Simulation of digital mammographic images using GAMOS

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Introduction

Virtual Clinical Trials (VCTs) are increasingly vital in medical research, particularly for testing new mammography techniques. VCTs depend on detailed anatomical models, like those provided by VICTRE[1], and accurate simulations using GEANT4[2] (through GAMOS toolkit [3]), which model complex x-ray interactions. This study enhances imaging simulations, contributing to the development of advanced diagnostic methods in mammography, and ultimately improving early breast cancer detection.

Material and Methods

Our study presents a comprehensive *in silico* model of digital mammography systems using the Monte Carlo (MC) technique. We simulated the basic geometry of a Siemens Mammomat Inspiration system to demonstrate the model. Figure 1 shows the geometry of the simulation.

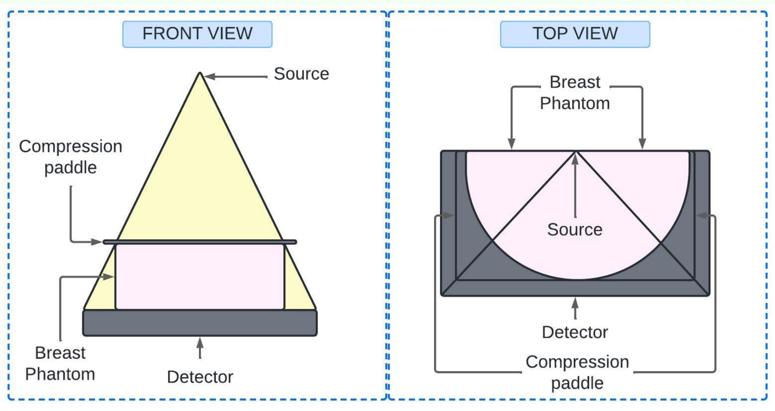

Figure 1: *Simulation setup.*

Phantom

Two types of phantoms were used: voxelized phantoms generated with VICTRE, and a homogeneous phantom based on AAPM TG-195 [4] for dose validation. The VICTRE-generated phantoms allow for detailed and customizable breast models (see Fig. 2).

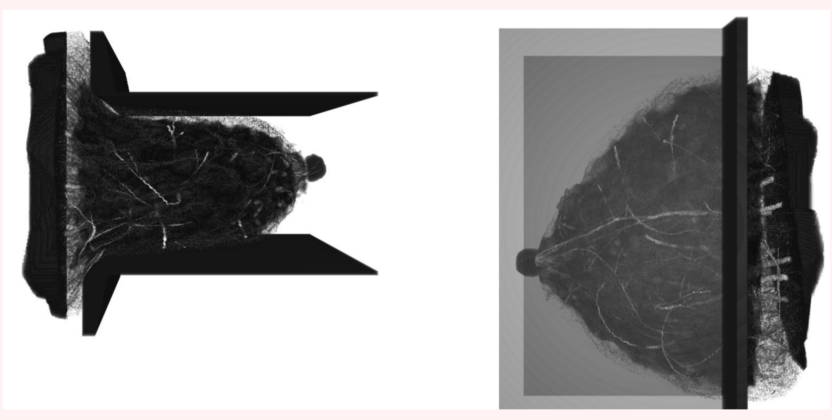

Figure 2: *Voxelized Phantom generated by VICTRE.*

Detector Model

The simulation model replicates a Siemens Mammomat Inspiration system. The detector, simulated as both a detailed real-detector (MCD) using amorphous selenium and a simplified virtual detector (VD), stores energy in each pixel, with the VD optimizing efficiency by avoiding internal interactions.

Image Formation

Image formation was achieved by reconstructing the deposited energy into pixel values. The process included converting deposited energy into charge, adding electronic noise, and applying blurring effects. Sensitivity curves were generated to align the simulated detector with real-world data.

Physics Assumptions

Several modifications and assumptions were made to optimize simulation time, such as assuming ideal beam collimators and ignoring fluorescence within the patient.

Verification and Validation

Key metrics such as Normalized Noise Power Spectrum (NNPS), Modulation Transfer Function (MTF), and Detective Quantum Efficiency (DQE) were calculated. Dose verification was performed using the AAPM TG-195 [4] phantom. The Mean Glandular Dose (MGD) was calculated directly, aligning with clinical standards.

Results

The results of our simulation model demonstrate the capability to replicate key metrics of digital mammography systems, including NNPS, MTF, and DQE, as well as the ability to generate realistic mammographic images using voxelized breast phantoms. Additionally, dose calculations were performed. Below, we summarize the key findings, including a brief summary of the dose data and simulated mammographic images.

NNPS, MTF and DQE

Key metrics such as NNPS, MTF, and DQE were evaluated according to the methods described by the International Electrotechnical Commission (IEC 62220-1-2:2007. The NNPS was derived from flat-field images using several regions of interest (ROIs), and the MTF from edge images using the slanted edge method. The DQE was obtained using the MTF and NNPS results, following IEC guidelines (see Eq.1).

$$DQE(f) = \frac{MTF(f)^2}{NNPS(f)} \times \frac{q}{N_0} \quad (1)$$

where q is the number of electrons per absorbed photon and N_0 is the number of incident photons per unit area.

The results were compared with the specifications published by the National Health Service (Technical report, NHSBSP Equipment Report 1306, version 2, 2015). Below is the DQE curve:

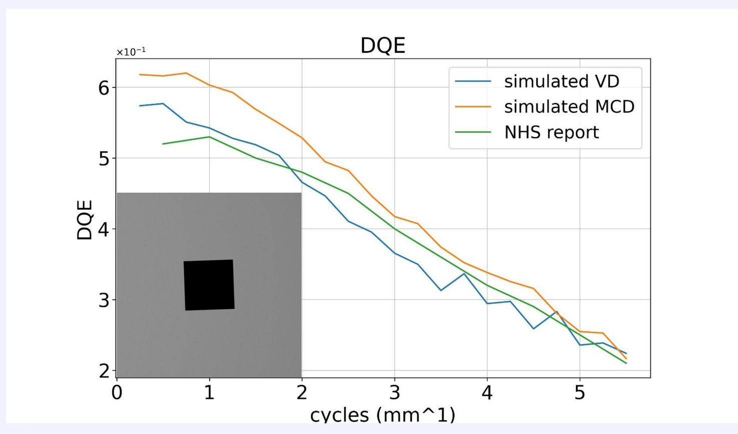

Figure 3: *DQE curve comparing the real and simulated detectors. Inset: Slanted-Edge image used.*

Dose Verification

To validate the accuracy of x-ray transport and interaction characteristics in our Monte Carlo simulation, we performed dose calculations using the AAPM TG-195 phantom [4] (Fig. 4).

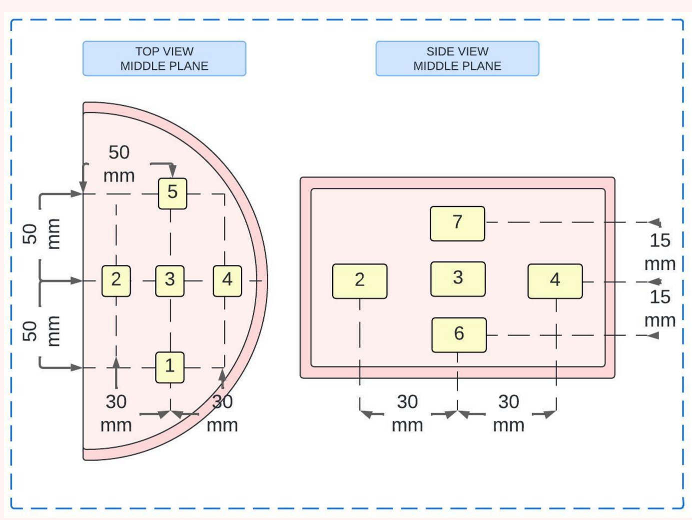

Figure 4: *AAPM TG-195 phantom diagram with the location of the VOIs.*

The dose was calculated at several key locations within the breast tissue and compared with the AAPM TG-195 report:

Location	Simulation (eV)	AAPM TG-195 report (eV)
Whole Breast	4685.5 ± 0.2	4700.46 ± 0.08
VOI 1	17.71±+ 0.02	17.782 ± 0.005
VOI 2	17.92 ± 0.02	17.993 ± 0.005
VOI 3	18.01 ± 0.02	18.074 ± 0.005
VOI 4	17.40 ± 0.02	17.550 ± 0.005
VOI 5	17.71 ± 0.02	17.787 ± 0.005
VOI 6	5.51 ± 0.01	5.573 ± 0.003
VOI 7	56.33 ± 0.04	56.29 ± 0.01

Table 1: *Energy deposited (eV) per initial photon with a monoenergetic point-source of 16.8 keV.*

Simulated Images

Simulations were performed using different voxelized realistic breast phantoms generated by VICTRE. The phantom parameters are summarized as follows:

Name	Fat Fraction	Compression Thickness (mm)	Resolution (mm)
Dense	0.40	35	0.1
Heterogeneous	0.66	45	0.1
Fatty	0.95	60	0.1

Below are example images generated from the simulations:

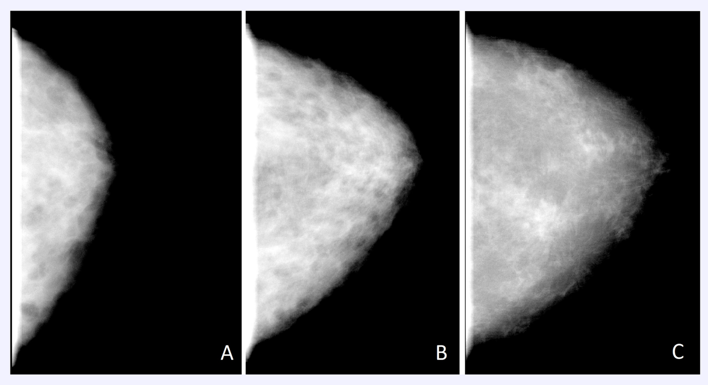

Figure 5: *Simulated mammographic images for voxelized breast phantoms: Dense, Heterogeneous, and Fatty.*

Discussion

Our comparative analysis indicates that the MTF for both the virtual and realistic detector models closely matches the MTF of an actual mammography system, as reported by the NHS.

The NNPS results show consistent trends across both simulated and actual detectors. The DQE results are similarly aligned with NHS measurements. This suggests that our simulated models replicate real-world detector characteristics.

Validation against AAPM TG-195 reference values has further confirmed the accuracy of our simulation framework.

Overall, our GAMOS-based simulation framework successfully replicates the performance standards of real-world mammography systems.

Conclusions

- This study validates a GAMOS-based simulation model using GEANT4, showing its accuracy in replicating mammographic imaging.
- The model aligns well with NHS data, proving its effectiveness in generating high-fidelity images of breast phantoms, which is crucial for developing advanced diagnostic tools.
- The model's application extends to virtual clinical trials, offering a reliable platform for accelerating the development of new mammographic technologies and AI-based methods.
- In summary, this work lays a strong foundation for future digital mammography research, supporting the advancement of virtual clinical trials in breast cancer detection.

Reference

[1] Christian G. Graff. A new, open-source, multimodality digital breast phantom. In Despina Kontos and Thomas G. Flohr, editors, *Medical Imaging 2016: Physics of Medical Imaging*, volume 9783, page 978309. International Society for Optics and Photonics, SPIE, 2016.

[2] S. Agostinelli et al. Geant4—a simulation toolkit. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 506(3):250–303, 2003.

[3] Pedro Arce et al. Gamos: A framework to do geant4 simulations in different physics fields with an user-friendly interface. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 735:304–313, 2014.

[4] Ioannis Sechopoulos et al. Monte carlo reference data sets for imaging research: Executive summary of the report of aapm research committee task group 195. *Medical Physics*, 42(10):5679–5691, 2015.