A novel anthropomorphic breast phantom for assessing performance of iodinated contrast-enhanced breast imaging systems

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Introduction

Decreases in breast cancer mortality can largely be attributed to improvements in breast imaging systems [1]. Unfortunately, testing these novel technologies on patients is costly, inefficient, and exposes patients to unnecessary radiation. Non-anthropomorphic phantoms used to evaluate image quality of new and modified full field digital mammography (FFDM), digital breast tomosynthesis (DBT), and breast computed tomography (bCT) systems can be misleading and over-estimate the efficacy of the systems in a clinical setting.

The angiogenesis process inherent to malignant breast tumors provides an opportunity to better image the lesion and its surrounding vasculature using contrast agents, such as iohexol. The purpose of this work is to develop an anthropomorphic breast phantom that models iodine uptake in fibroglandular tissue and lesions to robustly test contrast-enhanced breast imaging systems.

Methods

To determine the amount of iodine present in the doped printed ink, various square ink samples were printed onto parchment paper, which has been proven to show similar attenuation to adipose tissue in breasts [2]. The relationship between iodine level and effective linear attenuation coefficient μ_{eff} were then determined on a clinical FFDM system.

Printing was done on a Brother MFC-J450DW InkJet printer. Inks were fabricated largely using a 2:1 ratio of aqueous potassium iodide (KI) and/or sodium bromide (NaBr) at various concentrations and regular dye ink.

On the FFDM system, the phantom was imaged with a Mo/Mo target and filter, at 28kVp and 10mAs. The effective mu was measured directly from the FFDM shots after correcting for gain and nonuniformity.

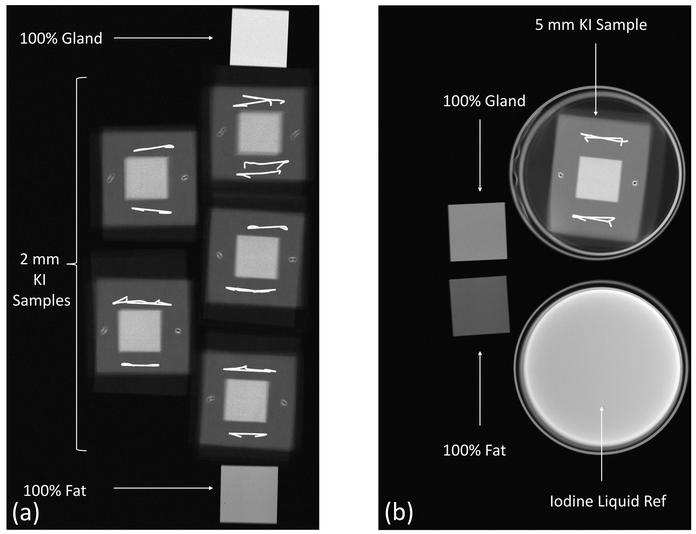
Various references were used to determine the appropriate salt concentration, including:

- 100% Glandular Reference
- 100% Fat Reference
- CIRS Iodine Chips
- Liquid Iodine Solution

Salt-Doped Ink Solutions Tested included:

- 66% 300 mg/ml KI + H_2O, 33% cyan dye
- 66% 600 mg/ml KI + H_2O, 33% cyan dye
- 66% 900 mg/ml KI + H_2O, 33% cyan dye
- 33% 260 mg/ml NaBr + H_2O, 66% cyan dye
- 66% 50-50 mixture of 300 mg/ml KI + H_2O and 260 mg/ml NaBr KI + H_2O, 33% cyan dye

Results and Discussion



(a) FFDM image depicting five 300 mg/ml KI + H_2O samples, 100% fat reference chip (bottom right), and 100% glandular reference chip (top right)
(b) FFDM image depicting 600 mg/ml KI + H_2O sample in a petri dish (top right), the liquid iodine reference (bottom right), 100% fat reference chip (bottom left), and 100% glandular reference chip (top left)

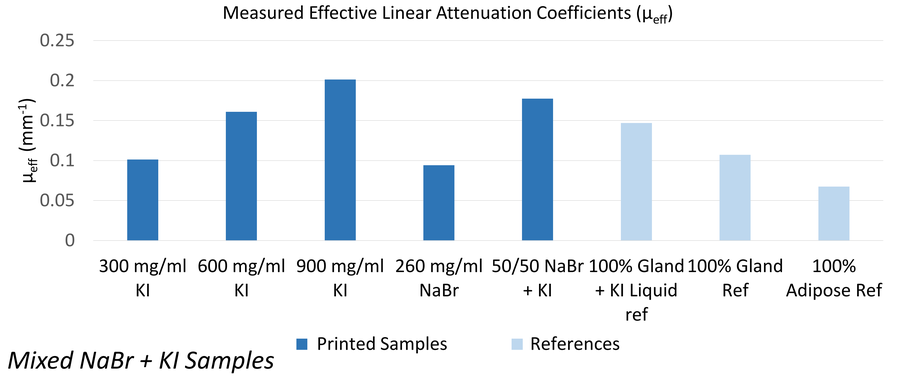
From FFDM images, the effective mu, μ_{eff} , was measured for the printed parchment paper samples and the various references of known iodine concentration/attenuation coefficient.

Baseline

The μ_{eff} of 300 mg/ml KI + H_2O was 0.101 mm^{-1}, comparable to the reference value for 100% fibroglandular tissue which is 0.107 mm^{-1}. 260 mg/ml NaBr + H_2O had an attenuation coefficient of 0.094 mm^{-1}, and therefore can also be considered a good concentration to dope ink with for fibroglandular tissue.

KI Samples

Printed KI samples with concentrations 300, 600, and 900 mg/ml had a μ_{eff} of 0.101, 0.161, and 0.201 mm^{-1} respectively. We can conclude that the printer deposits an amount of iodine onto the paper that is directly proportional to the iodine concentration in the doped ink.



Mixed NaBr + KI Samples

Adding KI as a contrast agent to the fibroglandular-equivalent bromine-doped ink can model the contrast enhancement in lesions and surrounding tissue in clinical FFDM images. A 50-50 composition of 260 mg/ml NaBr and 300 mg/ml KI ink was created. The measured μ_{eff} was 0.177 mm^{-1} . The attenuation of this printed sample is too high which when compared to fibroglandular-equivalent water doped with 6 mg/ml KI in a 60-40 mixture to model a contrast-enhanced lesion, with a μ_{eff} of 0.147 mm^{-1} . The concentration of iodine must be reduced in subsequent samples.

Conclusion

From these results, we can conclude that ink doped with NaBr is a viable option to inkjet print anthropomorphic breast phantoms. Further doping this NaBr-ink mixture significantly increases the μ_{eff} of the printed region, allowing for enhanced contrast in printed regions representing fibroglandular tissue and lesions.

Future Work

Future work includes experimenting with lower KI concentrations in the NaBr + KI doped ink to match the attenuation of the liquid iodine references. Following this, the established salt concentration values should be used to print a parchment breast phantom with iodine-and-bromine mixed ink that models a breast during iodine-enhanced contrast imaging at the time point of highest iodine uptake in the lesion studied.

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References

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