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Manufacture and characterization of a Bolus composed of water, bi-distilled glycerin, gelatin and formaldehyde

Oliveira[a] C.M., Brüning[b] F.F., Lyra[b] J.G.P., Zanetti[c] S.Y., Funchal[b] M., Fernandes[b] T.C.O.

[a] *Medical Physics Resident/Erasto Gaertner Hospital/Radiotherapy Department, 81520-060, Curitiba, Paraná, Brazil*

[b] *Medical Physicist/Erasto Gaertner Hospital/Radiotherapy Department, 81520-060, Curitiba, Paraná, Brazil*

[c] *Radiotherapy Technologist/Erasto Gaertner Hospital/Radiotherapy Department, 81520-060, Curitiba, Paraná, Brazil*

carlla.m.o@gmail.com

ABSTRACT

In years the bolus is used as human tissue compensator in treatments of superficial tumors using photons and electrons in the radiotherapy. In order to obtain a low cost and noncommercial bolus, it is proposed in this work to find an optimized bolus recipe composed of water, bi-distilled glycerin, gelatin and formaldehyde. It was manufactured 14 samples and it was evaluated their mass densities, homogeneity and malleability which M and N samples was classified for dosimetric analyses. The percentage depth dose (PDD) curves of M and N samples were measured and compared to the PTW RW3 solid water PDD curve for three energies, 6 MV, 6 MeV and 18 MeV. The PDDs comparisons results showed good agreement and differences smaller than 6% in the percentage depth values for depths smaller than 1,5 cm, except to 6 MeV electron energy which the sample N had difference of 17%. The M sample presented better results for the three measured energies and it was defined as the best recipe to a bolus between the analyzed samples in this work.

Keywords: **medical physics; radiotherapy; bolus; material characterization.**

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1. INTRODUCTION

Radiotherapy is an efficient method for the destruction of cells, using ionizing radiation. Therefore, can be used for oncological treatments [1,2]. The radiation dose prescribed by the radio oncologist doctor must be delivered with precision [3]. For this diagnostic imaging techniques, as computed tomography (CT), magnetic resonance (MR), ultrasound and positron emission tomography (PET) assist the radio oncologist in locating the target volume. Cancer patients who treat with radiotherapy have a contribution in 40% of the all cancer cures cases [3-5].

The choice of external beam unit can be made depending on the tumor depth. For example, tumors relatively shallow or moderately deep at the skin distance, as in the cases of head and neck, breast and body ends, x-ray units, with low energy megavoltage beam, are used (e.g. ^{60}Co, 4 MV or 6 MV). For treatment of deep tumors in abdomens and pelvis it could be medium and high energy (between 10 MV to 25 MV). Moreover, for superficial tumors, at most 5 cm deep, is used beams of charge particles, like electrons with energy between 4 MeV to 20 MeV [2].

In treatment of superficial tumors with photons or electrons, usual it is necessary the use of a bolus, in order to superficialize the dose and (or) regularize the patients' surface. The bolus is a human tissue compensator [2,6-8], that is, a material whose density should be approximately that of water. Because water presents a similar behavior, from the perspective of the interaction of radiation with matter and it correspond to 60% of the adult human body [9].

The bolus is positioned in direct contact with the patients' surface, or inside an cavity of the body. It can be made of various materials such as moistened gauze, "red wax" dentistry, "vaseline gauze" or synthetic oil gel with density very close to that of water, marketed as bolus *superflab*, among others [2, 6-8].

Radiotherapy services can use self-made bolus, noncommercial and manufactured using water, bi-distilled glycerin, gelatin and formalin. This bolus has low cost and can be manufactured easily [10]. This article proposes a detailed study of this bolus, optimized his recipe, analyzed his characteristics and tried to find the recipe with better cost benefit, homogeneous and with dosimetric characteristics of a beam in water.

2. MATERIALS AND METHODS

In this study different bolus samples were analyzed, which were manufactured by varying the proportions of part of their components: water and bi-distilled glycerin (density 1.25 g / cm^3) and 10% formaldehyde solution. In order to know the influence, the materials that compose it and check the materials resulting from the different proportions.

Table 1 shows the manufactured samples and their proportions. The amounts of gelatin were kept fixed.

Table 1: Samples analyzed in this paper.

Sample	Water (cm^3)	Bi-distilled glycerin (ml)	Gelatin (g)	Formaldehyde (ml)
A	0	100	75	5
B	100	0	75	5
C	100	0	75	0
D	200	0	75	5
E	0	200	75	5
F	100	100	75	5
G	100	200	75	5
H	200	100	75	5
I	200	200	75	5
J	300	100	75	5
K	300	200	75	5
L	300	300	75	5
M	400	300	75	5
N	400	400	75	5

2.1. Samples Manufacturing

Bolus was manufactured in the mold's room of the Erasto Gaertner Hospital in Curitiba, Paraná, Brazil. Samples A to E were made to verify the effect of water and glycerin concentrations on the bolus. The gelatin was mixed with each component and then the mixture was heated in a pot on a stove until completely dissolved. Everything mixed with a spoon. After 10 min, the foam that forms due to gelatin is removed, also with the spoon and then the 10% formaldehyde solution is added except for sample C.

The samples from F to N were manufactured as follows: the gelatin was hydrated with water, after the mixture was homogeneous, it was heated in a pot on a stove until completely liquefied, when the glycerin was then added and after 10 min the 10% formaldehyde solution. Everything mixed with a spoon. The foam formed should be removed during the process with a spoon to obtain a smooth and homogeneous bolus.

The mixture becomes liquid and can be placed in containers of different sizes and thicknesses. Allow 12 hours for the bolus to solidify completely.

2.2. Mass density and homogeneity

The mass density of the samples was calculated by direct mass and volume measurement, as well as an analysis of the Hounsfield units (HU) values was performed. The computed tomography of each sample was acquired by a standardized clinical tomograph (*GE Hispeed*), with the technique of 120 kVp, 130 mA and 3 mm slices. The tomograph is evaluated according to current legislation. The images resulting from the acquisition were later imported into Varian Medical Systems' Eclipse™ version 13.5 treatment planning system to determine sample HUs using a tool available in the system. The region of interest (ROI) analyzed for each image was 20 x 20 pixels, in order to not have a punctual reading, nor a large area.

2.3. Dosimetric Characteristics

The percentage depth dose (PDD) of two samples were measured and compared to the same curve obtained with a solid water phantom (PTW RW3 slab phantoms, density 1.045 g /cm^3). This measurement was performed with a parallel plate chamber (PPC05, IBA dosimetry) at a distance from the source to the surface of 100 cm, with a field size of 10 x 10 cm^2. A 6 MV photon beam of a CX linear accelerator (Varian Medical Systems) was used to measure PDD. And two clinical electron beams with 6 and 18 MeV energies were also used, representing two extremes of the energies clinically used in our radiotherapy department. For the measurement of electron PDD curves, measurements were made at a distance from the source to the surface of 100 cm with a 10 x 10 cm^2 applicator with the parallel plate chamber. We use a parallel plate chamber with PTW RW3 as it has more consistent results for low depths [10].

3. RESULTS

3.1. Qualitative malleability analysis of the samples

The samples were qualitatively analyzed at in order to know the behavior of his constituents in the final product and verified the malleability of the material. It is necessary that the bolus be malleable, to fit the shape of the patient. For a quantitative measure of the malleability, can be made using a Shore durometer 00. In the absence of such instrument was created a qualitatively scale.

The samples were evaluated by three researchers and the malleability was rated on a scale from 0 to 5, where 0 is a non-malleable material and 5 is a very malleable material. The results of this analysis it is show in Table 2.

Table 2: Qualitative malleability analysis results.

Scale	Samples results by each research			Samples results
	Research 1	**Research 2**	**Research 3**	**Final**
0	A	A	A	A
1	B, E	B, E	B, E	B, E
2	C, D, F, G, H	C, D, F, G, H	C, D, F, G, H	C, D, F, G, H
3	I, J, K	I, J	I, J, K	I, J, K
4	L, M	K, L, M	L, M	L, M
5	N	N	N	N

3.2. Mass density and homogeneity

The mass densities were obtained with measures of mass and volume, as show in Table 3, where is also shown the values of density obtain by the average of the mean values of HU [11, 12]. This was measured using ROI's of 20x20 pixels. Moreover, the measures were analyzed in three different slices, of the bolus tomography images. Two in regions close to the extremity of the samples, and one in the central region.

Table 3: Mass densities values measured and obtained by average of the mean HU values in three different slices of the bolus tomography images.

Samples	Densities (± 0,01 g/cm³)	Densities by HU values (g/cm³)
A	1,20	1,20
B	0,99	1,03
C	1,02	1,08
D	1,02	1,02
E	1,19	1,25
F	0,96	1,07
G	1,12	1,19
H	1,11	1,16
I	1,14	1,19
J	1,11	1,12
K	1,14	1,17
L	1,21	1,19
M	1,13	1,16
N	1,13	1,18

For the homogeneity analysis the averaged of the mean values of HU were evaluated, as well as the maximum, the minimum and the standard deviation values, also obtained by the software. The results are show in the Figure 1. Samples with the standard deviation values in all measurements below 10%, i.e., which had the smallest variation in HU values and also graphically, were considered homogeneous. These were: I, J, K, L, M and N.

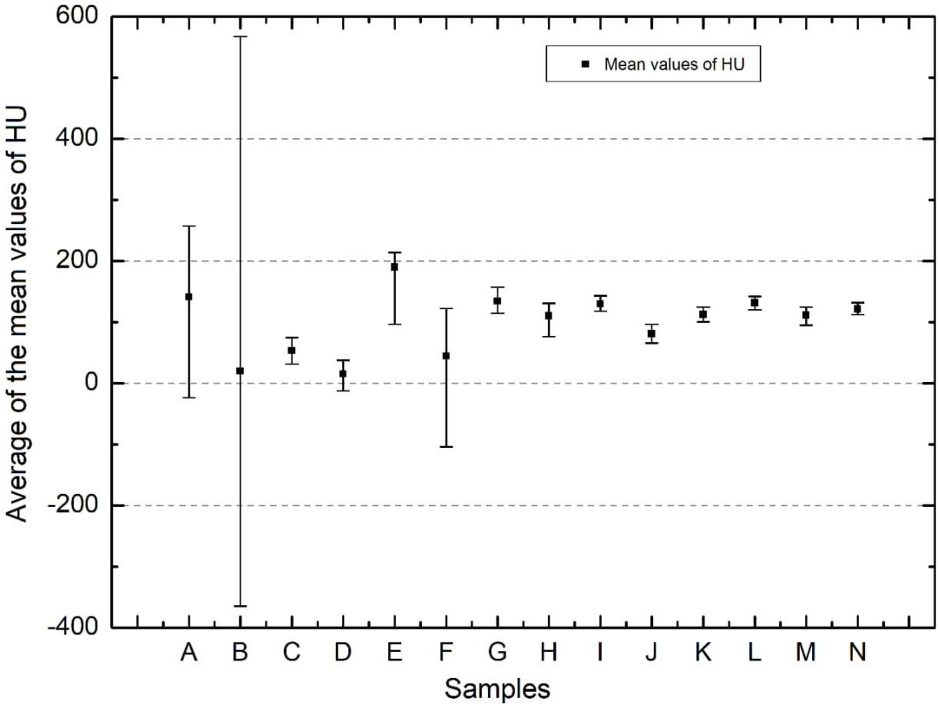

Figure 1: *Averages of the mean HU values. The upper limit is the average of the maximum HU values and the lower limit is the average of the minimum HU values.*

Through the density values obtained and the homogeneity and malleability analysis, the bolus chosen to perform the dosimetric measurements were M and N. Sample L would also be a good one, since it was homogeneous, malleable and the density by HU was close to the chosen ones. However, the mass density measured showed a greater difference compared to the solid water plate.

3.3. Dosimetric characteristics

Samples of various thicknesses from each bolus were made and the PDD of samples M and N were measured. The results were compared with the same curve obtained for the solid water phantom. Figure 2 shows the measurements for a 6 MV clinical photon beam, Figure 3 and 4 for the 6 and 18 MeV clinical electron beams, respectively.

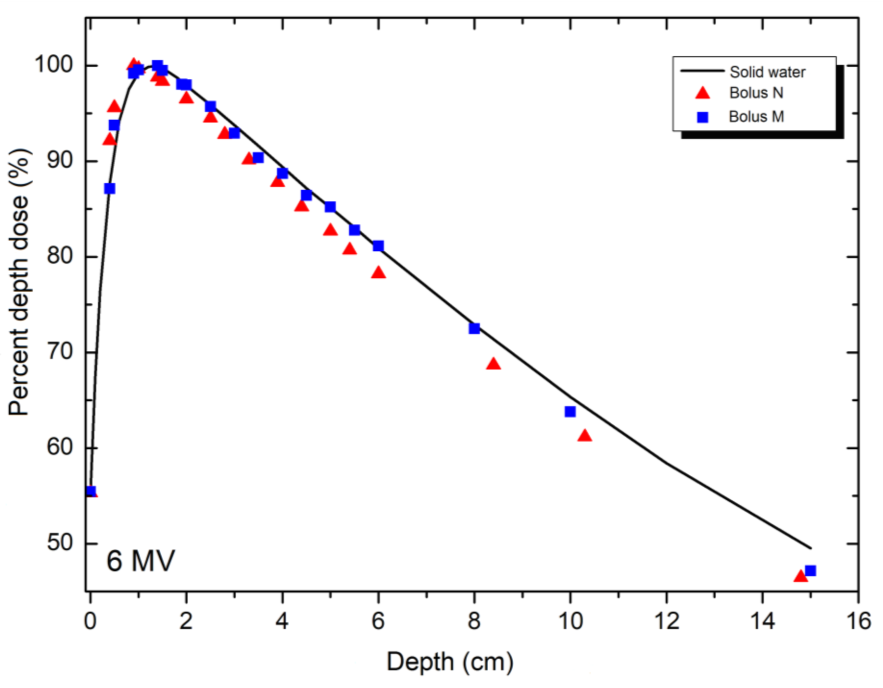

Figure 2: *Percent depth dose measured for a 6 MV clinical photon beam energy.*

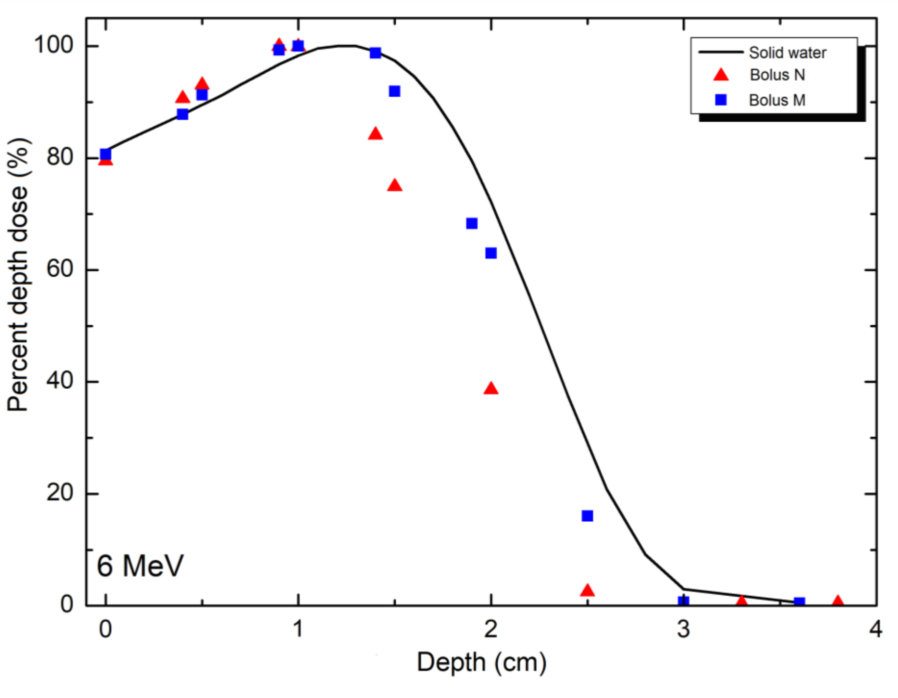

Figure 3: *Percent depth dose measured for a 6 MeV clinical electron beam energy.*

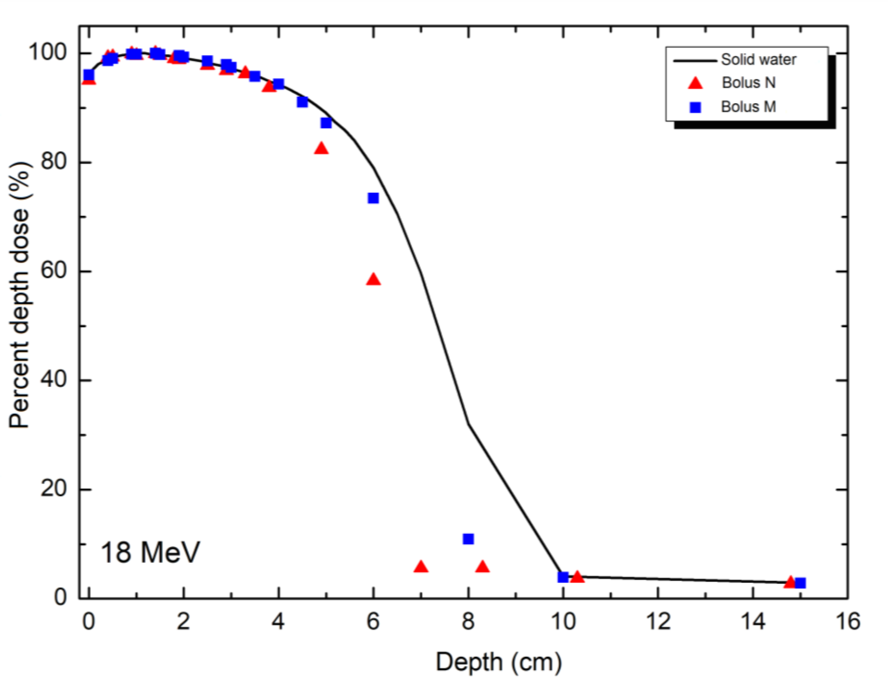

Figure 4: *Percent depth dose measured for a 18 MeV clinical electron beam energy.*

4. DISCUSSION

The advantage of using non-commercial bolus is its low cost, but the challenge is to obtain a homogeneous, malleable and durable material with comparable density to water. First, different recipes was investigated, in order to know the effects of the materials that composed the bolus.

After the manufacture of samples A, B, C, D and E it was concluded that glycerin and formaldehyde are components that influence the bolus hardness, since samples A and E were more rigid and, when samples B and C were compared, it was noted that after the formaldehyde was added, sample B hardened rapidly.

The amount of gelatin was not altered, since preliminary tests showed that if the amount of gelatin increased, the resulting bolus is less flexible and with greater hardness. Thus, with less gelatin there is a bolus with lower hardness and higher flexibility.

When a bolus without formaldehyde was manufactured, its degradation was observed within 5 days. The bolus with formaldehyde lasted a minimum of four weeks. Some, after two months of manufacture, sealed in PVC film and kept in a controlled environment (e.g. room of a linear accelerator) showed no signs of degradation, such as the presence of fungal colonies.

The foam formed during bolus manufacture is due to gelatin and is proportional to how much gelatin and water are mixed during heating and in the liquefaction process. The foam should be removed as it generates heterogeneity in the final bolus and may result in air bubbles. As the amount of water increased, foam formation decreased. Therefore, less material is lost as foam.

The malleability analysis was performed qualitatively. It was observed that the increase of water and bi-distilled glycerin generated more malleable and flexible materials. When comparing the samples M and N, it was noted that glycerin influences malleability, as sample N was more flexible and transparent.

Mass density values resulting from direct mass per volume measurements and the averaged of the mean values of HU were less than 10% apart for all samples, except for sample F, that presented 11%. The difference between these values is due to the heterogeneities present in the bolus that can be observed in the measurements of HU values. Moreover, the heterogeneities can't be evaluated by direct mass per volume measurements.

For samples M and N the mass density values resulting from direct mass per volume measurements were 13% different from water mass density (0.997 g / cm3) and 8% when compared to solid water PTW RW3. The averaged of the mean values of HU varied 16% and 18% in relation to the water mass density for samples M and N, respectively. In relation to solid water PTW RW3 the values varied 11% for sample M and 13% for sample N. The following equation was used:

$$Deviation = \frac{|Value_{reference} - Value_{obtained}|}{Value_{reference}} \; x \; 100 \tag{1}$$

Observing Figure 1, the samples that obtained the smallest variation in HU values were I, J, K, L, M and N, whereas the sample B was the one that varied the most in HU values. However, its density directly measured obtained an excellent value. Therefore, it is concluded that only directly measured density values are not sufficient to analyze the bolus material.

After studying the malleability, homogeneity and mass density values for the mentioned samples, it is concluded that the materials M and N would be dosimetrically evaluated, as they obtained expected results in all analyzes.

With the manufacture of different thicknesses, it was found that bolus N is not suitable for use when thicknesses greater than 3 cm are required. Increasing the thickness results in a sample with high "sagging" so that gravity squashes the sample after its manufacture, changing the initially fabricated thickness.

Bolus M is less malleable than N, but its properties are preserved after drying of the samples. In the bolus thickness range used in the radiotherapy service, up to 1.5 cm, both samples showed reproducibility.

The PDD curves were established for the M and N samples and compared to the PDD obtained with the PTW RW3 solid water plate, it was observed in Figure 2, that the sample M presented a maximum difference of 3% up to 1.5 cm depth, while sample N had a maximum difference of 5% at the same depth, both for a 6 MV photon beam. In Figure 3, the results of the PDDs obtained with a 6 MeV electron beam showed an even greater difference for regions smaller than 1.5 cm, 6% for sample M and 17% for N.

For an 18 MeV electron beam, as shown in Figure 4, both M and N samples distinguished from the PTW RW3 solid water plate after depths greater than 5 cm with differences greater than 50% for bolus N and 20% for bolus M. For depths less than 1.5 cm, good agreement of PDD curves with differences less than 1.5% was found.

The results show that PDDs from sample M obtained a smaller difference than those from sample N when compared to PDDs from solid water PTW RW3 in depths below 1.5 cm. We associate this with the fact that N has a higher amount of glycerin and thus a higher density.

5. CONCLUSIONS

The results of the malleability analysis concomitantly with the mass densities data measured directly and by the Hounsfield mean values, defined the M and N samples for the dosimetric characteristics verification. The evaluated PDDs for the M and N samples showed agreement and little difference in the percentage depth dose values at depths less than 1.5 cm, excepted for electron beam of 6 MeV, which difference was 17 % for the sample N. M sample presented better results for the 3 energies measured and was defined the best recipe between the samples studied in this work. The recipe offers a low cost, durability, malleability, homogeneity and good dosimetric results in most used thicknesses in a radiotherapy department.

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