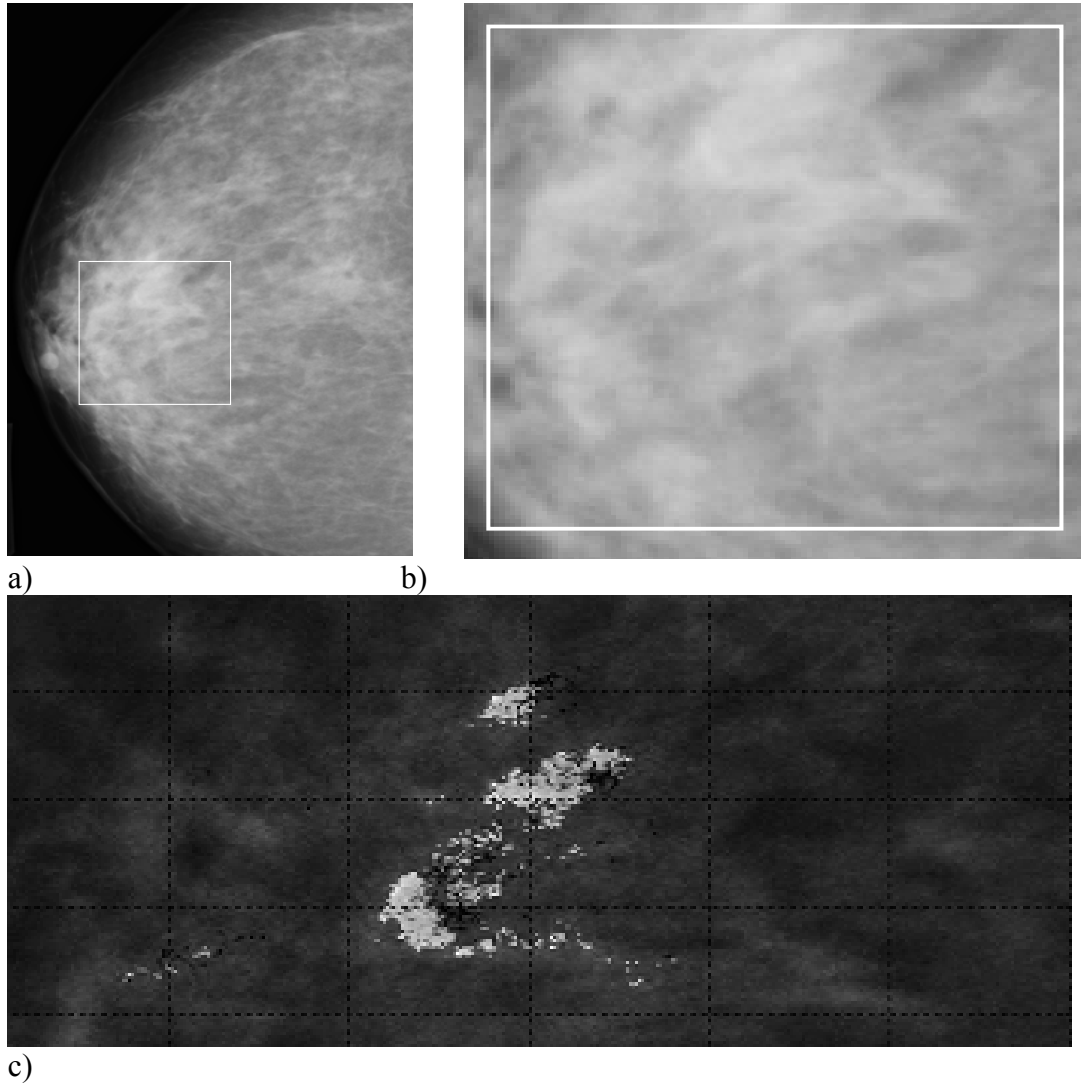


Figure 6. Mammograms of the breast with undetected cancer and microcalcifications

- (a) Traditional mammogram of the breast
- (b) Traditional mammogram of the suspicious part of the breast
- (c) Z-distribution of the suspicious part of the breast

Coordinates of darker microcalcification images correspond to healthy sections of the breast against the background of microcalcifications.

Coordinates of lighter microcalcification images correspond to tissue with microcalcifications against the background of healthy sections of the breast.

Since

$$\begin{aligned} \mu_T^H &< \mu_{Ca}^H, \\ \mu_T^L &< \mu_{Ca}^L \end{aligned} \quad (6)$$

reconstructed atomic number is determined by division of coefficients which obey the following inequalities

$$\frac{\mu_T^L}{\mu_T^H} > \frac{\mu_T^L}{\mu_{Ca}^H} < \frac{\mu_{Ca}^L}{\mu_{Ca}^H} \text{ and } \frac{\mu_T^L}{\mu_T^H} < \frac{\mu_{Ca}^L}{\mu_T^H} > \frac{\mu_{Ca}^L}{\mu_{Ca}^H} \quad (7) \dots$$

This explains the high contrast of double images of the microcalcifications.

Figure 6 presents mammograms of the breast with undetected cancer and microcalcifications. The microcalcifications are seen as double white and black points because of a small initial image shift.

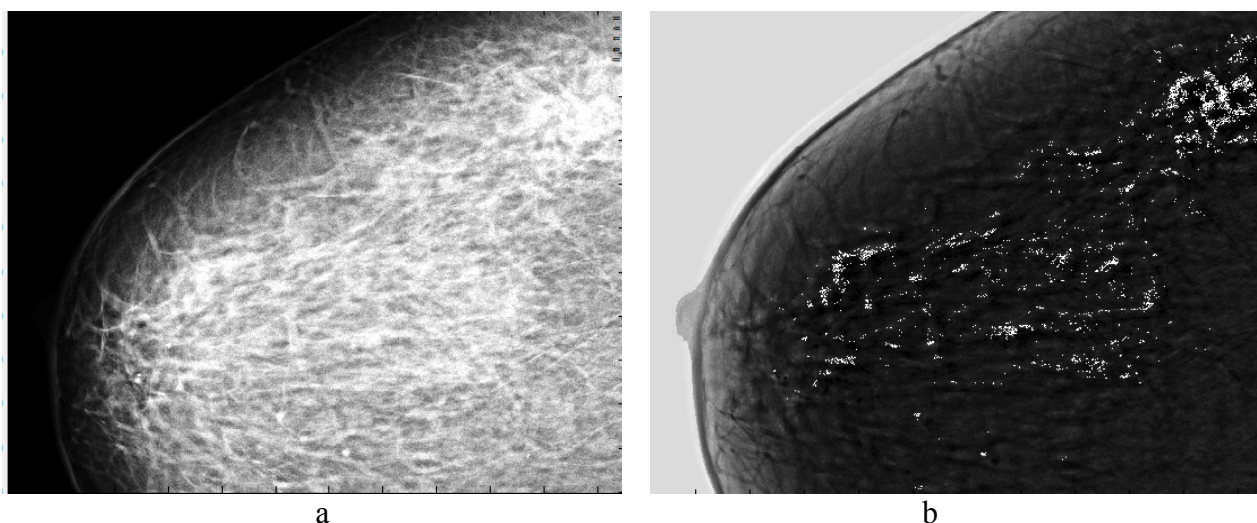


Figure 7

Figure 7 presents traditional mammogram of the mammary gland with microcalcifications (a) and visualizations of the effective atomic number distribution (b). Microcalcifications are seen significantly better at the atomic number distribution than at the traditional mammogram. The morphological analysis has confirmed presence of microcalcifications in these areas.

The distribution of the effective atomic number presents the opportunity to investigate the dynamic of its evolution and effectiveness of medical treatment.

4. Conclusion

Invariant visualization of the effective atomic number on the base of dual-energy dividing mammography enables improving the diagnosis of the mammary gland disease.

Reference

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