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Validation of a cylindrical phantom for verification of radiotherapy treatments in head and neck with special techniques

Validação de um fantoma cilíndrico para verificação dos tratamentos radioterápicos na cabeça e no pescoço com técnicas especiais

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Abstract

Verification of radiotherapy treatments in head and neck requires, among other things, small volume chambers and a phantom to reproduce the geometry and density of the anatomical structure. New documents from the ICRU (International Comission on Radiation Units & Measurements), Report 83, established the need for quality control in radiotherapy with special techniques such as IMRT (intensity-modulated radiation therapy). In this study, we built a cylindrical acrylic phantom with standing water, containing seven measuring points in the transverse plane and free location (0-20 cm) in the longitudinal plane. These points of measurement are constituted by cavities for the accommodation of the ionization chamber of 7 mm of mayor diameter (semiflex, pinpoint with build cup). The results of the phantom validation yielded percentage differences less than 1% in fixed beams and less than 2.5% in arc therapy for TPS Eclipse calculation. The preparation of this phantom, particularly made to verify the head and neck treatments, was simple and reliable for checking the dose in radiotherapy with fixed beams and/or special techniques such as arc therapy or IMRT, so that will be sent to various radiotherapy centers in the country for dosimetric verification in such treatments.

Keywords: quality control, radiotherapy, intensity-modulated radiotherapy.

Resumo

A verificação dos tratamentos de radioterapia na cabeça e no pescoço exige, dentre outras coisas, câmaras de pequeno volume e um fantoma para reproduzir a geometria e a densidade da estrutura anatômica. Em novos documentos da ICRU *(International Comission on Radiation Units & Measurements)*, Relatório nº 83, estabelece-se a necessidade de haver controle de qualidade na radioterapia com técnicas especiais, como IMRT (radioterapia de intensidade modulada). Neste trabalho, foi construído um fantoma cilíndrico de acrílico com água estável, contendo sete pontos de medida no plano transverso e localização livre (0 a 20 cm) no plano longitudinal. Esses pontos de medida são constituídos por cavidades para acomodar a câmara de ionização de 7 mm de diâmetro maior (Semiflex, *Pinpoint with build cup*). Os resultados da validação do fantoma produzem diferenças percentuais menores que 1% em feixes fixos e menores que 2,5% na terapia com arcos para o cálculo TPS (sistema de planejamento de tratamentos) Eclipse. A preparação desse fantoma, feita particularmente para verificar os tratamentos para a cabeça e o pescoço, foi simples e confiável na verificação da dose na radioterapia com feixes fixos e/ou técnicas especiais, como terapia com arcos ou IMRT; portanto, será enviada a diversos centros de radioterapia no país para verificação dosimétrica em tais tratamentos.

Palavras-chave: controle de qualidade, radioterapia, radioterapia de intensidade modulada.

Introduction

Special treatments of radiation therapy should be dosimetric checked to ensure they receive a given dose volume. To make a dosimetric verification, it is necessary to have a phantom to reproduce the configuration of the treatment plan and simulate the structure of the patient. The absolute or relative dosimetric data used for dose calculations derived from measurements made in water, since it is the main component of the human body[1-5].

In areas with peculiar anatomical geometry, such as head and neck, standard phantoms (water cube) does not successfully reproduce this geometry, so the dosimetric control for a specific patient would not take place under

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similar conditions. For that reason, we recommend using a phantom that resembles the geometry and density of the anatomical structure, carrying out measurements closer to reality[1-5].

In this paper, we present the design and validation of a phantom for verification of radiotherapy treatment in head and neck. This phantom, with the support of the Institute of Public Health of Chile (ISP), will move to different radiation therapy centers in the country in order to evaluate and verify dosimetric treatment of head and neck with different special techniques.

Given the physical and chemical characteristics, it was decided to use a water phantom in a container of PMMA (acrylic), since it has a similar electron density ($\rho_{e,agua}$=5.85 and $\rho_{e,acril,}$=6.6), besides being a user-friendly material, durable and affordable[6]. Due to the physical characteristics of PMMA, it has minor differences with the measured dose in water. These are due to scattering in excess and energy absorption mass coefficient $\left(\frac{\mu_{en}}{\rho}\right)$, characteristic of this material. These differences can be corrected by a factor that reduces excessive scatter (*ESC*), and another, d_p, to adjust the depth of measurement, making it equivalent to that of water[7,8].

PMMA thickness equivalent to water is determined by the following equation:

$$d_W = \frac{\rho_P}{\rho_W} \cdot \frac{\left(\frac{Z}{A}\right)_P}{\left(\frac{Z}{A}\right)_W} \cdot d_P \qquad (1)$$

where:

d_p and d_w are the thickness of the acrylic and water;

ρ_P and ρ_W are the density of the acrylic and water;

$\left(Z/A\right)_P$ and $\left(Z/A\right)_W$ are the ratio of average atomic number and mass of acrylic and water, respectively[7].

It is necessary to correct the greater dispersion of photons produced in this material because of the electron density of PMMA. This point was raised by Casson[9] and discussed in the Protocol of the AAPM[10]. The correction factors for excess dispersion are listed in Table 1[7,8].

Table 1. Correction factors for excessive scatter for thickness and field sizes

Energy	Thickness (cm)	Field size 5	10	20
5 MeV	0.4	1.001	0.999	0.999
	0.8	1.000	0.999	0.998
	1.0	1.000	0.999	0.998
	1.5	0.999	0.998	0.998
	2.0	0.998	0.997	0.998
	3.6	0.996	0.996	0.997
	5	0.994	0.994	0.996

The reference values were taken from Attix[7] and interpolated for the thicknesses of acrylic of the phantom.

Material and methods

The materials needed for construction and validation of this phantom were:

Construction of phantoms:

- Acrylic cylinders.
- Acrylic tray.
- Rubber stoppers.
- Chloroform.
- Bi-distilled water.

To validate the phantom:

- Helical Tomography Phillips.
- Eclipse Software version 8.1. PBC algorithm.
- PTW ionization chamber Semiflex 0,125 cm^3.
- Unidos E electrometer, PTW.
- Varian Linear Accelerator “Clinac 21 iX”.

Phantom design

To determine the diameter of the cylinder, it were reviewed 30 CT scans of head and neck of adult patients, obtaining values between 12 and 16 cm in diameter neck. Given this, it was made a PMMA cylinder of 20 cm long by 14 cm in outer diameter.

For the choice of measurement points, two mutually perpendicular planes X and Y are considered, a point was located in the center of the circle in X plane at a distance 1/3 *r* (*r* = radius) and at a distance 1/2 *r* in Y plane; it was made in order to take points at different depths depending on the rotation of the phantom (Figure 1).

Validation process

We performed a CT scan of phantom with axial slices 5 mm thick. Phantom axially focused, locating at the center of it (center of the tube n. 3) in the isocenter, marking the central reference points denoted by lasers, scans the room (Figure 2b).

To validate the phantom, numerous measurements were made based on the Protocol 398 of the IAEA for a fixed standard field and SSD=100 cm, with the ionization chamber located at different depths allowing phantom, ensuring that the central beam impinges directly on the camera with

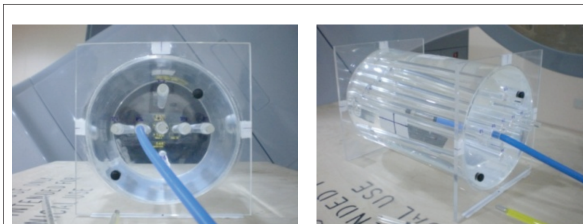

Figure 1. Front (left) and oblique (right) views of cylindrical phantom NM-1420 Beta, housing Semiflex ionization chamber of 0,125 cc. Measurement sites are horizontally located at a distance of 1/3*r* and vertically to 1/2*r*. The holes not used by the ionization chamber are occupied by acrylic rods 6 mm diameter.

minimal disturbance of PMMA (3 mm + 1 mm)[11,12]. These measurements were made with and without PMMA bars located in different cavities of phantom (Figure 2a).

We used bars of 6 mm diameter to fill the tubes for the accommodation of the camera and, thus, reduce the shock generated by a cavity with air when it does not fill the cavity.

Another set of measures was made with the central beam shining directly into the column and row of cavities for the accommodation of the ionization chamber, placing the latter at different depths with and without filler bars (Figure 2b).

It was planned a simple, direct and fixed field in the TPS, based on the configuration of Table 2. The ionization chamber was located in the tube of interest (1 to 7) with their effective point in the center of the beam, irradiating the phantom according to the plan set.

Using the equation 1, it was determined the correction factor for distance, C_{pl}. So, the maximum depth at d_m and each measuring point were calculated using the correction factor C_{pl}=1,147.

With the measurements obtained at different depths as cylindrical phantom allows (Figure 1), we determined empirically the PDD (percentage depth dose) and compared it with the PDD measured in water phantom used for the TPS (Table 3).

The doses measures were corrected for excessive scatter and depth. These correction factors were determined for the different thicknesses of acrylic from the phantom, according to the incidence angle of the central beam (Table 3).

Results

The correction of depth (displacement) varies from 0.5 mm to 4.9 mm, depending on the location of the measuring point and the incidence of the beam.

Despite the attenuation caused by PMMA rods, they strongly enhance the results of the measurements if they are performed without them. (Figures 3 and 4).

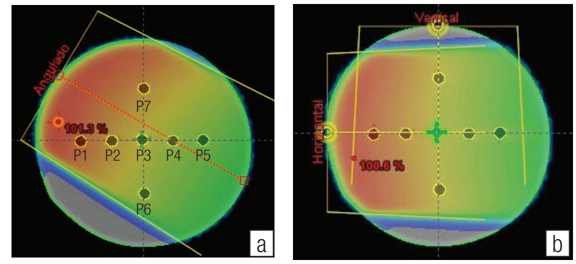

Figure 2. a) Front view of the cylindrical phantom with the beam passes at 315º the angle of the beam varies depending on the measuring point, so it falls directly on it (P4). b) The beam shining directly into a row and a column of camera holder cavities.

Table 2. Configuration for the cylindrical phantom irradiation

Collimator	0º	Stretcher	0º	Field size	10x10
SSD	100 cm	MU	50	Energy	6 MeV
Gantry angle	270º	0º	341º	321º	308
	300º	279.5º	295º		

Gantry's angles were calculated in such a way that the central beam falls directly on the place where one wants to measure the absorbed dose.

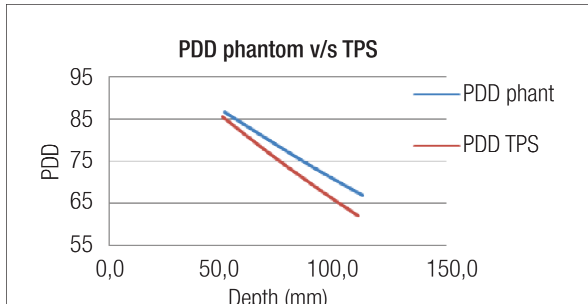

Figure 3. Measurements at different depths without filling acrylic rods; the beam incident at 0º and 270º passes through the various cavities in their way to the point of measurement.

Table 3. Comparison between measured PDDs cylindrical phantom with and without depth correction (*Hm/w*) and that used by the TPS measured in water

50 MU	Depth. TPS	Depth. Calc. Corr.	Dose measure no/corr.	PDD phant.	PDD TPS	Diff. %	Fact. depth. Hm/w'
Total thickness = 4 mm of Acrylic	30.0	30.6	46.92	93.47	94.34	0.9	1.010
	33.5	34.1	45.87	91.38	92.80	1.5	1.016
	47.1	47.7	43.06	85.78	87.17	1.6	1.017
	56.4	57.0	41.18	82.02	83.26	1.5	1.016
	70.0	70.6	38.45	76.59	77.66	1.4	1.015
	86.8	87.4	35.00	69.73	71.09	1.9	1.021
	104.1	104.7	31.83	63.40	64.81	2.2	1.024
						prom.=	1.016

It shows the depth of measurement (depth TPS), the depth of water equivalent thickness (depth calculated corrected), the PDD and the cylindrical phantom used by TPS, the percentage difference between them, and the depth correction factor *Hm/w'*.

Once the PDD of the cylindrical phantom was determined, we obtained the PDDs ratio. So, this depth correction factor *(Hm/w')* with excessive scatter factor (*ESC*) origin the *Hm/w* factor, allowing us to determine the absorbed dose at a point within the cylindrical phantom with a percentage difference less than 1% compared to the doses calculated by the TPS. (Figure 5 and Table 4).

For the evaluation of treatment with special techniques, rotational beam hemifields single and double (opposite) at different angles of rotation were verified. (Tables 5 and 6).

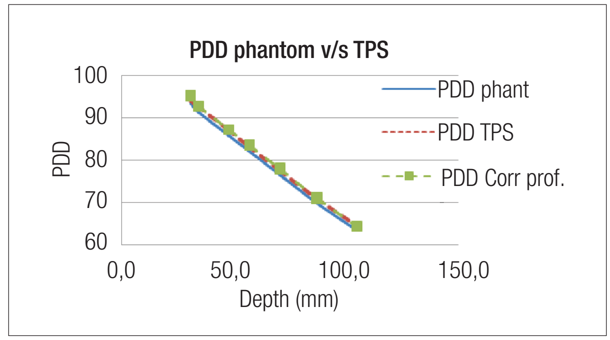

Figure 4. Comparison between PDDs used by TPS, measured in cylindrical phantom with and without depth correction.

Discussion

Measurements made without acrylic rods at points where the central beam pass through the cavities presented greater dosimetric changes due to reduced thickness of tissue.

The correction factor for excess scatter could be considered negligible because the thickness of acrylic phantom are very low and generate an excess of scatter between 0.07% and 0.45%.

The PDD of the cylindrical phantom, in respect of PDD in water phantom, showed differences between 1% and 2.3% without making corresponding corrections; however, considering the corrections by *Hm/w'* and *ESC,* the differences were less than 0.8%. One average factor *Hm/w=1.015* could be used to calculate dose at different depths, and the results would differ by less than 1%.

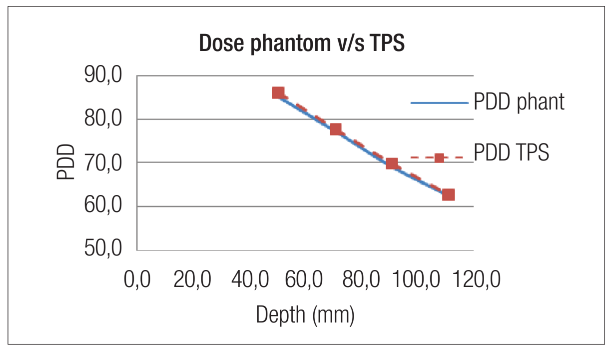

Figure 5. Measurements at different depths with acrylic rods filling inside the cavities. The central beam directly affects the spine and/or row of cavities to the point of measurement. Note the similarity between the PDDs.

Table 4. TPS calculated dose and measured in NM-1420 Beta phantom, corrected for depth *(Hm/w')* and excess scatter *(ESC)*

50 MU	Depth TPS	Depth calc. corr.	Dose meas.	ESC	Hw/m'	Dose phant.	Dose TPS	Diff. %
Total thickness = 4 mm of Acrylic	30.0	30.5	46.89	0.999	1.016	47.68	47.4	-0.6
	33.5	34.0	45.84	0.999	1.016	46.62	46.6	0.0
	47.1	47.6	43.03	0.999	1.016	43.76	43.5	-0.6
	56.4	56.9	41.18	0.999	1.016	41.84	41.8	0.1
	70.0	70.5	38.45	0.999	1.016	39.07	38.9	-0.4
	86.8	87.3	35.00	0.999	1.016	35.57	35.7	0.4
	104.1	104.6	31.83	0.999	1.016	32.34	32.5	0.5

Table 5. Absolute percentage difference between calculated dose and measured in TPS cylindrical phantom

Cylindrical phantom	Arc		MU	Difference %			
PLAN	INI	FIN		P1	P2	P3	P4
80 open	270	350	217	-0.1	-0.4	-	-
120 open	270	30	223	1.5	0.1	-0.1	-
150 open	270	60	228	2.1	2.1	0.0	-
180 open	270	90	233	1.5	1.7	-0.2	1.9

Missing values were not considered because they were in high gradient areas.

Table 6*.* Differences between calculated and measured doses to do in opposing arcs

Cylindric phantom	Arc		MU	Difference %			
PLAN	INI	FIN		P1	P2	P3	P4
80 open x2	0	80	106	0.4	0.1	-0.8	0.4
100 open x2	0	100	107	0.6	0.7	-0.5	0.3
150 open x2	0	150	112	0.9	0.5	-0.5	0.1
180 open x2	0	180	115	0.7	0.3	-1.1	-0.1

The P1, P2, P3, and P4 are measuring points (Figure 2a).

It is possible to incorporate such Pinpoint ionization chamber or micro Pinpoint, adapting PMMA bar to the geometry of each chamber.

Conclusion

The cylindrical phantom *NM-1420 Beta* turned out to be very practical, attainable and reliable to realize measurements in structures that resemble this geometry, with percentage differences less than 1% in fixed beams and less than 2.5% in rotational beams with respect to the TPS calculation.

It is very useful in verifying head and neck treatments, with stationary technique, arc therapy, allowing them to perform control in the various centers of the country where are made treatments with special techniques like arc therapy.

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