

Design and development of a pediatric phantom to entrance surface air kerma measurements

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Abstract

The objective of this study was to design and construct a new pediatric head phantom in order to simulate a five years old child. It was constructed in four parts in a cylindrical shape: two pieces in PMMA, one in aluminium and one in PVC. The pencil ionization chamber can be inserted in the PMMA pieces. All the materials are recommended by the ICRU report 44. Preliminary tests were made in the RQT radiation qualities (IAEA, TRS 457) in order to obtain the surface air kerma entrance and the absorbed dose.

1. Introduction

The need for images generated by high resolution CT scan to enable precise and reliable diagnosis is the reason for frequent studies in medical radiology. Their technological advances result in an acquisition speed increasing and the patient exposure time reducing. The possibility of the sedation elimination for pediatric patients, used to limit the children movement, is the reason for the increase in CT procedures in pediatrics exams [1,2]. Since the children have smaller body structure that is in constant change, they are more susceptible to a cancer development when they are exposing to high doses of radiation. Radiologists, technologists and physicians should taking account that low noise images, even if they do not have high resolution, can provide adequate diagnostic information. So, reducing parameters as kV and mAs it is possible to reduce the patient dose under CT procedures [3].

Although the International Atomic Energy Agency, IAEA, published in 2007 a code of practice (TRS 457) recommending procedures for dosimetric measurement in diagnostic radiology[3], and in 2011 its implementation providing a practical guidance to professionals at the Secondary Standards Dosimetry Laboratories (SSDLs) and to clinical medical physicists[4], a special guidance on dosimetric standards and methodologies related to dosimetry for pediatric patients undergoing diagnostic radiology was needed and in 2013 it was published the IAEA human health Series No. 24 [5].

The basic dosimetric quantities applied to CT measurements are: $C_{a,100}$ (free air kerma index), C_w (weighted index of dose), C_{vol} index (volumetric air kerma) and P_{KL} (air kerma-length product) [3].

The CT equipment uses collimated X ray beams and perform axial slices of the human body and the image is generated using a computational method were the CT numbers are in Hounsfield Unit (HU) related to the attenuation coefficient (μ) of each voxel (volume pixel) [6]. Physical and/or Computational phantoms are used to determine the CT quantities and evaluate the relation between the CT numbers and the organ density in terms of HU.

The diagnostic reference levels published by the Brazilian Health Ministry were determined using only typical adults water phantoms with 150 mm x 160 mm (head) and 150 mm x 300 mm (abdomen) [7]. The objective of this study was to design and construct a new pediatric head phantom in order to simulate a five years old child.

1.1 Physical and Computational Phantoms

A variety of phantom types has been developed with the aim of quality control programs dosimetry and research measurements. All of them (physical and computational) are used to simulate the ionizing radiation transport and body tissue interaction.

Many types of material can be used to build physicals phantoms as solid PMMA, water filled or anthropomorphic. They can be seen in Fig. 1 [6,8,9].

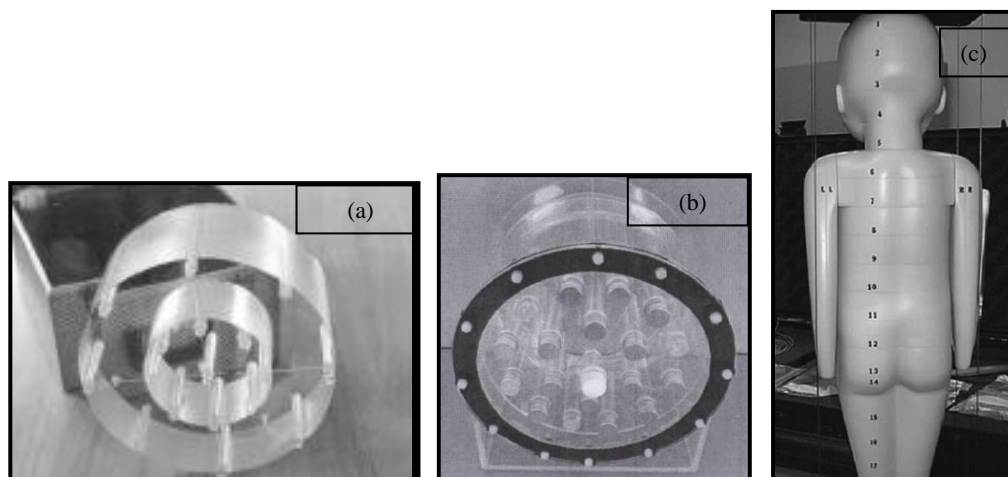


Figure 1: (a) PMMA solid phantom, (b) Water filled PMMA phantom, (c) 5 years old anthropomorphic phantom

Fig. 2 shows two adults computational phantoms, male and female, named MAX_AA (Male Adult voXel_Average-Average) and FAX_AA (Female Adult voXel_Average-Average).

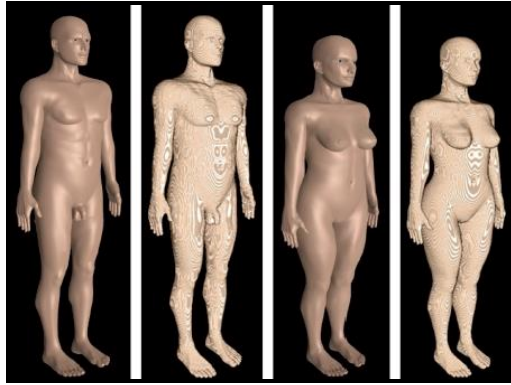


Figure 2: MAX_AA and FAX_AA phantoms and their voxel version

2. Materials and Methods

2.1 The measurements were performed using a 9015 Radcal Dosimeter, with a pencil ionization chamber 10X5-3CT, with 3 cm³ shown in Fig 3.



Figure 3: Pencil ionization chamber and a 9015 Dosimeter, from Radcal Corp.

The CT standard radiation qualities were established in a X radiation system Pantak/Seifert, Isovolt HS 160 model, MXR-160/22 tube, voltage variation from 100 kV to 150kVp (RQT 8, 9 e RQT 10). The phantom was placed at 100 cm from the focal spot, Fig. 4.

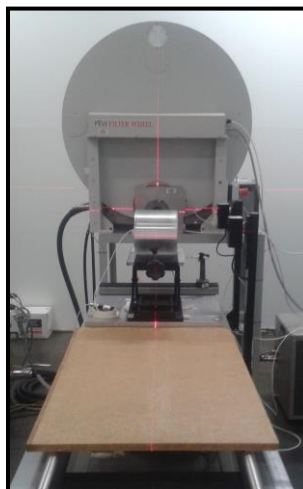


Figure 7: Set up of the X radiation system, Pantak Isovolt HS 160

2.2. Phantom Design and Construction

The phantom pieces were made using aluminum, PMMA and PVC billets by the workshop of IPEN.

The material choice must consider its human tissue equivalence, density and the attenuation coefficient related to the specific simulated tissue [10]. In this work, the pediatric phantom was designed in four cylindrical parts, simulating a five years old child head dimensions. Its materials characteristics follow the ICRU-Report 44 recommendation, as Table 1[11].

Table 1: ICRU – Report 44 tissue equivalence materials

Material	Description	Density (g/cm ³)
PMMA (muscle)	(C ₅ H ₈ O ₂) _n ; PMMA	1.17
Aluminum (bone)	Al	2.7
P. V. C. (bone)	(C ₂ H ₃ Cl) _n ;	1.35

The PMMA cylinders and rods with depth of 155 mm are in Fig. 5. The external cylinder has an external diameter of 160 mm and 20 mm of wall thickness which has a hole to insert the ionization chamber. The internal cylinder has 111.8 mm of diameter, a central hole to insert the ionization chamber and a valve to fill it with water. To make the phantom solid when the ionization chamber is not inserted, two PMMA rods with 155 mm were made.

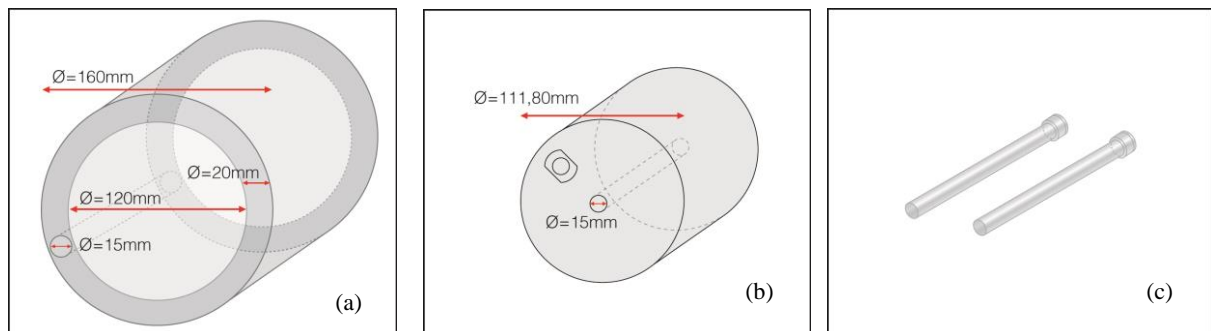


Figure 5: (a) external cylinder, (b) internal cylinder and (c) rods

One cylinder of aluminum and another of PVC were made to simulate the skullcap and they can be placed between the external and the internal cylinder, as presented in Fig.5. They were constructed with the same dimensions, 119.9 mm of external diameter and thickness of 4 mm. Their drawings are on Fig. 6.

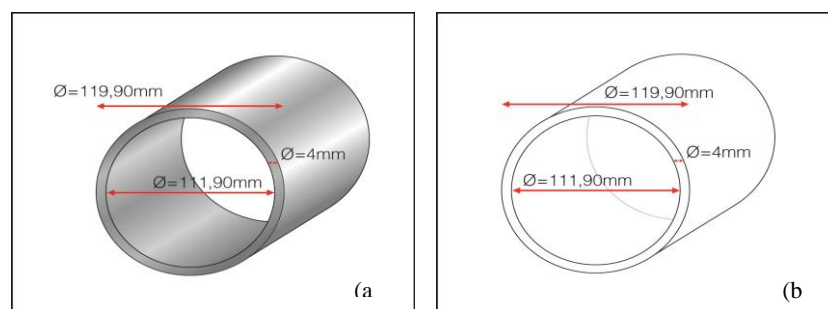


Figure 6: Skullcap cylinder (a) Aluminum and (b) PVC

The Fig. 7 shows how the pieces must be assembled to create the pediatric phantom.

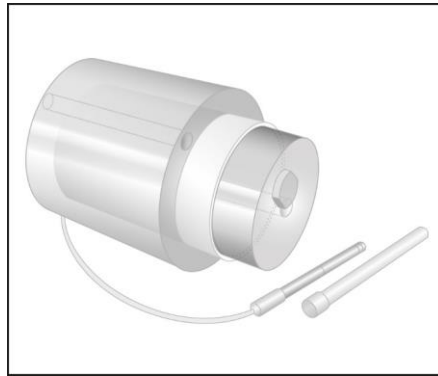


Figure 7: Pediatric phantom scheme

The peripheral measurements with the ionization chamber inserted were made in the regions showed in Fig. 8, varying the angle of the ionization chamber in relation to the X ray beam.

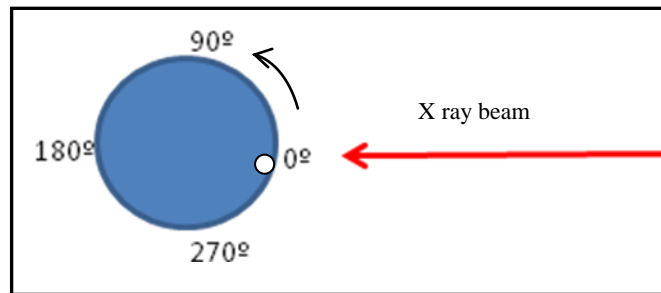


Figure 8: Ionization chamber positioning inside the phantom varying the angle in relation to the X ray beam

3. Results

The constructed pediatric phantom with all the pieces separated and mounted is presented in Fig. 9. The preliminary tests were made using the skullcap aluminum

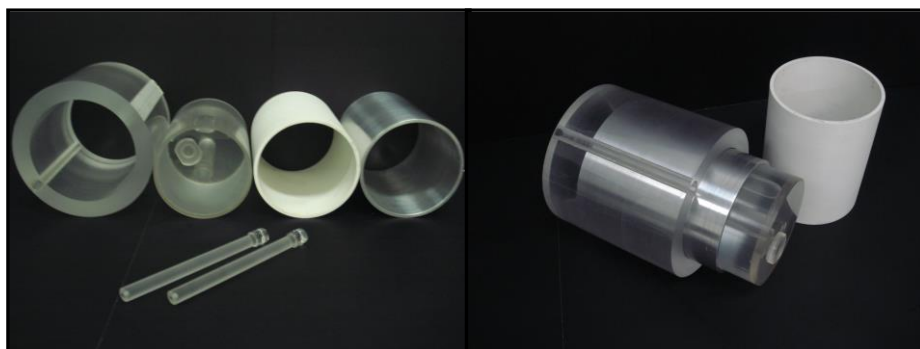


Figure 9: Pediatric head phantom constructed at IPEN.

So far, the $C_{a,100}$ (free air kerma index) and the C_w (weighted index of dose) were determined to each established radiation quality, using the TRS 457 recommendations. The obtained values are in Table 2.

Table 2: Obtained values of the CT index : $C_{a,100}$ (free air kerma index) and C_w (weighted index of dose)

Radiation qualities	$C_{a,100}$ (mGy)	$C_{PMMA,C}$ (mGy)	$C_{PMMA,P}$ (mGy)	C_w (mGy)
RQT 8 (100 kV)	2.267	2.265	2.047	2.119
RQT 9 (120kV)	3.48	3.483	3.141	3.255
RQT 10 (150kV)	5.77	5.765	5.188	5.381

4. Conclusions

The preliminary results show that the developed pediatric head phantom can be used to determine the main CT dosimetric quantities. The C_w obtained values are between the confidence level as suggested by the IAEA code of practice [3].

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