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STUDY OF MATERIALS FOR THE CONSTRUCTION OF PHANTOMS FOR RADIODIAGNOSTIC TESTS

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ABSTRACT

In this study were analyzed different polymeric materials and composites that have X-ray absorption characteristics similar to the human tissues. These materials will be used to develop phantoms for radiodiagnostic tests. The development of phantoms using these materials is important in dosimetry studies, image quality evaluation and optimization of radiodiagnostic acquisition protocols. The X-ray absorption was measures using the Hounsfield scale (HU) obtained by CT image, and these values were compared with typical values of human tissues. The homogeneity of the materials was done through the noise analysis of CT images. The test cylinders are 2.5 cm in diameter and 2.5 cm long and were constructed from solid water, Polyethylene, high and low viscosity polyester resin, ethylene-vinyl acetate (EVA) and others additional components. The cylinders were placed in a polymethyl methacrylate (PMMA) head phantom and the images were generated using a head CT protocol. The scans were performed on a General Electric CT scanner with 64 channels. The scanner was programmed in helical mode with image acquisition parameters and was performed using 120 kV, 100 mA.s and 1 cm of slice thickness reconstruction. The tested mixtures were found in the range of soft tissues and lungs. By making different mixtures of materials, it is possible to build different equivalent human tissues. The noise percentages found in the CT images are within the expected values used in the diagnosis.

1. INTRODUCTION

Phantoms are devices that can represent at different levels of complexity different tissues present in the human body. The development of phantoms, whether physical or computational, aims to achieve great similarities, whether physical, chemical and geometric with the human body to be applied in studies for diagnosis and treatment of diseases. The evolution in the technology of the equipment that are on the market has been encouraging the development and improvement of these devices in order to optimize image acquisition processes as well as improve radiological safety in the use of ionizing radiation [1, 2].

The phantoms have been built from epoxy resins mixed with different materials that have different molecular compositions and density, managing to approximate their physical properties to have X-ray absorption characteristics similar to human tissues. In dosimetry studies, small variations in density and geometry of materials do not generate large differences in the results obtained, and then the same material compound is used to represent different soft tissues in the construction of phantoms [3, 4].

The correct handling of mixtures allows a greater composite homogeneity and as a consequence, radiation interaction with composites is close to the human body interactions. The development of these composites is evaluated from its ability to attenuate electromagnetic radiation. CT numbers on the Hounsfield scale (HU) serve as standard for evaluating the ability of materials to simulate tissues. A low material homogeneity generates artifacts in CT images producing noise and degrading the image quality [2, 5].

The variation between CT numbers in CT imaging is correlated with changes in tissue density where there were interactions with X-ray beam. In healthy tissues, the CT number for muscles is in average 52.96 HU; adipose tissue is -84 HU; lung (inhale) is -820 HU and breast –20.90 HU, among others. The use of polymeric materials and their mixtures allow obtaining results of CT numbers close to those mentioned above [6-8].

2. MATERIALS AND METHODS

2.1. Materials

The materials used for the development of this study were: solid water, polyethylene, high and low viscosity polyester resin, acrylic resin and ethylene-vinyl acetate (EVA) mass. A polymethyl methacrylate (PMMA) head phantom with 16 cm in diameter with eight peripheral openings and one central opening of 2.5 cm in diameter per 2.5 cm in length. The CT scanner is a GE with 64-channels, model VCT and Dicom viewer to obtain the diagnostic image generated.

2.2. Methods

Test cylinders 2.50 cm in diameter and 2.50 cm long solid water, high and low viscosity polyester resin, acrylic resin and EVA were built. Most of these materials have a density close to that of water, which is why they were selected for this study. When solid-state cylinders were obtained, they were placed in the openings of a PMMA head phantom to perform CT scans.

Cylinders were identified from 1 to 7, according with the built material; solid water 1, polyethylene 2, low viscosity polyester resin 3, high viscosity polyester resin 4, acrylic resin 5, PMMA 6 and EVA 7. They filled the phantom openings and CT scans performed.

The head phantom was positioned in the isocenter of the CT scanner gantry. The CT scanner was setting in helical mode for head scans to realize acquisitions with the voltage of 120 kV, charge of 100 mA.s, 1.00 mm of slice thickness reconstruction and pitch of 0.984 to make scans of 5 cm.

The CT numbers analysis was performed select a CT axial image of the center slice. Four ROI´s were selected in each test cylinder image and the average CT numbers calculated.

Mixtures were made between materials with 1:1 and 2:1 proportions and new test cylinders were built. The PMMA, solid water, EVA and polyethylene materials were reduced to powder to be mixed with the liquid resin. CT scans were re-performed using the same acquisition parameters to obtain the CT numbers. The noise percentages in the image of each material were calculated using equation (1):

$$Noise\% = \frac{SD}{HU_{average} - HU_{air}} * 100 \qquad (1)$$

Where, Noise% is the percentage of noise CT image, SD is the standard deviation of the CT numbers of the image, $HU_{average}$ is the average value of the CT numbers and HU_{air} is the CT number of the air of reference.

3. RESULTS

The Fig. 1 show the head phantom with the openings filled with test cylinders and a CT axial image of the central slice.

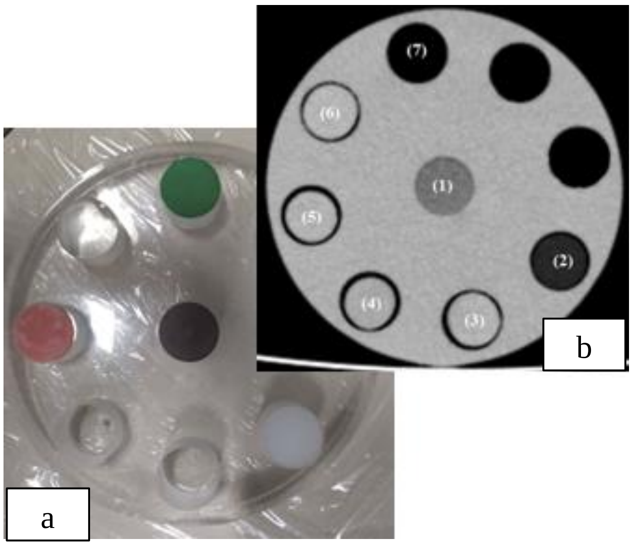

Fig. 1. Head phantom and test cylinders (a) and CT axial image of the head phantom (b).

The average CT numbers of the test cylinders obtained from central slice of the CT image with their standard deviation (SD) are shown in the Tab. 1. By comparing the CT numbers found in the image with the reported results [6-8], the low viscosity resin and EVA mass are selected as the basis for making the material mixtures. Materials such as solid water, polyethylene and PMMA were reduced to powder for homogeneous mixtures.

Tab. 1. CT numbers of materials.

Materials	**CT number**	**SD**
Solid water	127.47	47.74
Polyethylene	-104.88	35.47
Low viscosity polyester resin	97.80	64.24
High viscosity polyester resin	108.90	50.25
Acrylic resin	103.47	46.36
PMMA	124.91	45.59
EVA	-904.64	57.59

Solid water has a higher standard deviation than the CT number found, probably to the lack of care on the production line to obtain a homogeneous material. Acrylic, low and high viscosity resins have relatively close CT numbers. Low viscosity resin was selected because it is easier to work. The EVA was selected by its CT number close to the number reported for lung. The PMMA CT number is within those expected, as this material is used in phantoms as soft tissues.

When performing the mentioned mixtures and built new test cylinders, they were inserted into the head phantom and made new CT images to obtain the CT numbers of them. The Tab. 2 shows the CT numbers and SD of the low-viscosity polyester resin-based mixtures.

Tab. 2. CT numbers of the low-viscosity polyester resin-based mixtures.

Proportion	**Material**	**CT number**	**SD**
1:1	Solid water	126.93	7.77
	EVA	49.75	8.10
	PMMA	137.83	57.30
	Polyethylene	30.03	45.79
2:1	Solid water	136.05	3.26
	EVA	148.38	4.14

	PMMA	110.70	46.93
	Polyethylene	142.70	45.03

Mixtures of PMMA and polyethylene with low viscosity polyester resin had higher standard deviation values, probably at the homogeneity of the mixtures. From the results there is no evidence of a linear dependence between the proportions with the CT numbers found in the test cylinders.

Polyester resin-based materials had satisfactory results in simulating muscle. Unfortunately, none of the mixtures had a satisfactory result for similar breast tissue. Possibly using other types of proportions can be found mixtures that allow simulating this type of tissue. The Fig. 2 shows the calculated values in percentage of noise in CT images of polyester resin-based used equation (1).

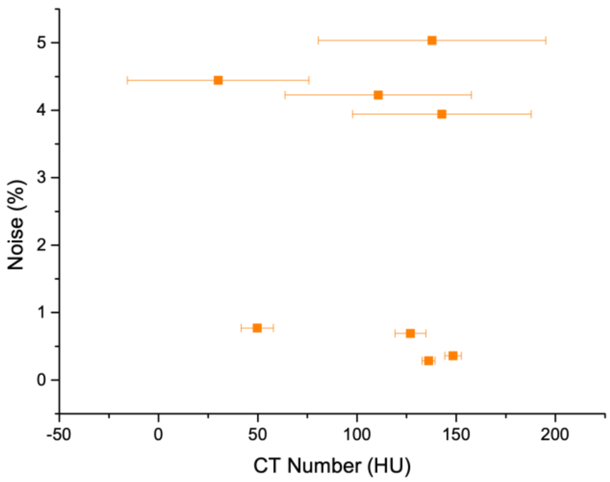

Fig. 2. Noise values in CT images of the polyester resin-based mixtures.

The Fig. 2 shows a higher percentage of noise in mixtures with higher standard deviation, thus demonstrating that more homogeneous materials generate less noise in the image. Mixtures that had greater homogeneity are related to solid water and EVA. The Tab. 3 shows the CT and SD numbers of the EVA based mixtures.

Tab. 3. CT numbers of the EVA based mixtures.

Proportion	**Material**	**CT number**	**SD**
1:1	Solid water	-687.44	46.57
	PMMA	-581.24	53.06
	Polyethylene	-663.07	21.06
2:1	Solid water	-709.02	64.94
	PMMA	-772.24	70.81
	Polyethylene	-823.10	40.90

All EVA-based mixtures show CT numbers close to the reported values for lung CT images as previously reported [6-8]. The mixture that showed less homogeneity regardless of the proportion used was with PMMA. The CT numbers found this mixture demonstrate predominance of X-ray attenuation properties that EVA has.

By doing better control of the mixtures, it is possible to achieve more homogeneous materials which generate fewer artifacts and noise index in the CT images. The CT numbers found in EVA-based mixtures are found in intervals to simulate healthy lung and with alterations.

The Fig. 3 shows the calculated values in percentage of noise in CT images of EVA-based used equation (1). The values found in the CT images were compared with the referenced in the literature [6-8].

The Fig. 3 shows a higher percentage of noise in mixtures with higher standard deviation, mixes in proportion 2:1 were the ones that had the highest percentage of noise in the image. The higher SD happened because the values are next the start of the CT number scale (-1000) and the thickness slice reconstruction is very thin (1 mm). The Fig. 4 shows comparisons materials results for muscle, lung, adipose and breast tissue.

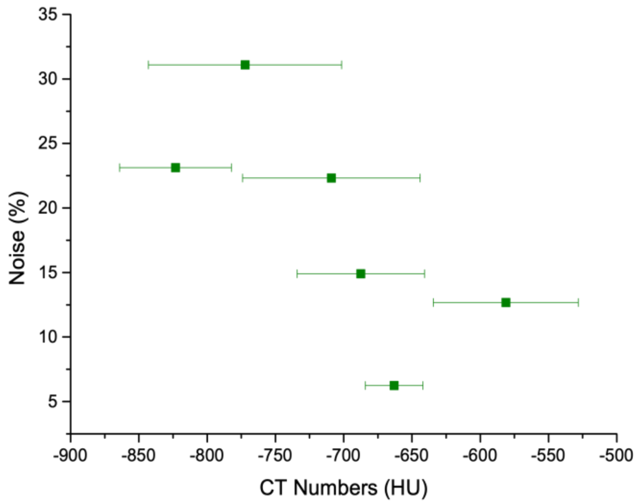

Fig. 3. Noise values in CT images of the EVA based mixtures.

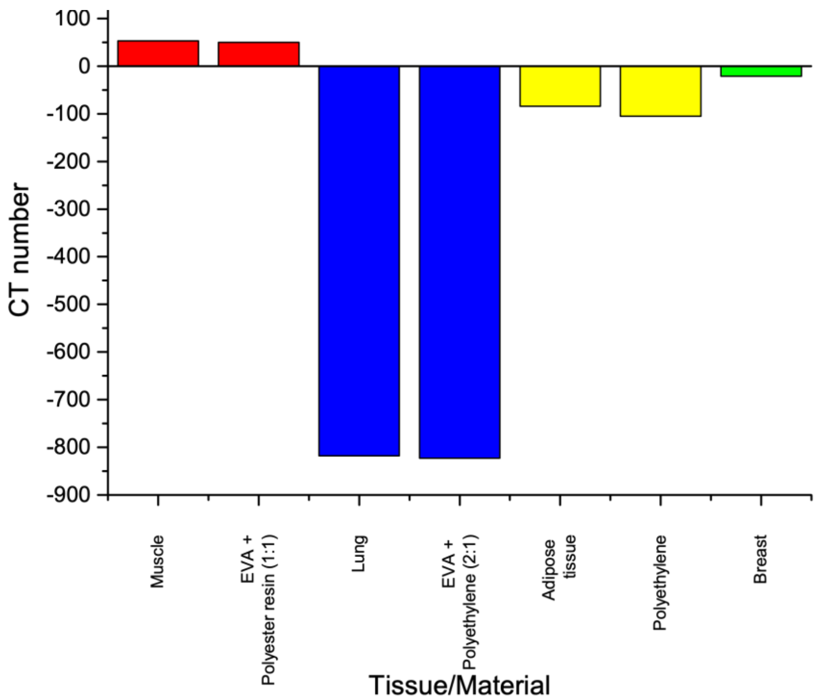

Fig. 4. Comparison of the material results with different tissues.

Materials that had a closer response to the tissues mentioned are shown in the Fig. 4. Polyester resin with EVA (1:1) had a deviation of 6.06%, EVA with polyethylene (2:1) had a deviation of 0.65% and polyethylene had a deviation of 24.86%. For breast tissue none of the test materials had a satisfactory result.

4. CONCLUSION

The results show that it is possible to develop technology using national and low-cost materials capable of delivering good results in dosimetry studies of ionizing radiation and CT image quality.

The use of different polymeric materials and their mixtures in different proportions allow to design and build phantoms for diagnostic and therapy images being able to attenuate X-ray beam with a similarity increasingly close to that of the tissues of the human body.

It is suggested to explore other types of materials of polymeric origin, other proportions and a control in the mixing procedures so that we can find closer results that can more accurately simulate different human tissues.

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REFERENCES

[1] S. J. Glick and L. C. Ikejimba, Advances in digital and physical anthropomorphic breast phantom for x-ray imaging, *Medical physics,* Wiley Online Library, Vol. 45, n. 10pp. 870-885 (2018).

[2] X. G. Xu and K. F. Eckerman, Handbook of anatomical models for radiation dosimetry, *CRC press, (2009*).

[3] P. Akhlaghi *et Al*, Determination of tissue equivalent materials of a physical 8-year-old phantom for use in computed tomography, *Radiation Physics and Chemistry, Elsevier*, Vol. 112, pp. 169-176 (2015).

[4] D. E. Hintenlang *et al*, Physical phantoms for experimental radiation dosimetry, Handbook of anatomical models for radiation dosimeter, CRC Press/Taylor and Francis Group Boca Raton, FL, pp 389 - 409 (2010).

[5] F. Zhang *et al*, Design and fabrication of a personalized anthropomorphic phantom using 3d printing and tissue equivalent materials, *Quantitate imaging in medicine and surgery,* AME Publication, Vol. 9, pp 94 (2019).

[6] M. B. Afafi *et al*, the effects of CT x-ray tube voltage and current variations on the relative electron density (red) and CT number conversion curves, *Journal of radiation research and applied science*, Taylor & Francis, Vol. 13, pp. 169-176 (2015)

[7] I. Koniarova, Inter-comparison of phantoms for CT numbers to relative electron density (red)/ physical density calibration and influence to dose calculation in tps, *Journal of physics: Conference series*, Vol. 1248, pp. 12-46 (2019).

[8] M. H. Hahn, Y. Y. Won, Bone mineral density and fatty degeneration of thigh muscles measured by computed tomography in hip fracture patients, *Journal of bone metabolism*, Vol. 23, pp. 215-221 (2016).