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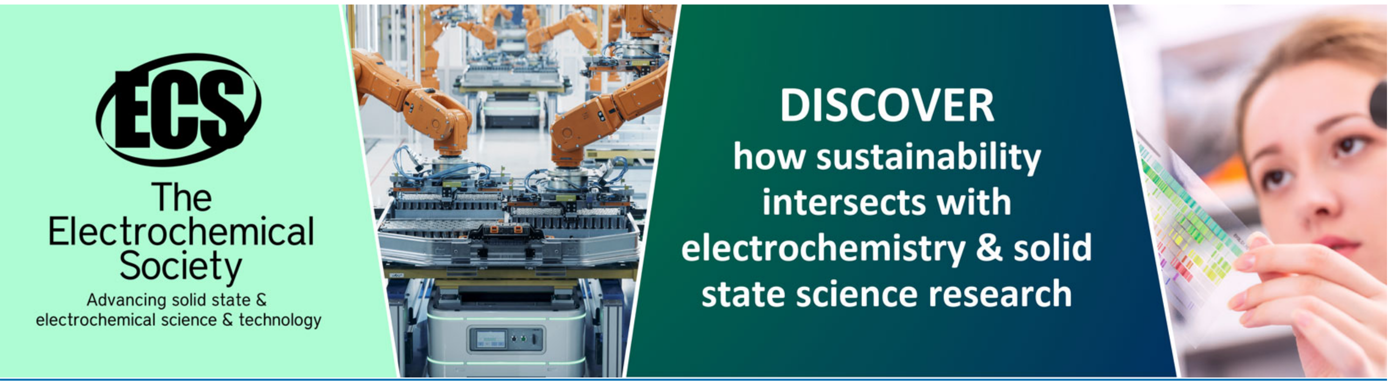

PVAL breast phantom for dual energy calcification detection

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Abstract. Microcalcifications are the main indicator for breast cancer. Dual energy imaging can enhance the detectability of calcifications by suppressing the tissue background. Two digital images are obtained using two different spectra, for the low- and high-energy respectively, and a weighted subtracted image is produced. In this study, a dual energy method for the detection of the minimum breast microcalcification thickness was developed. The used integrated prototype system consisted of a modified tungsten anode X-ray tube combined with a high resolution CMOS sensor. The breast equivalent phantom used was an elastically compressible gel of polyvinyl alcohol (PVAL). Hydroxyapatite was used to simulate microcalcifications with thicknesses ranging from 50 to 500μm. The custom made phantom was irradiated with 40kVp and 70kVp. Tungsten (W) anode spectra filtered with 100μm Cadmium and 1000μm Copper, for the low- and high-energy, respectively. Microcalcifications with thicknesses 300μm or higher can be detected with mean glandular dose (MGD) of 1.62mGy.

1. Introduction

Breast cancer is a major public health concern [1]. Microcalcifications are the principal indicator of breast cancer [2], thus the visualization and detection of microcalcifications is significant [2,3]. Dual energy (DE) imaging can enhance the detectability of calcifications by suppressing the tissue background structures [3]. With this technique, separate low- and high-energy images are acquired and a weighted subtracted image is produced.

Previous research works in dual energy imaging showed that the minimum detectable calcification size ranges from 300-355μm depending on the X-ray technique and the detection system [4,5]. Various tissue-equivalent-phantoms have been used for the experimental validation of these methods [4,5].

In this study, a dual energy imaging method is proposed for the early microcalcification detection. The prototype system used consisted of a modified tungsten (W) anode X-ray tube combined with a high resolution complementary-metal-oxide-semiconductor (CMOS) sensor. The breast equivalent phantom used was an elastically compressible gel of polyvinyl alcohol (PVAL). Contrast to noise ratio in the subtracted (dual energy) image (CNR_{DE}) was calculated for all the examined calcifications, while preserving MGD mean glandular dose (MGD) within examination levels [6].

2. Materials and Methods

Weighted log-subtraction was used to generate the DE subtraction images, $ln(DE) = ln(HE) - w ln(LE)$ where *HE* and *LE* are the high- and the low-energy images, and *w* is the weighting factor [7].

Experiments were carried out in a modified radiographic unit. A Del Medical Eureka X-ray tungsten (W) radiography tube was used with total inherent filtration of 3mm of aluminum (Al) [8]. The low-energy images were acquired at 40kVp with a cadmium (Cd) filter of 100μm thickness placed at the tube exit. For the high-energy images, a copper (Cu) filter of 1000μm thickness was placed in the beam at 70kVp. The detection system consisted of a terbium-activated gadolinium oxisulfide (Gd_2O_2S:Tb) phosphor screen (Min-R 2190 with a mass thickness of 33.91mg/cm^2) coupled to a CMOS photodiode pixel array (Remote RadEye HR) [9,10]. The CMOS photodiode array has a format of 1200x1600 pixels with a pitch of 22.5μm. The source to image receptor distance (SID) was set at 66cm. A large (1.2mm nominal) X-ray tube focal spot was selected.

The breast phantom used in the experiments of this study was an elastically compressible gel of polyvinyl alcohol (PVAL). A similar breast phantom of PVAL in ethanol and water was developed by Price *et al*. A solid yet elastically compressible gel was produced after being frozen and defrosted [11]. The linear attenuation coefficient of PVAL gels, with different concentrations ranging from 5% to 20% w/v (weight to volume), was in the range of 0.76 to 0.86cm^{-1} at 17.5keV. These values are very similar to the published breast tissue data at this energy, 0.8-0.9cm^{-1}. The breast tissue equivalent phantom used in this study was produced by mixing 50% ethanol, 50% water and 10% PVAL. The phantom thickness was 4cm. Figure 1 shows the mass attenuation coefficient of PVAL and breast tissue (ICRU-44) using published data [12]. As it can be seen from the plot, the coefficients are identical. The densities of the PVAL and breast tissue are 0.924g/cm^3 and 1.020g/cm^3 respectively, while the corresponding effective atomic numbers Z are 7.05 and 7.07 [13]. Three PMMA slabs of different thicknesses (0.2, 0.3 and 0.4cm) were used, in order to construct the phantom of microcalcifications (μC). In each PMMA slab, holes were opened and filled with a mixture of hydroxyapatite and epoxy resin (density 1g/cm^3) in order the amount of the HAp in each hole to correspond at a specific microcalcification thickness. The thicknesses of the calcifications in the μC phantoms ranged from: (i) 50 to 250μm in the 0.2cm thick μC phantom, (ii) 150 to 375μm in the 0.3cm thick μC phantom, and (iii) 100 to 500μm in the 0.4cm thick μC phantom.

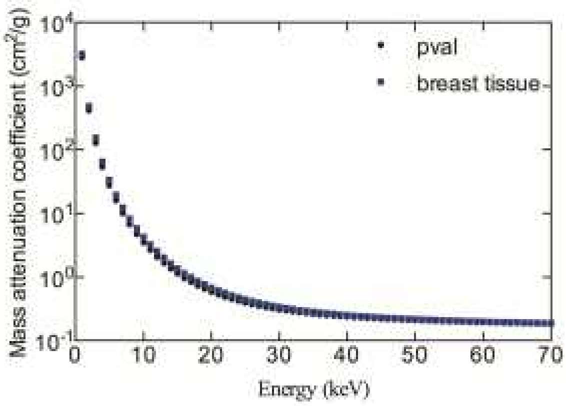

Figure 1. Mass attenuation coefficients of PVAL and breast tissue (ICRU-44).

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CNR was used as a measure of image quality and is a function of both the low- and high-energy images. The CNR_{DE} was calculated according to the following equation [14]:

$$CNR_{DE} = \frac{\left|\overline{S_{\mu C}} - \overline{S_B}\right|}{\sigma_B} \qquad (1)$$

where μC and B denote the mean signal of the microcalcification and background regions, and σ represents the standard deviation of pixel values in the background [14]. The CNR_{DE} threshold value for the detection of a calcification was equal to 3 [3].

The MGD was calculated using the practical relation of ACR [15] and previously published data [16].

3. Results and Discussion

Figure 2 shows the dual energy images of homogenous PVAL phantom combined with the examined three-calcification phantoms. The entrance dose was 1.92mGy, corresponding to MGD value of 1.62mGy.

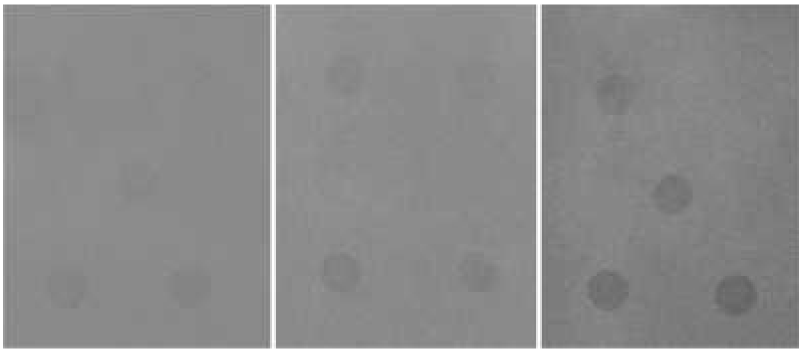

Figure 2. Dual energy images of the three-calcification phantoms of 0.2cm (left), 0.3cm (center) and 0.4cm (right) thick.

Table 1 shows the measured CNR_{DE} values of the three-calcification phantoms, with thicknesses ranging from 150 to 500μm for MGD values of 1.62 and 0.80mGy. Calcification thicknesses of 50 and 100μm could not be depicted in the DE image due to: (i) counting statistics leading to increase of image noise and (ii) low object contrast which was expected from the simulation study [17]. For this reason, CNR_{DE} values were not included in Table 1. The minimum detectable calcification thickness was 300μm, as yielded a CNR_{DE} value of 3.25 which is above the threshold of 3. In a previous dual energy study, the minimum detectable calcification size was reduced to 250μm after applying noise reduction techniques in the DE images [5]. However, in this study, noise reduction methods were not included.

Table 1. Measured CNR_{DE} values of the three-calcification phantoms.

Calcification thickness (μm)	CNR_{DE} **(MGD=1.62mGy)**	CNR_{DE} **(MGD=0.80mGy)**
150	1.71	0.79
200	2.11	1.39
225	2.53	1.41

250	2.58	1.97
300	3.25	2.31
375	3.38	2.56
400	3.71	2.65
500	4.63	3.01

4. Conclusions

In this study, a homogenous breast-equivalent-phantom was developed using polyvinyl alcohol, water and ethanol. A mixture of hydroxyapatite and epoxy resin was used for microcalcifications with various thicknesses. Contrast to noise ratio was calculated from the DE subtracted images. The minimum detectable calcification thickness was 300μm for mean glandular dose of 1.62mGy.

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References

[1] World Health Organization 2009 Available via: http://www.who.int/gender/women_health_report/full_report_20091104_en.pdf
[2] Mou X and Chen X 2007 *Proc of MICCAI (Australia)* vol 4792 p 596
[3] Lemacks M, Kappadath S, Shaw C, Liu X, Whitman G 2002 *Med. Phys.* **29** 1739
[4] Kappadath S and Shaw C 2005 *Med. Phys.* **32** 3395
[5] Kappadath S and Shaw C 2008 *Phys. Med. Biol.* **53** 5421
[6] EUREF 2006 European guidelines for quality assurance in breast cancer screening and diagnosis 4th ed European Commission
[7] Chung H, Ikejimba L, Kiarashi N, Samei E, Hoernig M and Lo *J Proc. SPIE 8668, Medical Imaging 2013: Physics of Medical Imaging* **86684L**
[8] Del Medical Systems Group, Roselle, IL [Online]. Available from: http://www.delmedical.com.
[9] Michail C, Spyropoulou V, Fountos G, Kalyvas N, Valais I, Kandarakis I and Panayiotakis G 2011 *IEEE Trans. Nucl. Sci.* **58** 314
[10] Seferis I, Michail C, Valais I, Fountos G, Kalyvas N, Stromatia F, Oikonomou G, Kandarakis I, Panayiotakis G. 2013 *Nucl. Instrum. Meth. Phys. Res. A.***729** 307
[11] Price BD, Gibson AP, Tan LT and Royle GJ 2010 *Phys. Med. Biol.* **55** 1177
[12] Boone JM and Chavez AE 1996 *Med. Phys.* **23**, 1997
[13] Billas I, 2011, Angiogenesis measurements in mammography using time-resolved dual energy analysis, MSc thesis, University of Patras. Available online: http://nemertes.lis.upatras.gr/jspui/handle/10889/4869
[14] Ducote JL, Xu T and Molloi S 2007 *Phys. Med. Biol.* **52** 183
[15] ACR 1999 Mammography, Quality Control Manual (Reston, VA: Americal College of Radioliogy)
[16] Boone J 1999 *Radiol.* **213** 23
[17] Koukou V, Martini N, Michail C, Sotiropoulou P, Fountzoula C, Kalyvas N, Kandarakis I, Nikiforidis G, Fountos G. 2015 *Comput. Math. Methods Med.* [in print]