EUROPEAN SYNCHROTRON RADIATION FACILITY

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Experiment Report Form

ESRF	**Experiment title:** Validation of complete software platform for phase-contrast breast tomosynthesis	**Experiment number**: LS-2537
Beamline:	**Date of experiment**: from: 23/02/2017 to: 27/02/2017	**Date of report**:
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Report:

The purpose of the experiment was to test, optimise and validate the accuracy of the newly developed software platform for simulation of phase-contrast (PhC) tomosynthesis images. Specifically, three main goals were set: **1. Study the properties of the available 3D printing materials; 2. Acquire images in phase contrast tomosynthesis and CT by using the in-house developed realistic breast phantoms; 3. Acquire images in tomosynthesis and CT mode of biological samples for testing reconstruction algorithms.**

Task 1. Study the properties of the available 3D printing materials

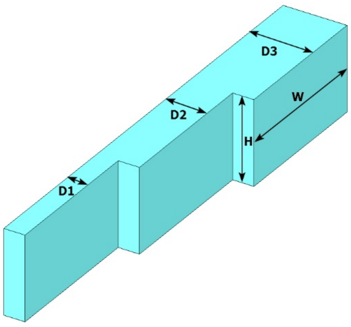
Twenty one materials were evaluated in Task 1 and listed in Table 1. Seventeen of them are used in the 3D printing technology. The selection of those materials is determined by the fact that they are commonly used, relatively easy to fabricate and inexpensive. Specifically, the first seven materials (ABS, Brick, Hybrid, Nylon, PET-G, PLA and PVA) are thermoplastic polymers used by Fused Deposition Modelling (FDM) printing technology. They are available in the form of wire spool. Materials 8-17 (Black, Clear, Flex, Grey, NDBase, NDC+B, NDCast, NDSG, Tough, White) are polymer resins in a liquid form, and are used with Stereolithography (SLA) technology. They have different properties and are used in diverse applications, such as dental medicine, aerospace, optical prototyping, etc.

Table 1. List of materials used in Task 1.

Number	Substitute	Abbreviation	Printing technology	Density/SE g cm^{-3}
1	ABS[1]	Acrylonitrile Butadiene Styrene	FDM	1.019±0.002
2	Brick[1]	-	FDM	1.232±0.003
3	Hybrid[1]	-	FDM	1.227±0.003
4	Nylon[1]	-	FDM	1.111±0.002
5	PET-G[1]	Polyethylene terephthalate glycol-modified	FDM	1.236±0.003
6	PLA[1]	Polylactic Acid	FDM	1.251±0.003
7	PVA[2]	Polyvinyl Alcohol	FDM	1.097±0.013*
8	Black[2]	-	SLA	1.183±0.002
9	Clear[2]	-	SLA	1.180±0.002
10	Flex[2]	-	SLA	1.137±0.003
11	Gray[2]	-	SLA	1.175±0.002
12	NDBase[3]	-	SLA	1.190±0.004
13	NDC+B[3]	-	SLA	1.194±0.004
14	NDCast[3]	-	SLA	1.206±0.004
15	NDSG[3]	-	SLA	1.190±0.004
16	Tough[2]	-	SLA	1.181±0.003
17	White[2]	-	SLA	1.178±0.002
18	Paraffin			0.907±0.002
19	Double Silicon[4]			1.152±0.002
20	PMMA	Polymethyl methacrylate		1.193±0.001
21	Gelatine			-

[1]https://www.lpfrg.com/en/filament/
[2]https://formlabs.com/materials/
[3]http://nextdent.com/products/base/
[4]http://en.zhermack.com/Technical/Silicones/Duplication/C400820.kl
* measured with a gauge

Three types of step wedge phantoms (scale S, M and L) were manufactured with three 3D printers: Leapfrog Creator Dual, Form1+ and RapidShape D30 (Figure 1a). The dimensions of the step wedge phantoms are specified in the Figure 1b.

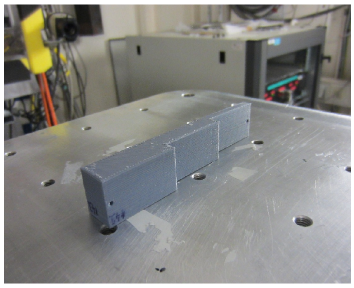


(a)

Dimensions of the three step wedge phantoms.

Parameters	**Step 1**	**Step 2**	**Step 3**
Thickness D, mm	2	4	6
	5	10	15
	20	30	40
Height H, mm		20	
Width W, mm		20-35	

(b)



(c)

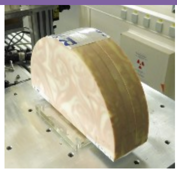
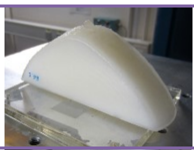
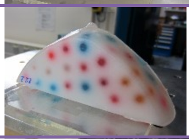
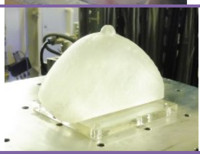
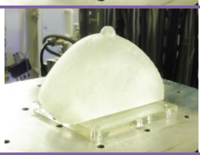
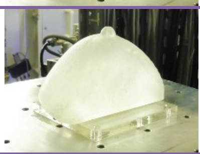
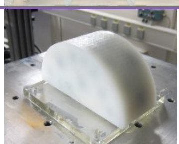
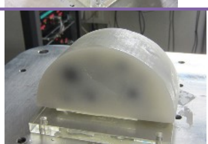
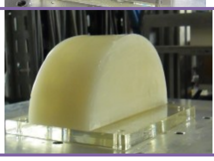
Figure 1. Step-wedges used in the study: (a) step-wedge phantom design, (b) dimensions of the step-wedges, (c) measurements with the printed step-wedge phantom from tough resin.

The linear attenuation coefficients of the investigated materials were determined from measurements at ID17, as shown in Figure 1c. The beam width and height, defined by a slit system placed in front of the sample, were 100 mm and 7 mm, correspondingly. Three photon energies of the incident beam were used – 30 keV, 45 keV, and 60 keV. The values were selected to be interest for phase contrast breast imaging but also to assure stability of energy and the photon flux at the beamline. All images from this experiment were processed and evaluated. Results are ready to be submitted in March 2018 to *Phys Med Biol* [1].

Task 2. Acquire images in phase contrast tomosynthesis and CT by using the in-house developed realistic breast phantoms.

This Task included 12 breast phantoms, summarised in Table 2. A 60keV incident energy was used.

Table 2. Custom manufactured phantoms used in Task 2.

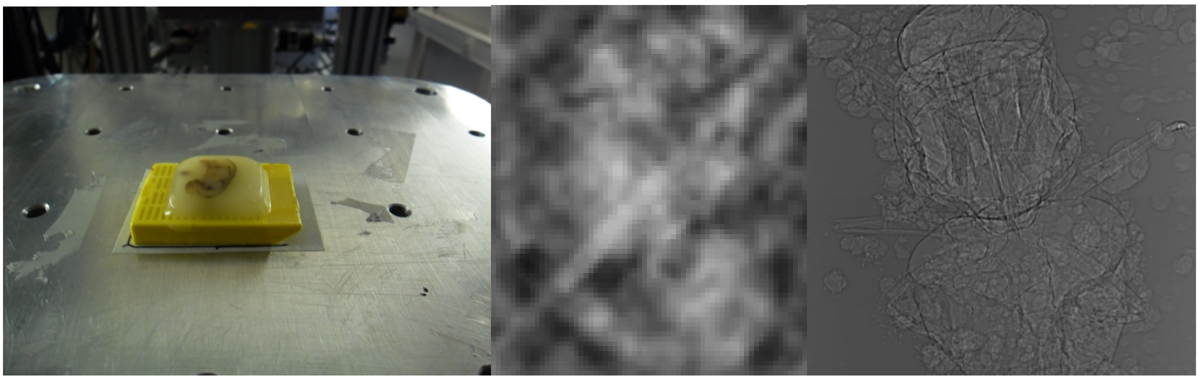
Breast phantom	Picture	Materials used	Thickness, mm
Phantom 1 **BR3D** **http://www.cirsinc.com/products/all/51/br3d-breast-imaging-phantom/**		Epoxy resins	50
Phantom 2 **Breast 5 fat**		External shape – clear resin Filled material – animal fat	31(1.7 wall thickness)
Phantom 3 **Breast 5 paraffin**		External shape – clear resin Filled material – paraffin	31(1.7 wall thickness)
Phantom 4 **Breast 5 water balls**		External shape – clear resin Filled material – water balls and animal fat	31(1.7 wall thickness)
Phantom5 **Breast 7 fat**		External shape – grey resin Filled material – animal fat	49(2.4 wall thickness)
Phantom6 **Breast 7 paraffin**		External shape – grey resin Filled material – paraffin	49(2.4 wall thickness)
Phantom 7 **Breast 7 water**		External shape – clear resin Filled material – water	49(2.4 wall thickness)
Phantom8 **CIRS**		http://www.cirsinc.com/products/modality/6/tissue-equivalent-phantom-for-mammography/	45
Phantom 9 **LUCMFR1**		PMMA spheres in a PMMA container filled with water	50
Phantom 10 **Semi Cyl GreyBalls paraffin**		External shape – white resin Filled material – grey resin balls and paraffin	43(3 wall thickness)
Phantom11 **Semi Cyl GreyBalls fat**		External shape – white resin Filled material – grey resin balls and fat	43(3 wall thickness)
Phantom 12 **Semi Cyl compartments fat**		External shape – white resin Filled material – clear resin compartments and paraffin	43(3 wall thickness)

The detector was a tapered optics FReLoN 2k CCD camera, a fast readout and low noise charge coupled device with a pixel size of 47 μm and a field-of-view 95 mm × 95 mm. The detector was placed at a distance

of 11 m downstream below of the end surface of the phantoms. The detector was placed on a fixed platform and the phantoms were mounted horizontally on a motorized scanning translation stage that could also rotate around a vertical axis and translate vertically. Images for tomosynthesis were obtained by the following setup. Each phantom was scanned by rotating the phantom stage in a full arc of 180^0 and projection views were recorded every 1^0. From the whole set of 180 images, for tomosynthesis we used 26 projection images were used for tomosynthesis in an arc from 65^0 to 115^0, where 90^0 is the direction normal to a face of the phantom slab.
First results will be reported at the ECMP conference, Copenhagen in August 2018[2].

3. Acquire images in tomosynthesis and CT mode of biological samples for testing algorithms.

Thirteen histology samples with breast cancer fixed in paraffin and one 4cm paraffin block with a fixed inside fly were scanned in both tomosynthesis and CT mode with the PCO camera. Results are under evaluation. Figure 2 shows the measurements with the breast sample, and the comparison between images of a fly fixed in a 4cm paraffin block obtained at clinical mammography system and ID17. Part of them were included in the new proposal submitted in July 2017 for national research funding FNI2018. The project led by K Bliznakova is entitled "*Advanced technologies for cancer screening and diagnosis based on phase-contrast imaging technique*" scored 99 out of 100 points and received funding for the next three years 2018-2020 (H-17/45).



(a) (b) (c)

Figure 2. Acquiring images from biological samples: (a) histology sample. Comparison between x-ray images of a fly fixed in paraffin and imaged at (a) clinical mammography imaging and (b) at ID17.

References:

[1] D Ivanov, K Bliznakova, I Buliev, G Mettivier, P Russo, J Vignero, H Bosmans, P Popov, Alberto Bravin, Z Bliznakov "**Suitability of low density materials for 3D printing of physical breast phantoms**", to be submitted in Phys Med Biol
Abstract:
Breast physical phantoms are a basic tool for the assessment and verification of performance standards in daily clinical practice of x-ray breast imaging modalities. Another important application of theirs is for testing and evaluation of new x-ray breast modalities to be potentially established, e.g. Breast Computed Tomography, dual-energy breast CT and phase contrast mammography and tomography. Nowadays, there are no or there are a limited number of breast physical phantoms available for this purpose. In particular, for the case of phase contrast imaging, there are no suitable physical phantoms to mimic the refractive properties of the real breast tissue.
The aim of this study is to explore available low-cost 3D printing technologies and available range of materials such as resins, polylactic acid, nylon, acrylonitrile butadiene styrene, etc., to determine their attenuation and refractive properties and to compare them to the properties of the breast tissues: adipose, glandular tissue, lesions and skin.
To achieve that, three dedicated step wedge phantoms were computationally modelled. Each phantom consists of 3 steps with a rectangular area of 20mm x 35mm. Thus, total of 9 steps of different thickness ranging from 2mm to 40mm were available. Physical objects were then produced from the models using stereolithographic (SLA) and fused-deposition modelling (FDM) technologies. A total of 17 plastic printing

materials – 7 for FDM (ABS, PLA, PVA, Nylon, Brick, Hybrid and PET-G) and another 10 resin materials used with SLA were studied. PMMA, paraffin and double silicon were also included for comparison purposes.

The absorption and the phase characteristics of the materials were evaluated at ID17, ESRF, Grenoble for energies between 30keV and 60keV. For lower energies, the properties were evaluated at GE Senographe mammography system. X-ray images were acquired with and without the phantoms and further processed to obtain logarithmic attenuation maps and then, the energy-dependent linear attenuation coefficient of these materials. Comparison with theoretical data for glandular, adipose and skin tissues as well as for PMMA was also performed. The refractive index decrement δ of the examined materials was evaluated as percentage difference from that of reference materials. The refractive index for selected materials was additionally calculated and compared to theoretical data.

From the studied materials, most of the resins, the nylon and the gelatine show absorption properties close to the absorption properties of the glandular tissue, while ABS and PLA show absorption characteristics close to these of the adipose tissue and the skin. The refractive indexes of these materials - Flex, Grey, Clear, ABS and PLA however differ from the reference materials (gland, adipose and skin) up to 30%.

These results are useful in the design and production of a new physical phantom of the breast with anatomical and radiological characteristics and in particular a new anthropomorphic phantom.

2. K Bliznakova *et al* "**Computer-Based Platform for Phase Contrast Breast Imaging**", ECMP 2018, 21-23, Copenhagen

Abstract:

Purpose: *This paper presents a complete and validated computer-based system dedicated to x-ray phase contrast breast imaging research. The system comprises three main modules: (a) a module for generation of computational breast models, (b) a module for generation of phase-contrast x-ray images from computational phantoms in 2D and 3D acquisition setup, and (c) a module for image reconstruction.*

Methods: *The module for computational breast models is based on the BreastSimulator tool, used to generate breast models of various sizes and to compress them to a desired thickness. The module for the generation of phase-contrast images is used to model the image acquisition geometry and formation of x-ray images. The image reconstruction is done with a software tool, based on an in-house built reconstruction techniques class library, which is a dedicated object-oriented library for x-ray based applications.*

The capability of this system to correctly calculate phase-contrast tomographic images was tested by comparing simulated versus experimental images obtained from anthropomorphic breast phantoms. Three anthropomorphic computational breast phantoms were designed from white and grey resin by using the available stereolithography 3D printer. Experimental projection images were acquired and simulated images were generated, considering a breast tomosynthesis setup. Experiments were conducted at beamline ID17, ESRF. Simulations replicated the experimental setup. Images in a tomosynthesis mode were generated and tomograms were calculated by using the reconstruction module.

Results*: Results show very good visual agreement between simulated and experimentally obtained tomosynthesis images. In addition, selected tomosynthesis images from the physical and computational breast phantoms were quantitatively evaluated for set of imaging parameters such as skewness, kurtosis, the power-law exponent, β, of the power spectrum and fractal dimension. Analysis and the comparison of these parameters between simulated and experimental images also show a very good coincidence.*

Conclusions: *The platform is currently used in the process of development of a dedicated breast phantom for phase contrast imaging techniques. The system will be a valuable tool in studying new x-ray imaging techniques based on phase contrast, such as phase contrast tomosynthesis and CT.*