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Characterization and Development of Anthropomorphic Phantoms Liver for Use in Nuclear Medicine

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Abstract**—**The objective this study was to characterize and develop anthropomorphic liver phantoms in tomography hepatic procedures for quality control and improvement professionals in nuclear medicine. For the conformation of the anthropomorphic phantom was used in plaster and acrylic. We constructed three phantoms representing processes with liver cirrhosis. The phantoms were filled with ^{99m}Tc diluted with water to obtain the scintigraphic images. Tomography images were analyzed anterior and posterior phantom representing a body with a greater degree cirrhotic. It was noted that the phantoms allow the acquisition of images similar to real liver with cirrhosis. Simulations of hemangiomas may contribute to continued professional education of nuclear medicine, on the question of image acquisition, allowing of the study parameters such of the matrix, energy window and count statistics.

Keywords**—**Nuclear medicine, liver phantom, control quality

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I. Introduction

THE liver is the largest organ in the human body, weighing in human adults between 1200 and 1500 g. This organ is located on the right side of the abdominal cavity, upper quadrant, protected by the ribs. Its function is to purify the blood, breaking down certain chemicals and other manufacturing. Generally, the liver presents soft, but in the case of the liver with cirrhosis, this fabric has appearance cicatrizal firm, like stone, which means a permanent damage to the body, because blood cannot cross it and the mass liver decreases over time, losing the ability to produce useful proteins and drugs and to sue and [1]. In liver scintigraphy is administered to the patient the radiotracer ^{99m}Tc-sulfur colloid, for the location of the organ in images by Single Photon Emission Computed Tomography (SPECT). This type of test is indicated in the investigation of focal hepatic lesions in severe liver disease such as cirrhosis and acute hepatitis. For these diseases, the results of the images show reduction in the amounts of radiotracer uptake by the liver [2, 3].

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For detection of tumors of this organ there is the area of lower and higher uptake of the radiotracer. Some camera of three scintillation detectors can detect with diameters from 1.4 cm and very small lesions. Hemangiomas are benign tumors composed of blood vessels of new formation, that generally have diameters smaller than 3 cm. In the study of liver morphology in nuclear medicine there is the size and shape of the body, noting the presence or absence of intra hepatic lesions [4].

Technological advances in nuclear medicine, related to the area of diagnosis and therapy, have provoked greater interest in the quality images acquired in this medical specialty. These advances also have allowed the development of phantoms for evaluation procedures and quality control of equipment and training professionals.
The objective this study was to characterize and develop anthropomorphic liver phantoms to procedures tomography (SPECT) for control quality of hepatic images and improvement professionals in nuclear medicine.

The observed parameters in the procedures were matrix pixels, the window energy and the number of counts (cts).

II. Materials and Methods

The first step of this study was the examination of the material basis of phantom construction of the samples; the second was the characterization of the acrylic exposed to high doses from gama rays high doses and the third was the construction and validation of the anthropomorphic liver phantoms.

Initially, tests were performed to evaluate the hardness, elasticity and density the main material used in the development phantoms, that were acrylic.

To samples development was used a form of plastic and acrylic. The acrylic used was a self polymerizing JET Classic; after its preparation it has became solid, without loss or mass increase. For temperatures above 65°C it becomes liquid acrylic and viscose, losing the object's geometry. To this study the samples was prepared with dimensions of 5 mm × 50 mm × 25 mm (Figure 1).

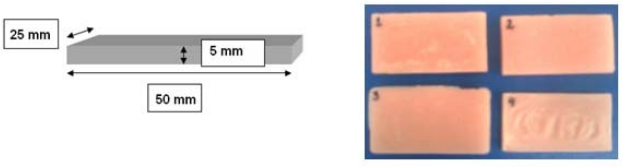


Fig. 1 Dimensions of the specimens of acrylic and visual appearance

The irradiation process of acrylic samples was performed at the Department of Nuclear Energy, Federal University of Pernambuco (DEN-UFPE). The equipment used was 220 Gammacell manufacturer MDS Nordion, model GC 65R in 220E (ASSY), with Co-60 source. In the analysis were investigated samples non-irradiated and irradiated to doses from 1 kGy to 50 kGy. These tests were performed because the amorphous materials subjected to irradiation can changes its characteritics due to interaction of radiation. So how do we expect which the phantoms developed can be reused many times, it was considered necessary to evaluate possible changes in composition due irradiations.

A. Hardness and Elasticity

After irradiation the specimens were carried out analysis of hardness and elasticity. The measurements were performed on a Shimadzu equipment (DUH-2115), load-unload mode with a force of 100 mN and hold time of 4 s. The hold time is the time that the diamond stands still when it reaches the maximum force applied.

B. Density

The samples densities were obtained through experiments by Archimedes' principle, comparing the results with literature data. It is noteworthy that as the density of acrylic is close to the human body (acrylic d = 1.19 g / cm ³ d ≈ d = water body 1g/cm3), this material may be suitable for simulations of body organs human.

C. Raman spectroscopy

In the experiments of Raman spectroscopy was used to model Dispersive Raman Spectrometer manufactured by Bruker® Senterra Optik®, with the helium-neon laser wavelength of 633 nm (red). For the analysis it was used laser power of 10 mW, objective lens 20 xA and the spectral range of 400-1800 cm^{-1} with resolution 5.3 cm^{-1}, thereby providing the main vibration modes of acrylic.

D. Conformation of the anthropomorphic liver phantom

For the development of anthropomorphic liver phantoms were used as a model of adult human livers from Museum of Human Anatomy Professor. Osvaldo da Cruz Leite, of the Federal University of Sergipe. These organs were preserved in formalin for use in educational activities for students of this institution.

The phantoms have the geometry of an adult human liver in stage of cirrhosis. Inside the phantom with greater stope of cirrhosis were included materials that simulate three nodes representing three hemangiomas; hemangiomas with a diameter of 10 mm and two 20 mm.

The anthropomorphic phantoms representing the initial stage and intermediate of cirrhosis liver were built with the purpose of guiding students and professionals in nuclear medicine for continuing education the improvement of the quality control equipment. For this defective, some images are obtained with regions of higher or lower uptake of the radionuclide to demonstrate the level of liver cirrhosis and other types of lesions. Figure 2 shows the three anthropomorphic liver phantoms manufactured.



Fig. 2 Anthropomorphic phantoms representing the liver in (a) initial state cirrhotic, (b) intermediate and (c) advanced

In the Figure 3 (a) we can see an image of the phantom shown in Figure 2 (c) and photograph of the structures that simulated hemangiomas (Figure 3 (b)).

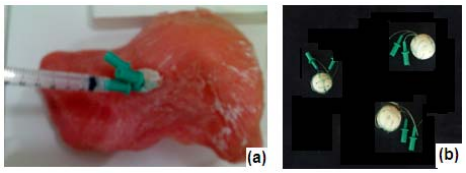


Fig 3 Phantom representing liver cirrhosis in early stage disease and photograph the objects that simulate the three hemangiomas

Scintigraphic images obtaind the phantoms were filled with ^{99m}Tc diluted with water.

III. Results

The measures of hardness and elasticity of samples of the material showed compared to values obtained by other authors [5-7]. In this work, the hardness Vickres found was between 13.0 and 15.0 HV and elasticity between 2.0 and 5.0 N/mm^2. As hardness and elasticity of the material did not change significantly, it can be said that acrylic is presented as a material resistant to radiation doses to which it was exposed (up to 10 Gy), which indicates that the phantoms constructed not suffer significant damage after repeated uses because the doses emitted by technetium liver exam in nuclear medicine are usually low compared to those applied in the material analyzed in this work. Moreover, the energy range of radionuclides used in diagnosis is 140 keV and 511 keV for technetium-99m and fluorine-18, respectively [8]. Table I shows the hardness and elasticity of the samples with no exposure to radiation and irradiated.

TABLE I
HARDNESS AND ELASTICITY OF THE SPECIMENS

	Specimens				
Parameters	1	2	3	4	5
Absorbed dose	-	1 kGy	10 kGy	30 kGy	50 kGy
$H_{máx}$ (µm)	4,89 ± 0,01	4,92 ± 0,04	4,94 ± 0,03	4,98 ± 0,04	4,96 ± 0,02
Hardness (HV)	14,79 ± 0,01	13,72 ± 0,23	13,58 ± 0,17	13,58 ± 0,17	13,58 ± 0,17
Elasticity (N/mm^2)	3,79 ± 0,98	3,98 ± 0,91	3,63 ± 0,80	3,83 ± 0,93	3,86 ± 0,95

The hardness of the non-irradiated sample was 14.79 HV. Hardness of sample exposed to Co-60 showed a reduction 7.70%, approximately, if compared to the non-irradiated sample. The elasticity of the non-irradiated sample was 5.5% higher than that of the body irradiated with 1 Gy and 4.2% higher than that of one irradiated with 1 Gy and 4.2% higher than the specimen exposed to 10

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Gy, as shown in Table 1. We assume that this small difference was caused by air microbubbles that were formed in the acrylic during polymerization process.

According to Fortes (2007) there is no standard that determines the minimum value of dental acrylic resin hardness to which the material is deemed appropriate such use.

Another important factor observed in the analysis with the samples, comparing non-irradiated and irradiated, is that exposure to radiation caused a gradual darkening in acrylic. Visual observation showed that non-irradiated sample (the leftmost in Figure 3) showed clearer than the samples irradiated. Likewise, sample irradiated with 1 Gy (sample in the center of the picture) was clearer than the one irradiated with 10 Gy.



Fig 4 Representation of the specimens irradiated

It is noteworthy that the density of the specimens, rather than 1.19 g/cm^3, density was 1.15 g/cm^3. Thus, we assume here also that the lower value was due to the presence of micro bubbles of air resulting from the polymerization process.

Raman spectra show that the intensity of the first seven peaks did not suffer displacement. In this case, we note that the intensities of the peaks of un-irradiated specimen were smaller compared with the irradiated group. So we can say that the specimens that were irradiated with 30 and 50 kGy showed peak intensity greater than the samples of 1 and 10 kGy. One can then assume that this difference was due to staining, since the samples were exposed to higher radiation doses were dimming, absorbing more light. In this case, we consider a good result compared to that found by Fortes (2007), who presented the Raman spectra in the range of Raman shift of 600, 800, 980, 1440 and 1780 mm, which is the same range found in our study. It is noteworthy that the author uses the same type of resin. Figure 5 shows the Raman spectra observed in the specimens.

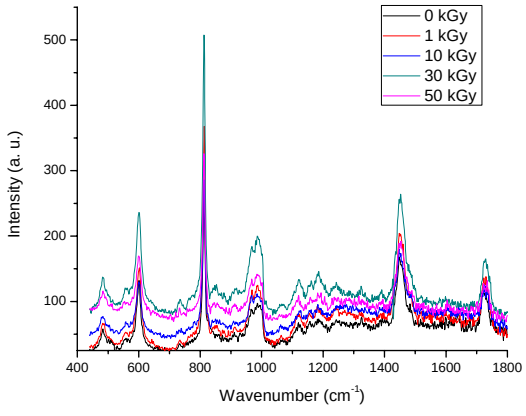


Fig 5 Raman spectroscopy acrylic resin, after curing, un-irradiated and irradiated

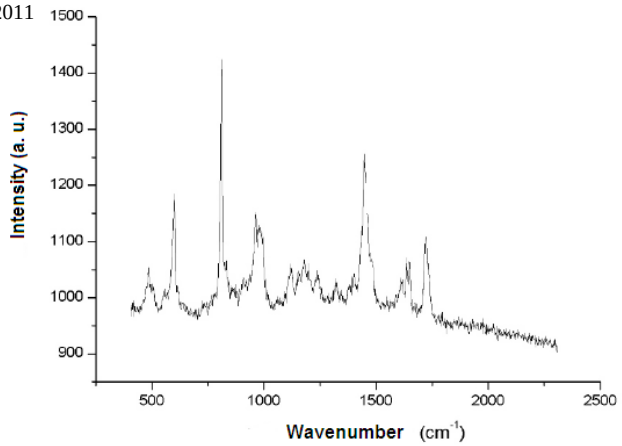


Fig. 6 Raman spectroscopy acrylic resin after polymerization (modified: Fortes, 2007)

On the results of SPECT, we can see that the images of the phantoms are similar to the real liver with cirrhosis (Figure 7c) [9]. We analyzed images of the anterior and posterior simulator representing a body with a greater degree cirrhotic (Figure 7).

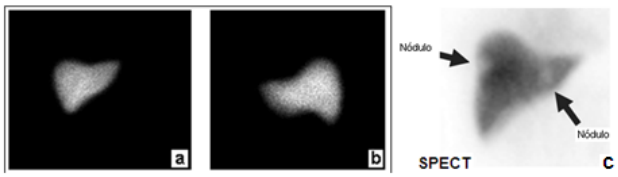


Fig.7 Afterimage (a) and anterior (b) simulator and an indication of cirrhotic nodules (c)

Based on the methodology of Ferreira and Souza [10] were introduced for the simulation of the artifacts found in the liver phantom representing the initial state and advanced cirrhosis. Thus, objects were included, representing hemangiomas to analyze the spatial resolution of the scintillation camera and professional training of nuclear medicine. These studies relate to the simulation of hot nodules, i.e., with radioactive material within such nodules.

We observe other characteristics of hemangiomas in the simulator, such as low resolution to 100 kcts and an enhancement in hemangiomas to count statistics from 1000 kcts. These features improve the spatial resolution, because a greater number of counts allow a better view of the findings on images obtained in scintillation cameras. Thus, adequate counting statistics can result in optimizing the quality control image of acquisition equipment and training of professionals.

The distance source-detector or detector-phantom is an important factor for image acquisition, because the lower the patient-detector distance the better the results displayed in the studies and findings for organ [11]. Typically, the ideal distance between the patient and the detector is 5 cm. Here, all images were obtained at that distance.

Figures 8 and 9 show the images obtained with arrays of 64 × 64, 128 × 128, 256 and 512 × 256 × 512 pixels. It was observed that the images of Figure 5, obtained with arrays of 64 × 64 and 128 × 128 pixels, it was not possible to visualize the hemangiomas, only from the matrix 256 × 256 pixel display that was possible.

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Figure 9 shows the images of phantoms representing the state of liver cirrhosis and middle initial. Through this figure it is confirmed that the matrix of 256 × 256 pixels is more appropriate for this type of examination.

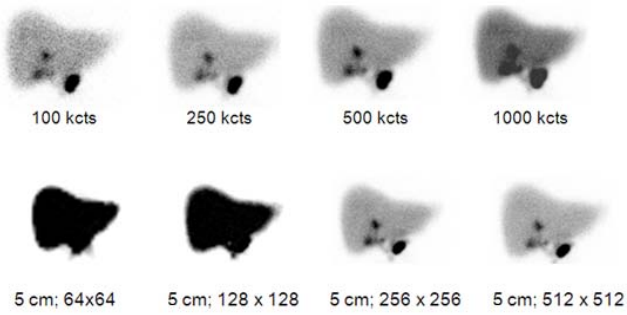


Fig. 8 Images obtained with different matrices and count statistics, with a distance of 5 cm (detector-phantom)

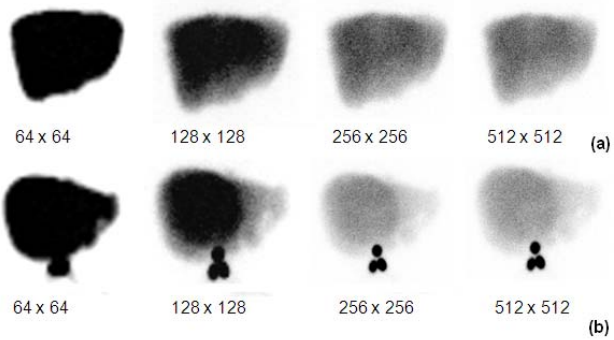


Fig. 9 Images obtained with different matrices using anthropomorphic phantoms with initial state (a) and intermediate (b) of liver cirrhosis

IV. Conclusion

Verified through measurements, the hardness of acrylic un-irradiated hardness decreased compared to irradiated acrylic, this reduction was an average of 7.70%. The elasticity of the un-irradiated specimen was found to be 5.5% higher than that of the body irradiated with 1 Gy and 4.2% higher than the specimen exposed to 10 Gy. In this case, we assume that this small difference was caused by micro bubbles of air that were formed in the material at the time of the polymerization acrylic.The results were satisfactory, because the specimens have only changed the color when irradiated. Raman spectra showed that the intensity of the peak first to seventh peak without shift neither to the right nor to the left.

Thus, one can say that this material can be used for the conformation of phantoms, as a phantom constructed with that material, after several uses in training and test sessions, being exposed to radiation only changes the color. However, the characteristic observed in the Raman spectra showed that the radiation in the material will not influence the images obtained in nuclear medicine, radiation damage does not influence the structure of the material. Another important factor considered in this study is that future, we can study this acrylic resin for application in dosimetry in nuclear medicine and other areas that work with dosimeters for high doses, such as food irradiation. This material is found in dental supply store for a price reasonably low relative to industrialized acrylic colorless.The results obtained with the phantoms were satisfactory. We realize that the images obtained with arrays of less than 256 × 256 pixels were not possible to visualize the hemangiomas. Therefore, it was observed that the images of phantoms representing the state of liver cirrhosis with the initial and intermediate matrix 256 × 256 pixels is most suitable for this type of examination.Based on these results, the images were shown to be suitable for quality control and training professionals regarding continuing education [4, 11]. The phantoms represent adequately developed structures with liver cirrhosis and images are for research and analysis of hemangioma of the location and size of the region of interest.Simulations can contribute to continuing education of professionals related to nuclear medicine. Through analysis of the images is possible to study parameters such as matrix size, energy window and count statistics. Therefore, the simulations of hemangiomas may also serve to evaluate the profile of planar and tomographic images, such as spatial resolution and tomographic areas with artifacts.

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