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DOSIMETRIC FEASIBILITY OF HETEROGENEOUS PHANTOM MATERIAL USED IN RADIOTHERAPY

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ABSTRACT

The objective of this study is to analyze the feasibility of low-cost materials, which are adapted to commercial phantoms, used in quality and control in lung cancer treatments for radiotherapy. The studied materials are acrylic, three types of wood and ethylvinylacetate, obtaining computed tomography (CT) images with a Toshiba Asteion on two phantoms. One anthropomorphic thorax CIRS®, and another homogeneous acrylic cavity-plug type of the ArcCHECK® system under reference conditions clinic. Measurements of the Hounsfield units (HU), relative electron density (DE) and physical density (DF) were made. The radiation-matter interaction was also calculated with the MonteCarlo Monaco® (TPS) calculation algorithm, and finally the experimental measurement was carried out with the System PinPoint 3D 31016 dosimetric ionization chamber and PTW UNIDOS E T10010 electrometer, irradiating with an ELEKTA® Synergy linear accelerator under the calculation conditions, in order to compare the experimental and simulated conditions. As a result, the materials are discriminated according to their relevance to be used as a thorax simulator, finding that the wood of Ochroma pyramidale presents a value of HU, DE and DF approximated to the lung tissue. So it is dosimetrically viable as compatible material for the construction of phantoms of the thoracic region.

Keywords: dose, radiotherapy, lung, QA, phantom, planning system, dosimetry.

INTRODUCTION

Radiation therapy is the second most effective technique to treat cancer after surgery [1], it uses high-energy radiation beams for this purpose, which are generated by equipment called a linear accelerator; and which under clinical conditions executes the plans treatment under the conditions calculated in the treatment planning system (TPS), from calculation algorithms that predict the transport of photons and electrons in matter [2]. In order to effectively evaluate the correct functioning of the equipment and the delivery of the treatment dose, it is necessary to implement the use of phantoms. All this added to the different processes that provide the attention of the radiotherapy process, have led to improvements in the precision and accuracy of treatment delivery.

The evolution of TPS, has also allowed us to get closer to the real conditions referring to the various densities present in a human body. In the case of low-density tissues, the inclusion in the dose calculation algorithms should consider the change of environment and its heterogeneity, especially in lung cancer treatments. Since the thorax region has quite marked variation in homogeneities, where it is located from bone (related to the rib cage or vertebrae of column) to air (within the alveoli), there are undoubtedly radiological differences that must be included in the calculation process. The recommendations by the working group 65 of the American Association of Physicists in Medicine (AAPM) [3], establish the need to include the corrections in the calculation and although they are not entirely precise “they are closer to the real values than those without corrections for inhomogeneity”[4].

Within radiotherapy treatment there are also different processes that allow to obtain an optimal result [5]: simulation as a process of immobilization and acquisition of images, planning as a process of contouring the volumes of interest and calculation of the dose and the delivery of treatment, where the dose is delivered in the linear accelerator. Just before delivery of treatment, a specific patient quality control is performed, a procedure that aims to verify that the dose calculated in the TPS corresponds to the dose delivered in the accelerator. The use of phantoms is essential to meet the objective [6], which makes it necessary to perform a tomography of the phantom, take it to the TPS, reproduce the calculation, proceed to measure it under experimental conditions at the accelerator and determine the specific relative error for the case.

The verification processes vary according to the specifications of the phantoms, their use can have different purposes: the cubic polymethylmethacrylate (PMMA), homogeneous with a density equivalent to water, which follow the recommendations of the AAPM 120 [7], are easy to use and install, allow to measure the dose at different depths; the cylindrical ones (for example the cavity-plug of the ArcCHEK® system), also homogeneous, with suitable geometry for verification of IMRT and VMAT deliveries and the anthropomorphic ones, manufactured in a way that they represent sections and heterogeneities of the human body. The last ones have been used effectively, identifying difficulties in planning or administering treatment, which are not perceived with the use of homogeneous geometric phantoms [8]. Since the dose arrangement is influenced by the change of medium, especially at the density interface, the planning system should be able to accurately determine this influence, but it has been shown according to Gurjar and col, Kishore and col [8] [9] an increase in the dosimetric error in heterogeneous phantoms. This due to the ability of the TPS to reproduce the experimental measurement and also to the limitations present with the measurement instruments in terms of the ability to offer a more exact dose value, therefore, it is considered that the use of heterogeneous phantoms, offers a more precise information of the dose delivery.

There are different types of anthropomorphic phantoms for commercial use (IMRT thorax CIRS® 002LFC, Alderson Radiation Therapy phantom ART, ATOM® phantom, etc.), but few radiotherapy centers in Colombia have them due to their high cost. Therefore, this study is carried out in order to evaluate dosimetrically materials that can be used to replace low-density lung-like media and thus, be able to generate adaptations on commercial homogeneous phantoms, which allow planning taking into account the change of medium. Considering that lung tissue, according to the report of the International Commission on Radiation Units and Measurements (ICRU 44) [10] reports values of 0.26 g / cm3 and -950 to -750 of density and Hounsfield units respectively and the values Relative electron density 0.213-0.297 determined from Kalef, J. and et [11], materials that have similar characteristics will be studied. Proposing the use of viable materials in the simulation of the lung parenchyma has been reported and they have been discriminated by their physical characteristics, such as wood [8] [9] [12] [13].

The present study analyzes physical and dosimetric characteristics of compatible materials similar to the structure of the lung, its comparison will be carried out by performing punctual dose measurements on the reference phantom CIRS® 002LFC. Which is a heterogeneous anthropomorphic phantom of the thorax, which represents different types of tissues of the human body, through interchangeable inserts. To do this, it will first be physically characterized (HU, physical density and relative electron density) with three types of wood and the polymer ethylmethylacetate; Similar materials to the lung parenchyma will be used as inserts where an ionization chamber will be positioned and specific dose measurements will be taken to be compared with the patented CIRS® (epoxy) insert. Lastly the dose measurements will be taken in the homogeneous phantom ArcCHECK ® cavity-plug and the difference in dosimetric error due to the use of a low-density insert will be established.

For the first time, we report a dosimetric study of different low-cost materials which model low-density media such as the lung and can be implemented in CIRS® and cavity-plug® phantoms to make specific patient quality control measures. As a result, we found that “balso” wood is dosimetrically feasible, unlike other woods and ethylvinylacetate.

MATERIALS AND METHODS

The present study physically and dosimetrically characterizes three types of wood: Ochroma pyramidale (balso), Pinus radiata and Cedrela odorata commonly known in Colombia as “balso”, pine and cedar respectively; a thermoplastic polymer called ethylvinylacetate and the CIRS® epoxy phantom materials (Figure-1a) representing lung density and cavity-plug® acrylic (Figure-1b) replacing water. To determine the Hounsfield UH units and relative electron density, the Toshiba® Asteion tomograph and the Monaco software were used. The tomography was configured with a slice thickness of 2.0 mm, a tube operating voltage of 120 kV, and a current parameter 150 mAs. The density of the materials was determined from the mass-volume relationship and a function that relates the Hounsfield units to the density of the material. The materials are molded with a cylindrical shape to be implemented in the phantoms as shown in Figure-1. The materials have an orifice through which it can be inserted a cylindrical PinPoint 3D ionization chamber with a sensitive volume of 0.016 cm3, which has a nominal response of 400 pC / Gy.

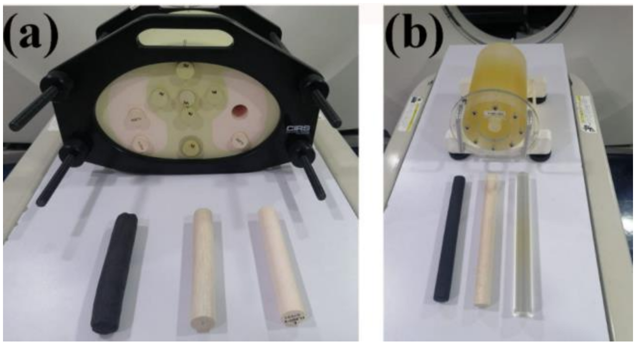


Figure-1. Trade phantoms a. CIRS®, b. cavity-plug®. The cylinders are interchangeable inserts, where the ionization chamber is positioned to carry out punctual dose measurements.

The charge is collected using a PTW® UNIDOS E electrometer with 300 V polarization. With this dosimetric system, a point dose verification is performed under reference conditions: 6 MV photons using an ELEKTA® Synergy linear accelerator, 10 x 10 field cm2 and 100, 200 and 300 MU. The planning is carried out in the Monaco system with the Montecarlo calculation algorithm and the comparison of the dosimetric difference is made for each of the measurements.

RESUSLTS AND DISCUSSIONS

The dosimetric characteristics of the three types of wood and the ethylmethylacetate polymer are analyzed (Figure-2). The materials were scanned with the tomograph with a technique commonly used in the clinic, the images obtained are transferred to the Monaco planning system. In it, central regions of interest of radius r = 1.0 cm are made, in several axial slices to quantify the HU and the relative electron density, as shown in Figure-3.

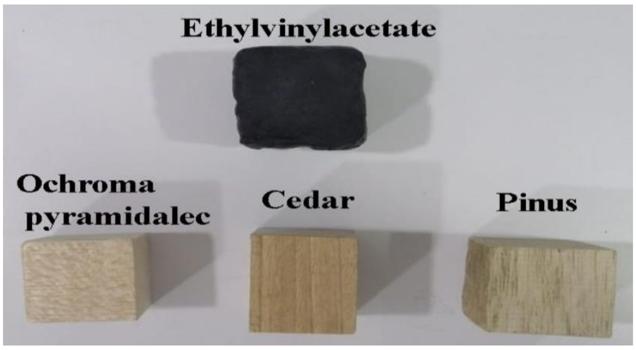
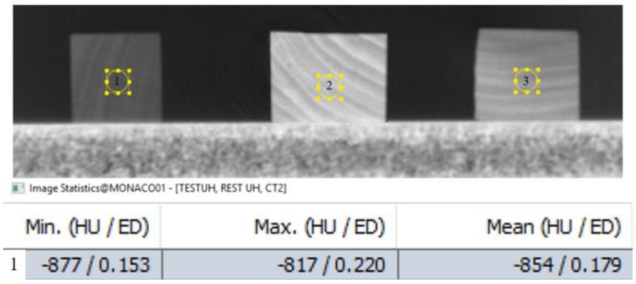


Figure-2. Ethylvinylacetate cubes and three types of wood.



	Min. (HU / ED)	Max. (HU / ED)	Mean (HU / ED)
1	-877 / 0.153	-817 / 0.220	-854 / 0.179

Figure-3. Image acquisition in the tomograph of the wooden cubes.

The physical density of a material ρ, under certain conditions is related to the Hounsfield units, as shown in equation 1 [14]:

$$\rho = \frac{CT}{1000} + 1 \tag{1}$$

Where CT is the number of Hounsfield units. It is compared with the density calculated from the mass-volume ratio. The results are summarized in Table-1.

Table-1. Summary physical characteristics of different materials.

	Density[1] (g/cm^3)	**Density HU (g/cm^3)**	**UH**	**Electronic Density**
Lung	0,260[2]	0,01 a 0,25	-950-750[2]	0,207 ±0,06[3]
Balso	0,233	0,147	-852,2 ±12,6	0,199 ±0,012
Pinus	0,555	0,426	-574,6 ±27,8	0,530 ±0,022
Cedar	0,682	0,636	-363,7 ±10,5	0,660 ±0,036
Ethylvininylacetate	0,220	0,130	-870,0 ±12,8	0,146 ±0,017

[1]Relationship between mass and volume. [2]Data reported by ICRU 44.[3]Values determined on a patient at the center.

The results of Table-1 indicate that the preferred materials to emulate low-density tissues close to the lung are “balso” and ethylmethylacetate, due to a lower density and Hounsfield units and when compared with the physical characteristics of the lung parenchyma, they are obtained close values. In such a way, that these two materials are chosen to design the inserts that will go inside the phantoms.

Balso wood, ethylvinylacetate and phantom inserts are characterized: CIRS® epoxy, and cavity-plug® acrylic. The reference material is the CIRS® epoxy insert (Figure-4 left), since it is a patented material and the manufacturer reports it with a very close similarity to lung tissue [15]. Image acquisition is performed for each of the inserts within the CIRS® phantoms (epoxy, ethylvinylacetate and “balso”) and Cavity-plug® (acrylic, ethylvinylacetate and “balso”).

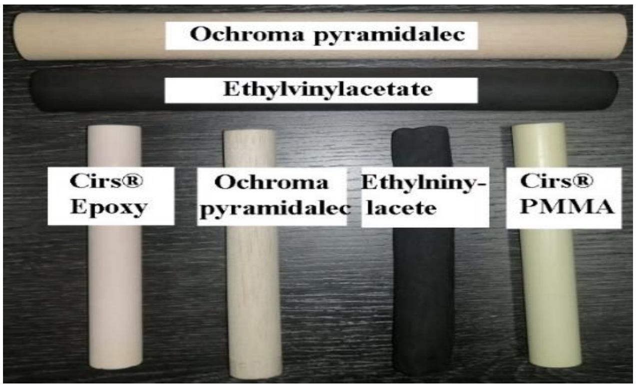


Figure-4. Cylindrical inserts in different materials used with cavity for ionization chamber.

In the planning system the physical characteristics previously described are discriminated. Figure-5 shows a cross section of the CIRS phantom with the wooden insert in position 1 and the epoxy insert in position 2. The data obtained are reported in Table-2.

Image Statistics@MONACO01 - [18092020, CIRSepoxy, CT2]

CT2 ☐ Show Image Statistics For Other Loaded And Registered Studysets VOI Diameter (cm):

	Max. (HU / ED)	Mean (HU / ED)	Median (HU
1	-912 / 0.113	-940 / 0.081	-939 /
	Max. (HU / ED)	Mean (HU / ED)	Median (HU
2	-865 / 0.167	-878 / 0.152	-878 /

Figure-5. Use of the Monaco planning system to measure the physical characteristics of the inserts.

Table-2. Density, UH and electron density measurements for different inserts. For the Epoxy insert the values are those reported by the manufacturers.

	Density g/cm^3	**UH**	**Electronic Density**
Epoxy CIRS®	0,210	-849,0±12,6	0,205 ±0,008
Balso	0,233	-913,9±7,7	0,168±0,016
Ethylvininylacetate	0,220	-910,2 ±10,5	0,190 ±0,025
Acrílic CAVITY	1,046	116,0±1,1	1,082±0,001

When comparing tables 1 and 2 it is evident that the HU of the "balso" and ethylvinylacetate materials are different, their absolute error is 61.7 HU and 40.2 HU respectively, and even so, the values obtained are between the representative ranges of lung.

Dosimetric Measurements under Reference Conditions

With the dosimetric system, ionization chamber and an electrometer, a 6 MV photon beam, generated in the accelerator, point dose verification is performed for different phantom configurations (CIRS®-cavityplug®) and inserts (materials designed and conventionally used). The dose calculation was carried out using the Monte Carlo algorithm of the TPS Monaco with the following configuration: 10 x 10 cm^2 field in the isocenter under SAD conditions. The configuration made in the planning system is reproduced in the accelerator, ensuring that the sensitive volume of the ionization chamber is located in the isocenter by means of an image verification through the XVI cone beam tomography system of the linear accelerator (Figure-6).

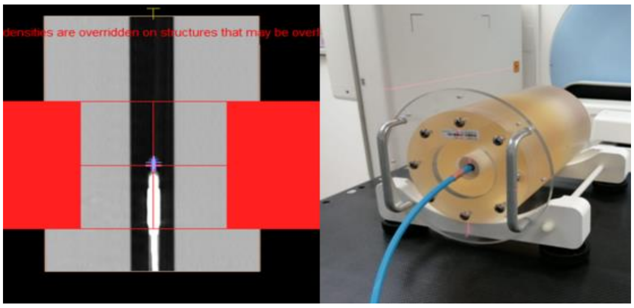
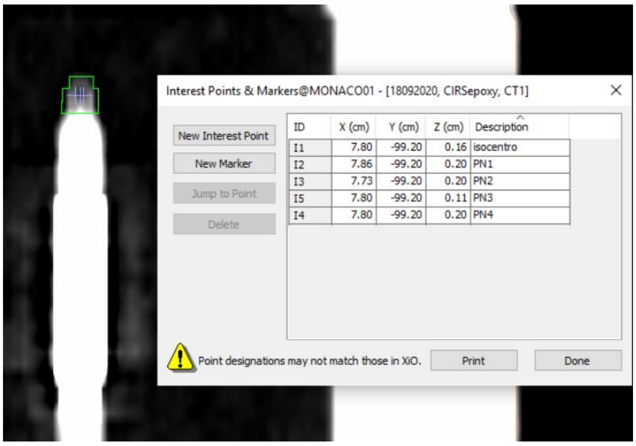


Figure-6. cavityplug® phantom with wooden insert in planning and mounting system for measurement on linear accelerator.

For the calculation of punctual dose in the TPS, as seen in Figure-7, five points are determined within the sensitive volume of the ionization chamber, after the calculation is made, an averaged dose reading value is obtained with its respective standard deviation.



Interest Points & Markers@MONACO01 - [18092020, CIRSepoxy, CT1]

ID	X (cm)	Y (cm)	Z (cm)	Description
I1	7.80	-99.20	0.16	isocentro
I2	7.86	-99.20	0.20	PN1
I3	7.73	-99.20	0.20	PN2
I5	7.80	-99.20	0.11	PN3
I4	7.80	-99.20	0.20	PN4

Point designations may not match those in XiO.

Figure-7. Visualization of points of interest in the Monaco planning system.

In the linear accelerator, after the respective positioning of the phantom, based on the load obtained by the dosimetric system, the dose value is established by making the respective corrections of the calibration factors factor NDW and KQQ and influence KTP As can be seen in Figure 3, the average difference in the percentage error in the CIRS® for the three types of inserts was 2.01%; 2.36 % and 2.37 % for epoxy, wood and ethylvinylacetate respectively.

Table-3. Comparison of percentage error of dose obtained in the measurement process in the linear accelerator and the calculation in the TPS for the CIRS® phantom with different inserts.

UM	Epoxy LA	Epoxy TPS	%	Wood LA	Wood TPS	%	Ethylvininylacetate LA	Ethylvininylacetate TPS	%
100	96,09	94,2	2,01	96,42	94,2	2,36	97,09	94,5	2,37
200	192,18	188,4	2,01	192,84	188,4	2,36	194,18	189	2,37
300	288,27	282,6	2,01	289,26	282,6	2,36	291,27	283,5	2,37

The measured and calculated dose values for the wood materials and ethyl vinyl acetate in the CIRS® phantom present values very close to that of the Epoxy reference material (Table-4). The calculated dose in the TPS for epoxy and balso wood is the same (94.2 cGy) and for ethylvinylacetate it is 0.32% apart (94.5 cGy).

Table-4. Percentage difference of dosimetric error for the three CIRS phantom configurations and normalized to the measured dose of the Epoxy material.

Percentage Difference %	EPOXY	BALSO	ETHYLVININYLACETATE
Respect the same	2,01	2,36	2,37
Normalized mean Epoxy	0	0,34	0,67
TPS Normalized a Epoxy	0	0	0,32

The average percentage error in the cavity-plug® phantom for acrylic and wood inserts is 0.30% and 2.40% respectively. (Table-5).

Table-5. Percentage difference in dosimetric error for the cavity phantom.

	ACRILIC	BALSO
Percentage Difference%	0,30	2,40

The dosimetric difference for the homogeneous and heterogeneous phantoms is 0.30% and 2.01% respectively, this shows that in the heterogeneous phantom the error is greater and is associated with the ability of the TPS to accurately determine the deposition of dose. Regarding the materials (wood and ethylvinylacetate) both are viable in physical and dosimetric terms, even so, ethylvinylacetate presents a difficulty, in relation to its construction, it has rudimentary molding, it requires drying work and although it has low density, it shows elastic properties and fragility before handling. Unlike balso wood, a material that has greater support, support and resistance to handling, it makes it a suitable substitute for low-density material.

CONCLUSIONS

There is a dependence of the backscatter material to Hounsfield units in “balso” wood and ethylvinylacetate, this maximum absolute error is 6.7% (approximately 60 HU), values that still preserve the similar physical characteristics of the lung. The equation that relates HU to DF is verified from the mass and volume formula, finding values within 6-20% of difference. The dose values obtained with the balso insert compared to the CIRS® epoxy phantom is within 0.3%. The dosimetric error of the cavity-plug® phantom goes from 0.3% to 2.4% when changing the acrylic insert for the balso wood, although the dosimetric error increases, it is within the tolerance values and they are values that allow to reproduce more real conditions of the patient. “Balso” wood (technical name) is a dosimetrically viable material to be used as a low-density medium to simulate the lung.

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