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A method for material decomposition in dual-energy contrast enhancement digital mammography

M. Kahani [a], A. Kamali-asl [a,*], H. Ghadiri [b], S. Hashemi [a]

[a] Radiation Medicine Engineering Dept., Shahid Beheshti University, Tehran, Iran
[b] Department of Medical Physics and Biomedical Engineering, Tehran University of Medical Sciences, Tehran, Iran

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ABSTRACT

Background and purpose: Dual-energy mammography is a technique which is being used for accuracy enhancement of the breast cancer diagnosis especially in dense breasts. It is also a valuable and practical way for obtaining detailed information about tumor's size, disease progression and micro-calcification detection which is the earlier sign of breast cancer. The aim of this study was to investigate the possibility of separating different thicknesses of micro-calcifications, Iodine, and Bismuth contrast agents, simultaneously.

Material and methods: A breast phantom was made from acrylic and olive oil containing various density thicknesses of Iodine and Bismuth contrast agents. To simulate micro-calcifications, different thicknesses of the Aluminum sheets were used and placed in the phantom as well. In this work, an X-ray tube with Tungsten anode and a flat panel semi-conductor detector were used for imaging processes. To customize the X-ray spectrum, a combination of copper and aluminum were used as filters to optimize the X-ray high energy spectrum in dual energy imaging.

Results: According to the results, separating of Iodine images was prepared by using of Iodine's k-edge property for thicknesses greater than 0.5 mg/cm^2. Also, Bismuth and Aluminum images with thicknesses greater than 0.53 mg/cm^2 and 200 μm, respectively, were isolated automatically by material thicknesses estimation method in dual-energy imaging technique.

Conclusion: The results demonstrated that Iodine and Bismuth contrast agents together with micro-calcifications can be separated from breast tissue with good accuracy by using proposed dual-energy contrast enhanced mammography technique.

1. Introduction

Breast cancer is a malignant tumor that starts growing from cells of the breast. It is often seen in women, but rarely in men too [1]. One of eight women will be diagnosed with breast cancer, which is a major cause of cancer death among women with an age of 40–44 years old [2]; hence, its diagnosis and treatment is very important. Digital mammography provides the possibility of accurate diagnosis of breast cancer, particularly in the early stages with optimizing every stage of imaging, image processing, and displaying the image in comparison of analog mammography [3]. Another important benefit of digital mammography rather than the film mammography is that it allows for advanced imaging techniques, such as dual energy imaging. In some cases, such as dense breasts, there is not the detection possibility of full and accurate tumor extent in single-energy imaging; or micro-calcification detected in the breast tissue despite high contrast, is very

* Corresponding author.
E-mail address: A_kamali@sbu.ac.ir (A. Kamali-asl).

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difficult which is an important factor in earlier diagnosis of breast cancer, due to overlapping tissues and their small sizes. In these cases the dual-energy technique by applying appropriate methods and using of contrast agent material can be used in order to reach better detection of disease extent [4]. Specific characteristics of tumor cells are the angiogenesis of tumor around and hyper physiological activity of these cells. If clinically to be able to simultaneously use two contrast agent and If these two suitable contrast agent materials along with two appropriate carriers are chosen in the way that one of the contrast agent can penetrate inside the tumor cells and make them obvious, while another one has not this capability; so, it can just flow in the vessels which feed tumors. In this way, it can be examined for cancer cell functions and also can see the anatomy of the vessels supplying tumors. All cancer cells can be detected accurately and appropriate location can be investigated for biopsy by using suitable techniques and separating images of these materials.

Different behaviors of materials attenuation coefficients at different energies leads to the possibility of material differentiation when dual-energy imaging is used due to dominance of photoelectric effect compared to Compton scattering effect in lower energies range. Basis of the dual-energy technique are entirely published and discussed in many articles [5–9]. This technique has been used for imaging tomography, chest radiology, and mammography [8–11]. Most of the dual-energy imaging methods based on weighted subtraction technique use a linear combination of logarithm of high and low-energy images to generate the dual-energy images [6,10]. Although the linear subtraction method is easily implemented in practice, it is susceptible to artifacts of remaining tissue's structures, because dual-energy image generation is essentially non-linear process [9,12,13]. In a study done by Jones et al. in 1985, based on 50 kV and 110 kV dual-energy scanning, it was shown that the broken bone below the breast could be imaged by dual-energy imaging method [14]. Aurelie in 2009 showed that thicknesses of each three materials, as water, adipose, and proteins, can be calculated by solving of three equations, three unknown systems by dual-energy imaging algorithm [15]. Brettle and his partners in 1994 theoretically modeled a dual-energy imaging system, which was based on linear subtraction technique [10]. In the study, Aluminum disks was imaged in diameter of 1 mm and different thicknesses (to simulate micro-calcifications) by dual-energy imaging technique when they had located under materials of 50% adipose equivalent and 50% glandular equivalent. The results demonstrated that calcium tissues greater than 470 μm could be separated by dual-energy technique; much smaller than what is visible on a mammography single energy.

The early stage detection of breast cancer and also, exact disease extent diagnosis has direct relation to appropriate treatment method selection and its performance. Thus, this study intends to apply some proper physical, mathematical and image processing methods, by using of suitable contrast agent materials and contrast-enhancing tumor. Finally, investigate the possibility of automatic separation of whole various materials in the breast equivalent phantom only with one dual energy imaging and report the results.

2. Materials and methods

2.1. Design and fabrication of breast equivalent phantom

A phantom was designed and fabricated to mimic the breast tissue in the mammography imaging system. Phantom's materials were selected based on their attenuation characteristics such that olive oil was used instead of breast adipose tissue and acrylic was used instead of glandular tissue, as shown in Fig. 1(a) with capability of mimicking various ratio of glandular tissue to adipose tissue, e.g. 30% glandular and 70% adipose, or 50% glandular and 50% adipose. A staircase shape container was built and used to embed contrast agent in the phantom, which has the capability of insert various contrast agent thicknesses (Fig. 1(b)). In this study 5 mg/ml of Iodine was used to evaluate various concentration of Iodine in breast tissue. So density thicknesses were simulated from 0.5 mg/cm^2 till 4 mg/cm^2 by using of staircase shape container of Iodine density and therefore, the related images were investigated. The width of each stair was 12.5 mm and their height was 10 mm. The overall thickness of phantom was 5 cm in X-ray beam direction made of 4 mm thickness of acrylic. (Fig. 2 shows the breast equivalent phantom perfectly and also the imaging geometry which was used in this study.)

Fig. 3 shows the placement of various contrast agents in the breast tissue equivalent phantom.

One of the early signs of breast cancer is the micro-calcification; therefor its detection is very important. Breast tissue micro-calcifications are very similar to Aluminum in features of radiation attenuation; hence, many researches use from Al's foils at various sizes and thicknesses [1]. In 2013, a study [17] was done and Aluminum thicknesses which produce similar image contrast with micro-calcifications in the same imaging condition were calculated. Based on this research, Al's thickness is equivalent of 0.85 micro-calcification's thickness averagely. The Aluminum thicknesses of 50, 100,150, 200, 300, 400, 500, and 600 μm were used to mimic the micro-calcification as shown in Fig. 3. These thicknesses of Aluminum are equivalent of 59, 118, 176, 235, 353, 470, 588, and 706 μm thicknesses of micro-calcifications, respectively [17].

2.2. Making of contrast agents

Iodine with atomic number of 53 and its probability to use in clinical procedures is one of the most common contrast agents. Iodine's k-edge energy is equal to 33 keV which has located on the suitable area of X-ray imaging in dual energy technique. To make a solution of Iodine, Ethanol (CH_3CH_2OH) was used as a solvent. Also a little amount of Potassium hydroxide (KOH) was used to increase the solubilization capacity and desired concentration of Iodine obtained. Finally, Iodine solution was made with density thickness of 5 mg/ml as a contrast agent.

Bismuth with atomic number of 83 and low toxicity, is being used as a contrast agent in clinical application and X-ray imaging. This material is available as Bismuth Nitrate which was used for making contrast agent. Nitric Acid was used as solvent and finally Bismuth solution was provided with density thickness of 2.65 mg/ml. Bismuth solution is