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Monte Carlo simulations for X-ray breast dosimetry using homogeneous and heterogeneous phantoms

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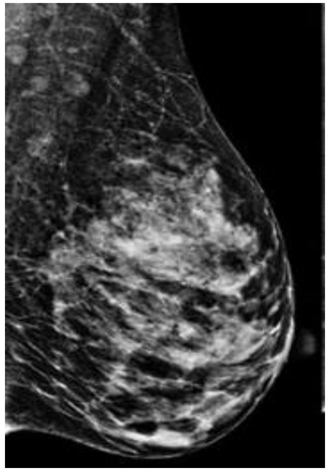
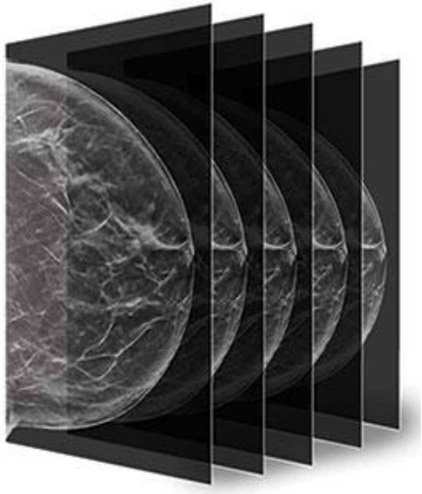
Breast imaging techniques

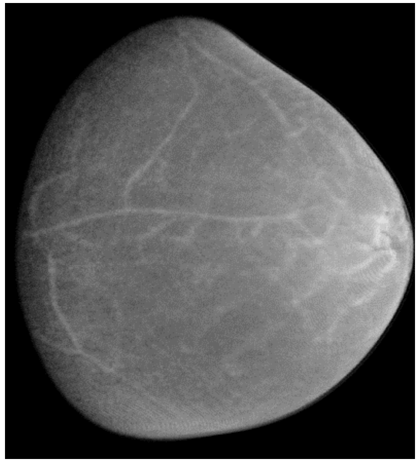
Digital Mammography (DM)



Digital Breast Tomosynthesis (DBT)

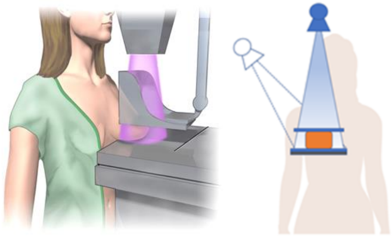


Breast Computed Tomography (bCT)

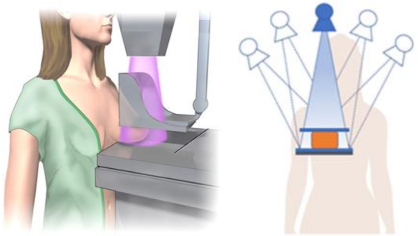


Evolution of breast imaging techniques

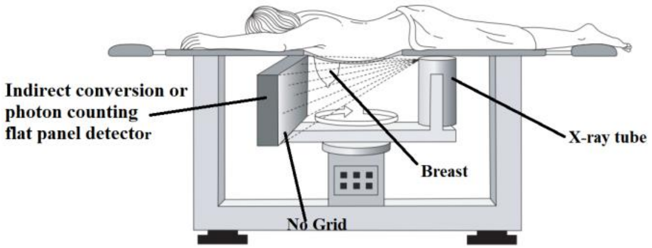
2D



pseudo-3D



3D



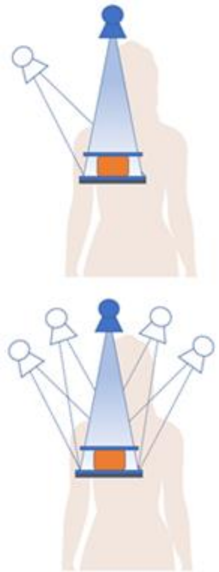
DM and DBT provide radiographic images of the compressed breast. In the first case two images for each breast are acquired (CC and MLO views), while in DBT the X-ray tube moves in an arc over the compressed breast and multiple projections are acquired and then reconstructed by a computer, forming pseudo-three-dimensional images.

In bCT the uncompressed breast hangs at the scanner isocenter in pendant geometry and the gantry rotates over 360 degrees around a vertical axis of rotation

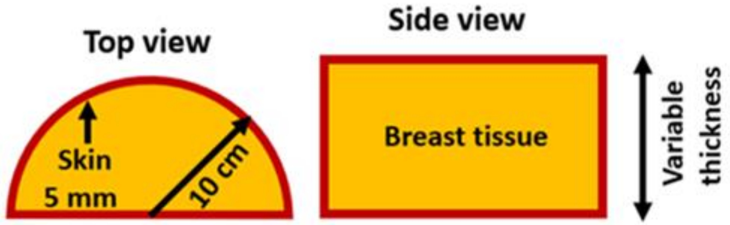
Tucciariello et al (2019). Monte Carlo Methods to evaluate the Mean Glandular Dose in Mammography and Digital Breast Tomosynthesis. In book: *Monte Carlo Methods*. *Nova Science Publishers*

Digital breast phantoms for dosimetry in MC simulations

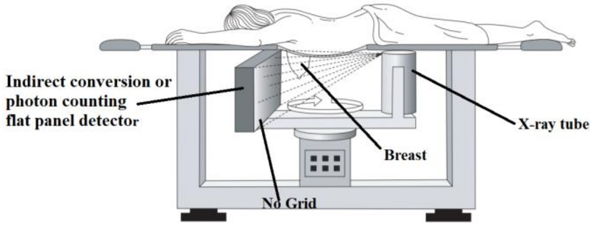
DM

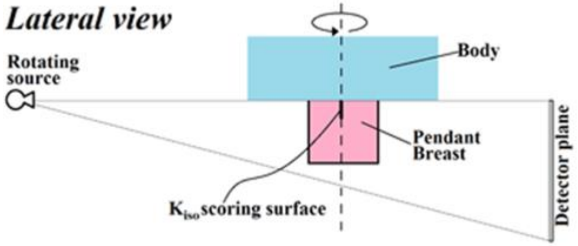


DBT



bCT





Elemental composition and density for glandular and adipose tissues.

Tissue	H	C	N	O	P	density (g/cm^3)
glandular	0.102	0.184	0.032	0.677	0.005	1.04
adipose	0.112	0.619	0.017	0.251	0.001	0.93

In Monte Carlo (MC) models, the breast digital phantom is modelled as a semi-cylinder with an outer layer of skin made by adipose tissue while the inner part is a **homogeneous mixture of adipose and glandular tissues**. Glandularities ranging from 0 to 100% are composed by mixing properly glandular and adipose tissues.
The glandular tissue is the radiosensitive tissue in the breast. Thus, Mean Glandular Dose (MGD) is the parameter used to assess dose delivered to the gland.

Tucciariello et al (2019). Monte Carlo Methods to evaluate the Mean Glandular Dose in Mammography and Digital Breast Tomosynthesis. In book: *Monte Carlo Methods. Nova Science Publishers*
Sarno et al. (2018). Normalized glandular dose coefficients in mammography, digital breast tomosynthesis and dedicated breast CT. *Phys Med. 2018 Nov;55:142-148.*

Dose assessment in MC simulations for dosimetry

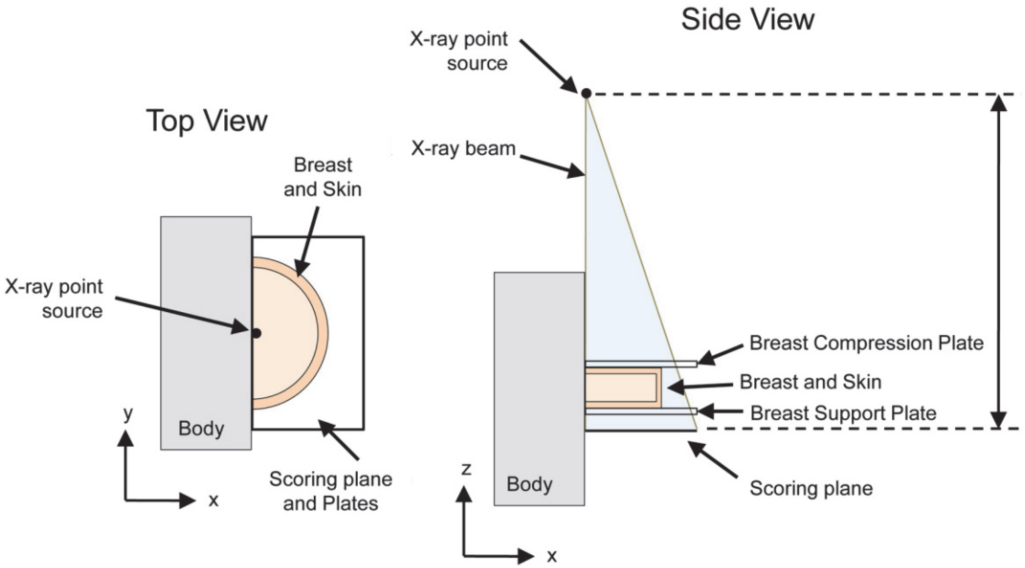
Mean Glandular Dose (MGD) = DgN · K

Where DgN coefficients are calculated via MC simulations and K is the incident air kerma on the breast surface

$$MGD\ [mGy] = \frac{G \cdot energyDeposited \cdot 1.6 \cdot 10^{-13}}{mass}$$

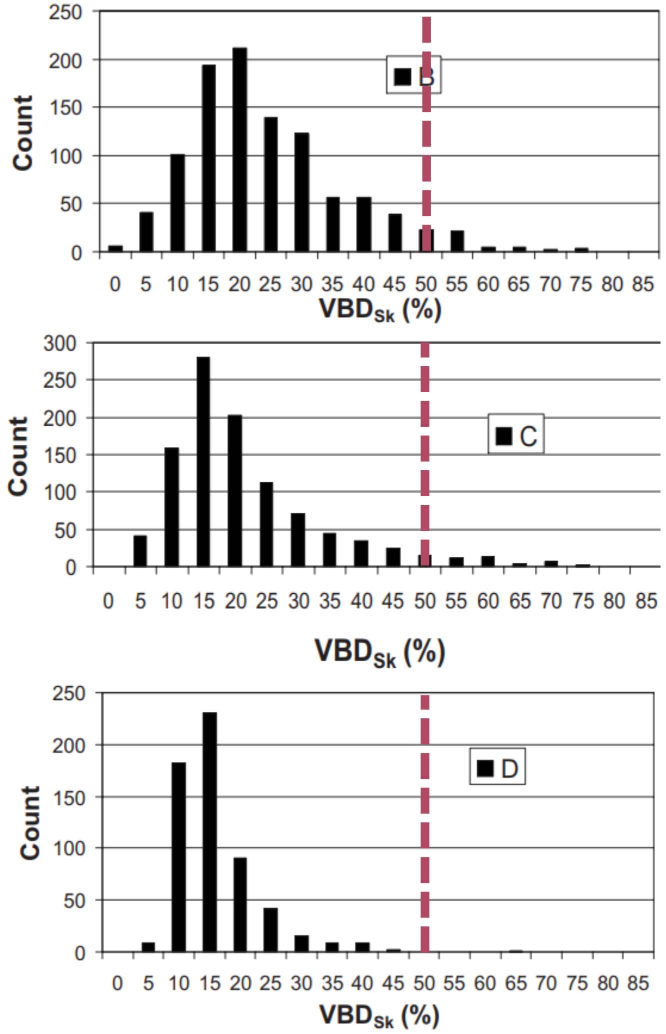
$$G = \frac{f_g\left(\frac{\mu_{en}}{\rho}(E)\right)_{glandular}}{f_g\left(\frac{\mu_{en}}{\rho}(E)\right)_{glandular} + (1-f_g)\left(\frac{\mu_{en}}{\rho}(E)\right)_{adipose}}$$

$$K\ [mGy] = \sum_i \frac{1.6 \cdot 10^{-13}\left(\frac{\mu_{en}}{\rho}(E_i)\right)_{air} \cdot E_i}{S\cos\vartheta_i}$$



Since MGD is not a physical quantity, it can't be measured directly after a X-ray examination but, as mentioned before, can be assessed by the use of dedicated conversion factors established with MC simulations, in which energy deposited to the breast from all the simulated photon can be scored and registered. This kind of approach is made possible thanks to certain geometry assumptions that depend on breast characteristics and allow to digitally reproduce a breast phantom model

Literature updates based in bCT



Medical Physics
The International Journal of Medical Physics Research and Practice

The myth of the 50-50 breast

M. J. Yaffe, J. M. Boone, N. Packard, O. Alonzo-Proulx, S.-Y. Huang, C. L. Peressotti, A. Al-Mayah, and K. Brock

2831 bCT patient exams have been analyzed and the Volume Breast Density (VBD) has been evaluated. **The mean VBD was found to be 14.3%** by volume with a standard deviation of 10.3% with skin excluded.

TABLE I. Characteristics of the four groups for whom density was measured. For each group the mean and standard deviation ( ) of VBD are given both for the "skin-included" and "skin-excluded" conditions. The difference between these means, the mean compressed breast thickness and the mean total breast volumes are also given.

Group	N	Mean age (Range)	Mean breast volume (cm^3)	VBD$_{Sk}$ (%) (σ)	VBD$_{NSk}$ (%) (σ)	ΔVBD (%)	Mean compressed thickness (mm) (σ)
A	191	53.8 (35–82)	769	25.6(12.6)	14.3(10.3)	11.3	N/A
B	1029	N/A	512	21.7(12.8)	16.8(11.5)	4.9	56(19)
C	1020	59.2 (40–85)	720	18.9(12.3)	14.2(11.1)	4.7	57(14)
D	591	61.4 (50–76)	755	13.7(7.5)	9.9(6.7)	3.8	65(11)
All groups	2831			19.3(12.1)	14.3(10.7)	5.0	

Literature updates based in bCT

The
Shih
K. Li

…mong 219 bCT data sets, the volume glandular …action VGF was examined in coronal and sagittal …anes of the breast, and the radial distribution of …east glandular fraction within a coronal bCT image …as examined for three breast regions.

Breast dose in mammography is about 30% lower when realistic heterogeneous glandular distributions are considered

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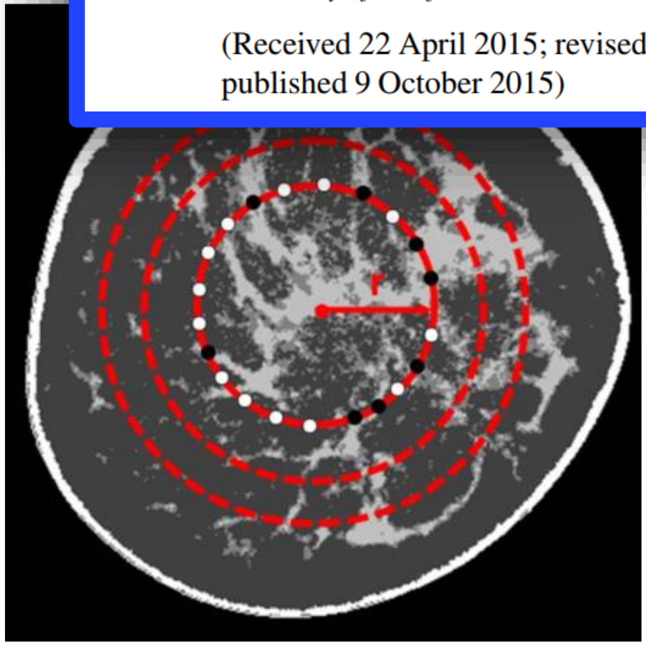
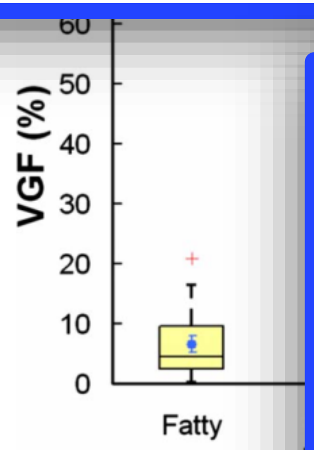
(Received 22 April 2015; revised 11 August 2015; accepted for publication 15 September 2015; published 9 October 2015)





Eur J Radiol. 2020 Aug 12;131:109216. doi: 10.1016/j.ejrad.2020.109216. Online ahead of print.

Mammography dose estimates do not reflect any specific patient's breast dose

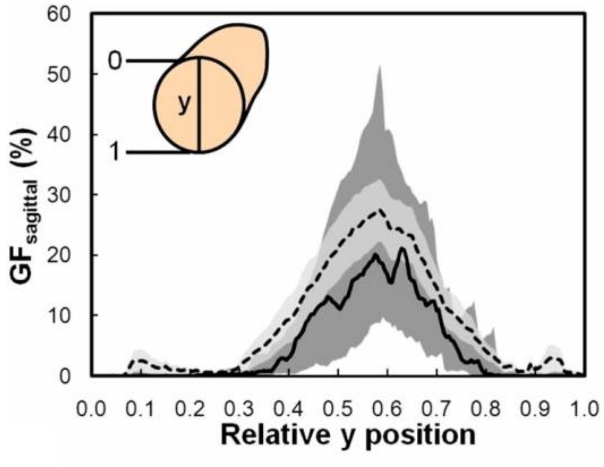
Ioannis Sechopoulos [1], John M Boone [2], David Dance [3], Ruben van Engen [4], Paolo Russo [5], Kenneth C Young [6]

Affiliations + expand

PMID: 32810700 DOI: 10.1016/j.ejrad.2020.109216

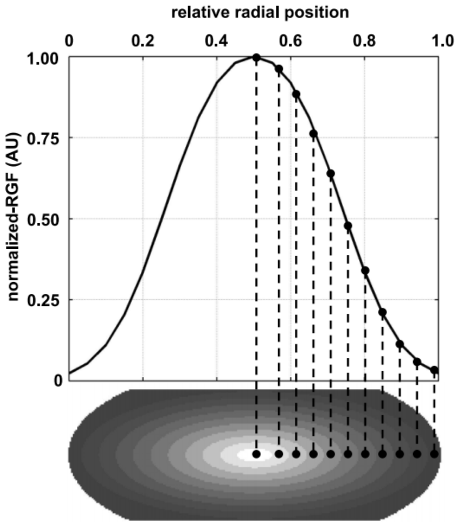
Heterogeneous digital breast phantom for MC dosimetry

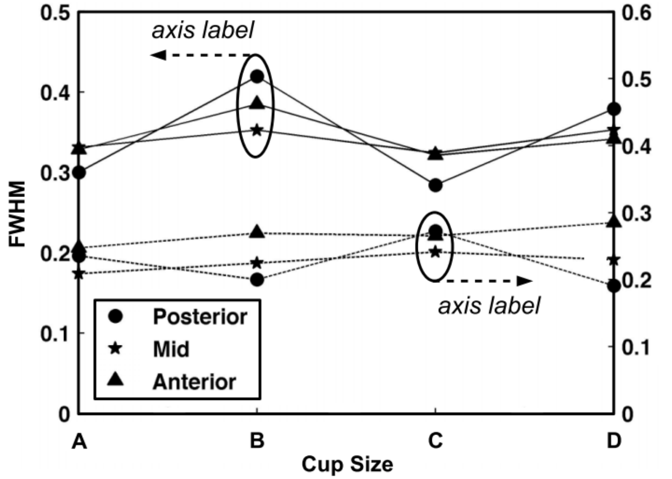
GEANT4 A SIMULATION TOOLKIT

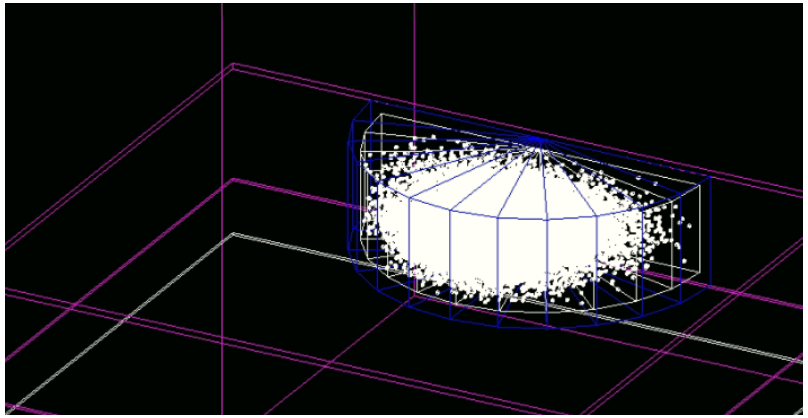


(Huang, 2009)

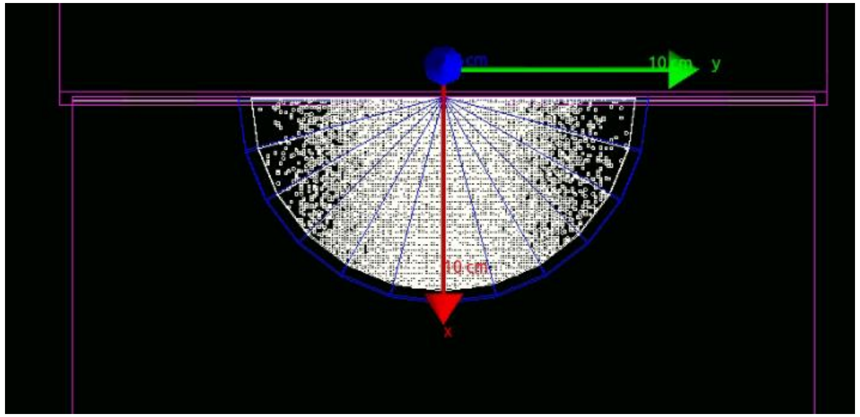
(Hernandez, 2015)



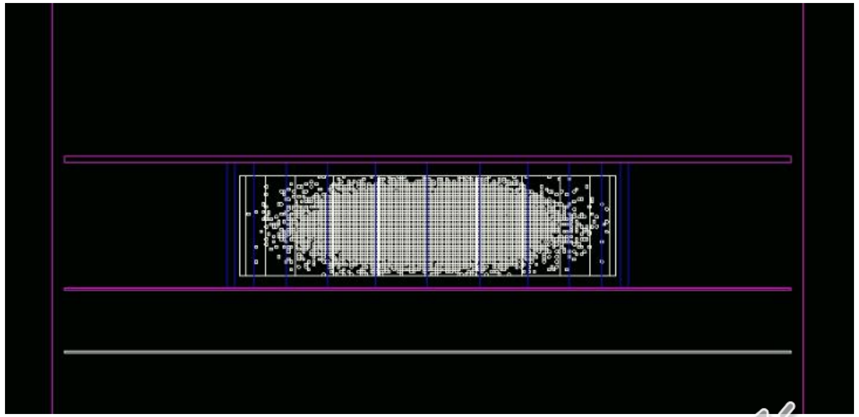




Perspective view



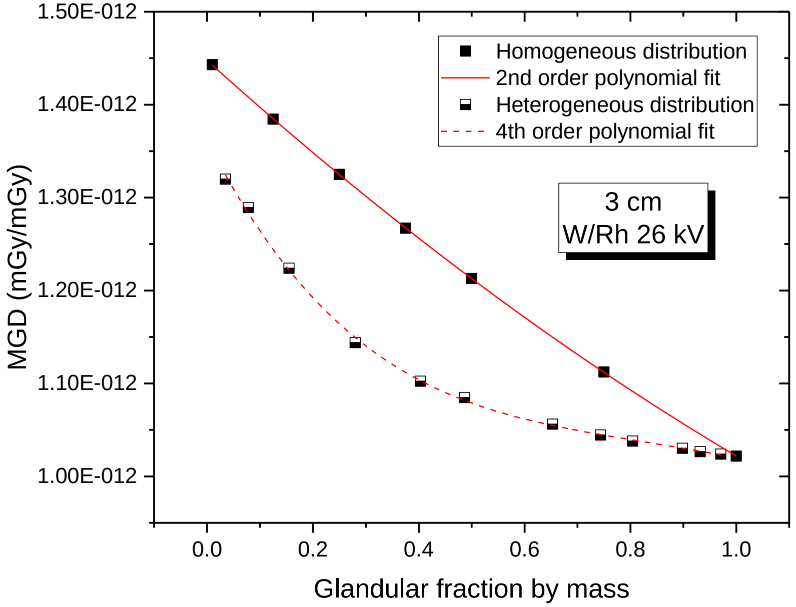
Top view

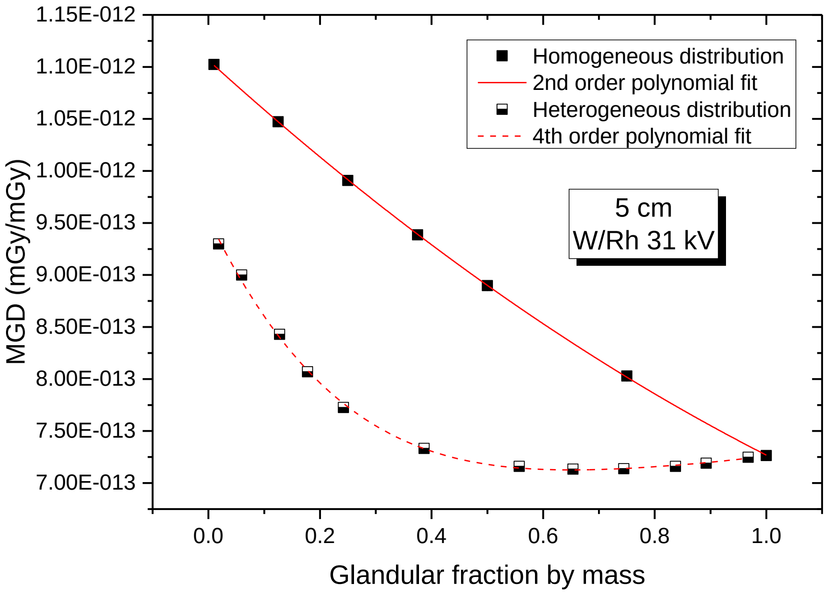


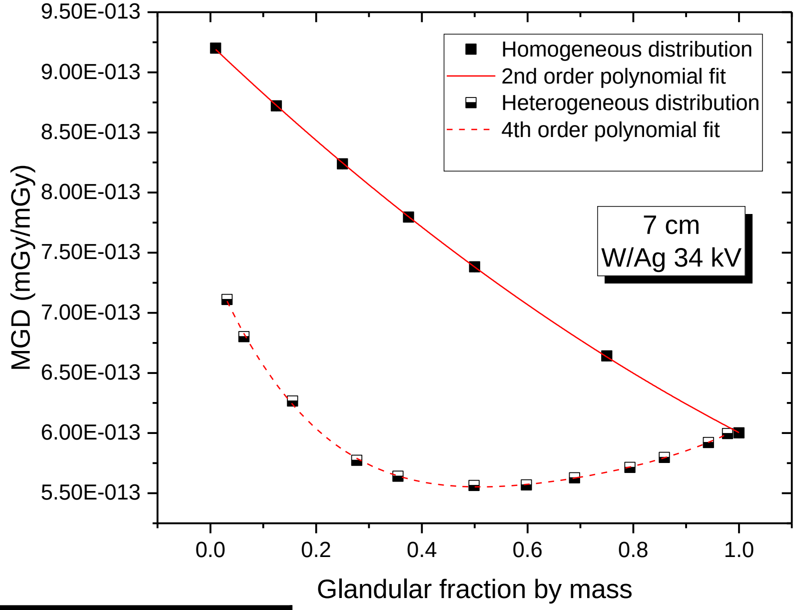
Front view

Huang et al. (2011). The characterization of breast anatomical metrics using dedicated breast CT. Medical Physics 38, 2180.
Hernandez et al. (2015). Breast dose in mammography is about 30% lower when realistic heterogeneous glandular distributions are considered. Medical Physics 42 (11).

Dose assessment using homogeneous and heterogeneous breast models







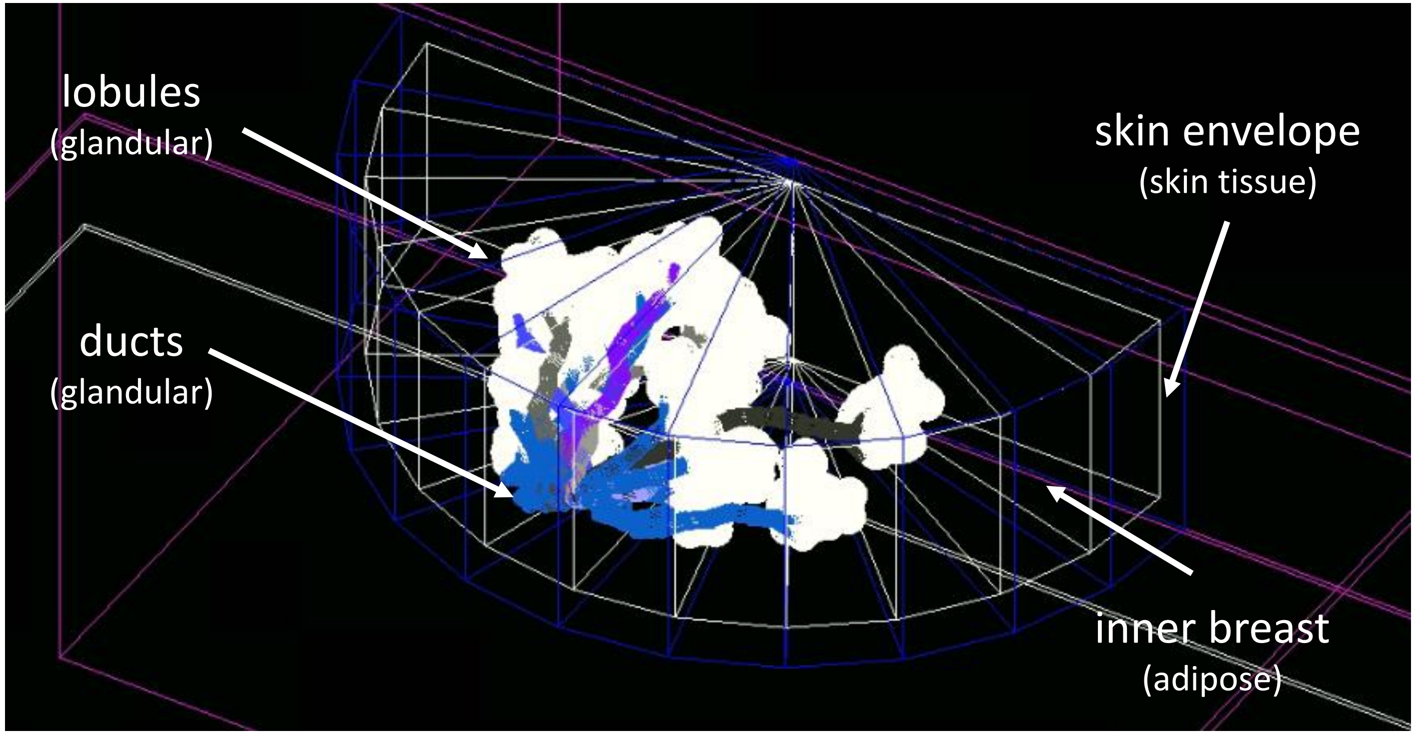
Hologic Selenia Dimensions DM investigation

	3 cm		5 cm		7 cm	
#	glandularity (normalized)	variation (%)	glandularity (normalized)	variation (%)	glandularity (normalized)	variation (%)
1	0.03	**-8.3%**	0.02	**-18.0%**	0.03	**-28.0%**
2	0.08	**-9.2%**	0.06	**-19.7%**	0.06	**-31.9%**
3	0.16	**-11.9%**	0.13	**-24.1%**	0.16	**-37.3%**
4	0.28	**-14.6%**	0.18	**-26.8%**	0.28	**-41.1%**
5	0.40	**-13.8%**	0.24	**-28.8%**	0.35	**-39.5%**
6	0.49	**-12.3%**	0.39	**-27.4%**	0.50	**-32.7%**
7	0.65	**-8.9%**	0.56	**-21.3%**	0.60	**-27.0%**
8	0.74	**-6.7%**	0.65	**-17.0%**	0.69	**-20.9%**
9	0.80	**-5.2%**	0.74	**-12.6%**	0.79	**-14.0%**
10	0.90	**-2.6%**	0.84	**-8.1%**	0.86	**-9.4%**
11	0.93	**-1.8%**	0.89	**-5.3%**	0.94	**-3.7%**
12	0.97	**-0.8%**	0.97	**-1.5%**	0.98	**-1.0%**

Heterogeneous breast phantom: a new geometry approach

A new heterogeneous breast model is proposed, which represents the gland tree inside the breast. The MC code provides various parameters which allow to modify the ducts geometry for reproducing different breast thicknesses and glandularities.

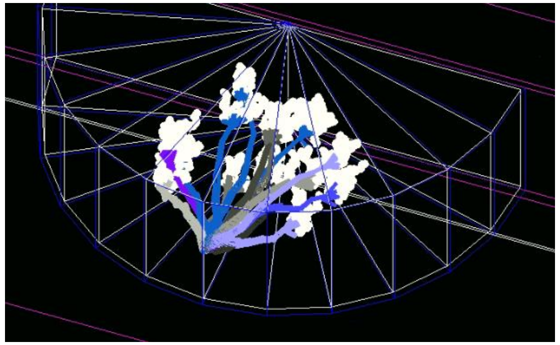
- Glandular ducts made by consecutive tubs starting from the nipple and developing towards the chest (10-30 ducts, glandular tissue).
- Each glandular duct end with a lobule, made by spheres. The amount of spheres can be changed in order to change the amount of glandular tissue (glandular).
- The remaining part of the breast is composed by adipose tissue



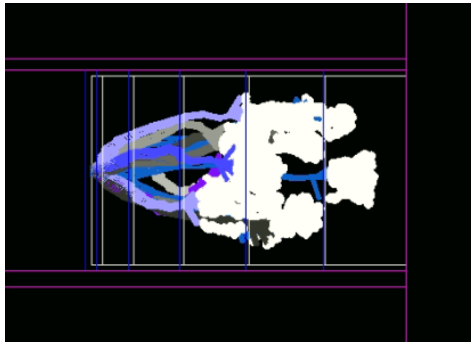
Heterogeneous breast phantom: a new geometry approach

Due to computational issues low glandularities can be performed. Simulations show remarkable fluctuations on dose estimates due to the different glandular trees between phantom models.

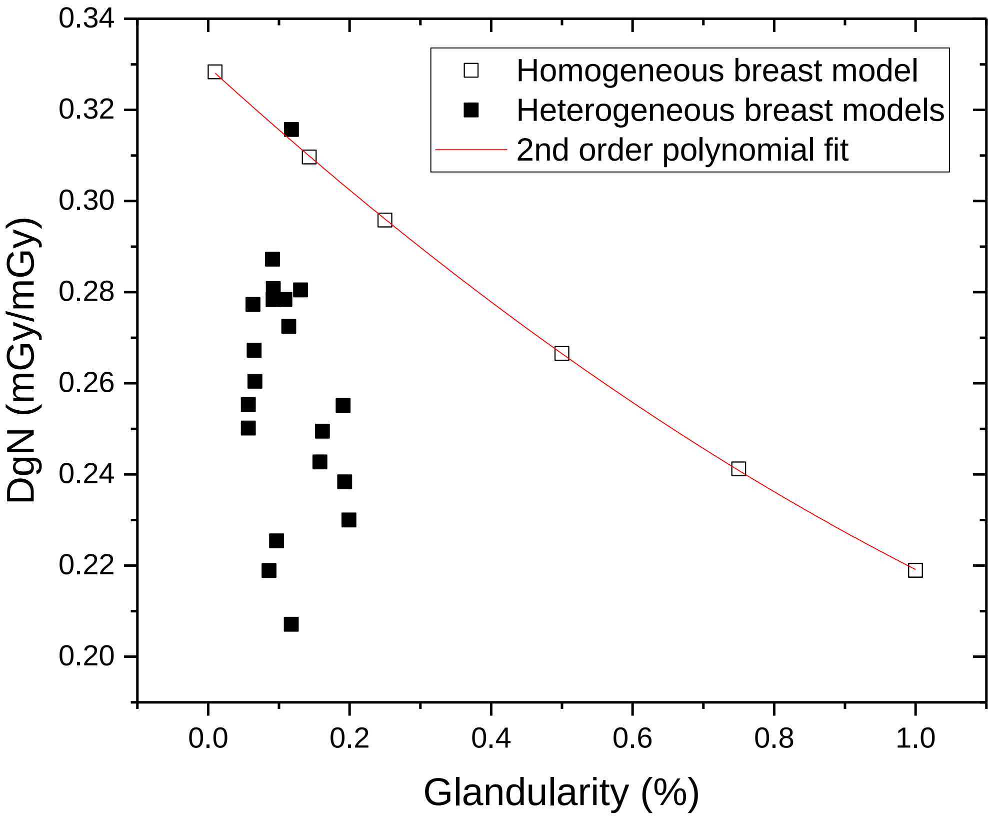
The non-symmetry of the gland tree (especially on the vertical direction) thus generates dose fluctuations on different models even with a similar glandularity.



perspective view



lateral view



Discussion

- X-ray dosimetry for mammography and tomosynthesis is performed with MC calculations using homogeneous breast phantoms. Digital phantoms are composed with a homogeneous mixture of adipose and glandular tissues for glandularities ranging from 0 to 100%.

- The advent on the breast CT, a new breast imaging technique, let to perform quantitative analysis on the breast tissue. The amount of glandular tissue and its spatial distribution have been evaluated, showing a non-uniform distribution of the gland and a lower mean glandularity.

- The purpose of our study is to reproduce a digital breast phantom based on the new literature updates and to compute dose estimates using MC calculations.

- Preliminary results using our method show a significant deviation of dose estimates from those obtained using homogeneous phantoms. Voxelized phantoms, respect to those obtained with mathematical solids, appear to be the optimal solution for reproducibility and for producing high-glandularity phantoms.

R.M. Tucciariello, P. Barca, D. Del Sarto, R. Lamastra, A.C. Traino, M.E. Fantacci

THANK YOU FOR YOUR ATTENTION!

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FONDAZIONE PISA

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