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Study of CT Acquisition Protocols Using Two Head Phantoms

Estudo de protocolos de aquisição de TC usando simuladores de duas cabeças

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Resumo

Os exames de Tomografia Computadorizada (TC) promovem uma deposição de dose maior do que os exames de radiologia convencionais. Esses exames aumentaram significativamente as doses dos pacientes e a dose coletiva, se tornando uma preocupação de saúde pública global. Há uma grande necessidade de aprimorar protocolos para buscar doses menores mantendo a qualidade da imagem diagnóstica. O desenvolvimento de objetos simuladores permite testar diferentes protocolos de aquisição. Neste estudo foram testados dois objetos cilíndricos simuladores de cabeça de polimetilmetacrilato (PMMA). Um dos objetos simuladores de cabeça de TC é o modelo padrão de cabeça com 16 cm de diâmetro e o outro objeto simulador de cabeça desenvolvido é menor com 12 cm de diâmetro. Ambos os objetos simuladores têm 15 cm de comprimento. Diferentes protocolos de aquisição foram realizados num tomógrafo Philips, modelo Access com 16 canais. A fatia central dos objetos simuladores foi irradiada sucessivamente e as medições foram realizadas usando uma câmara de ionização do tipo lápis para obter os índices de *kerma* no ar em PMMA ($C_{k,PMMA,100}$) e os índices de dose de CT (CTDI). A partir desses resultados, foram obtidos os valores de índice de dose em TC ponderado e volumétrico ($CTDI_w$, $CTDI_{vol}$) para varreduras de 10 cm da região central dos objetos simuladores da cabeça, no modo helicoidal. As varreduras foram realizadas utilizando diferentes valores de tensão (80, 100 e 120 kV) e carga (mA.s). Os valores de dose variaram de 5,59 a 21,51 mGy. O maior valor de dose registrado foi de 21,51 mGy para o objeto simulador de cabeça menor e 19,25 mGy para o objeto simulador de cabeça padrão com 120 kV. Considerando a geração de imagens com o mesmo objetivo diagnóstico, os resultados obtidos mostraram que o índice de dose volumétrica ($CTDI_{vol}$) apresentou maior valor de dose no objeto simulador de 12 cm de diâmetro. Este objeto simulador tem um volume menor que o de cabeça padrão.

Palavras-chave: Tomografia Computadorizada; Objeto Simulador; Dosimetria; Qualidade de Imagem.

Abstract

Computed Tomography (CT) scans promote a higher dose deposition than conventional radiology exams. These exams have significantly increased patient and collective doses and have become a global public health concern. There is a great need to improve protocols to seek for lower doses while maintaining the diagnostic image quality. The development of phantoms allows the testing of different acquisition protocols. In this study were tested two cylindrical head phantoms of polymethylmethacrylate (PMMA). One CT head phantom is the head standard test with 16 cm in diameter and the other head phantom developed is smaller at 12 cm in diameter. Both phantoms are 15 cm long. Different acquisition protocols were performed on a Philips CT scanner, Access model with 16 channels. The central slice of the phantoms was irradiated successively and measurements were performed using a pencil ionization chamber to obtain the CT air Kerma indexes in PMMA ($C_{k,PMMA,100}$) and CT dose indexes (CTDI). From these results, the CT Dose Index values weighted and volumetric ($CTDI_w$, $CTDI_{vol}$) were obtained to 10 cm scans of the central region of the head phantoms, in helical mode. The scans were performed using different voltage values (80, 100 and 120 kV) and charge (mA.s). Dose values varied from 5.59 to 21.51 mGy. The highest recorded dose value was 21.51 mGy for the smaller head phantom and 19.25 mGy for the standard head phantom with 120 kV. Considering the generation of images with the same diagnostic objective, the results obtained showed that the volumetric dose index ($CTDI_{vol}$) presented a higher dose value in the 12 cm diameter phantom. This phantom has smaller volume than the standard head phantom.

Keywords*: Computed Tomography; Phantom; Dosimetry; Image Quality.*

1. Introduction

Computed Tomography (CT) is one of the most used exams for radiological diagnosis in medicine. It is a very quick test and produces high quality images. However, the increasing demand for CT tests has a considerable impact on doses provided to patients and on the exposure of the population as whole, being a public health concern worldwide (2). According to UNSCEAR 2020/2021 report, the use of CT contributed with 62% of the collective dose from diagnostic radiological tests (3). Many factors collaborated to the increase in the demand for CT scans, including the constant technological evolution of the equipment associated to greater availability and a relative tendency to decrease exam costs (4,5).

Dose reduction in pediatric patients is already a concern among professionals from different areas of health, with international dose reduction programs, such as *Image Gently*, which aims to raise awareness among professionals, alert to the development of methods that can reduce the dose without compromising image quality in pediatric exams and provides specific guidelines for medical physicists (4,5). The risks of stochastic effects increase in children due to the tissue radiosensitivity allied to the long-life expectancy. The dose deposited in a pediatric patient is directly related to the energy that was retained during the process of exposure to ionizing radiation (5,6).

The increasing demand for CT scans in pediatric patients is mainly due to the high rates of traumatic injuries from car accidents, falls on bicycles, blunt trauma, traumatic brain injury, as well as a significant increase in the incidence of childhood neoplasms, being the CT images used in the diagnostic process (7,8). A retrospective study of a cohort of pediatric patients exposed to CT scans demonstrated that cumulative doses of 60 mGy to the brain may triple the risk of brain tumor (9). Therefore, acquisition protocols should be used that determine the reduction of the radiation dose without compromising the diagnostic quality.

Patients undergoing CT scans can range from neonates to oversized adults. However, radiation doses in CT are generally measured in cylindrical PMMA phantoms, that represent a standard adult patient. These phantoms are designed to simulate a head with 16 cm in diameter, and a body with 32 cm (10,11)

It is difficult to obtain reliable quantitative values of patient doses from any measurements performed on these standard phantoms, because patients have sizes and body compositions that can differ markedly from the phantoms, such as pediatric and obese patients. The development of phantoms allows testing different acquisition protocols (12,13). For this, the phantoms must have an X-ray beam absorption characteristic similar to the represented patient.

In this study, two CT head phantoms were used, the standard head phantom and another with smaller volume to observe the dose distribution and to obtain the dose index (CTDI). Different protocols were used in the phantom CT scans using three X-ray tube voltages.

2. Materials and Methods

The experiment was conducted using a Philips scanner, Access model with 16 channels. For the development of this work, experimental measures have been obtained using two head phantoms, both made in polymethylmethacrylate (PMMA). These phantoms were constructed by the research team of the Center for Research in Biomedical Engineering (CENEB), being a representative of a standard adult and a pediatric patient's head size. The standard adult head phantom is cylindrical with 16 cm in diameter and 15 cm in length. This phantom is considered the standard for the dose reference in head CT scans. The pediatric head phantom is also a cylinder and has a dimension of 12 cm in diameter and 15 cm in length, representing a smaller head. The Figure 1 shows the image of these phantoms placed in the isocenter of the CT scanner gantry.

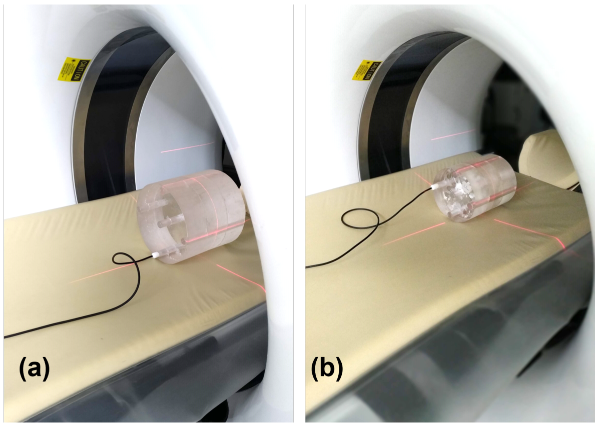

Figure 1. PMMA head phantom: (*a*) Adult standard; and (*b*) pediatric.

These cylindrical phantoms have five openings for positioning the dosimeters, one central and four at the peripheral openings, which are displaced from each other by 90°. The openings are 1.25 cm in diameter and 15 cm in length. The center of the peripheral openings is 1 cm from the edge of the phantom. Figure 2 shows an illustration with the dimensions of the adult and pediatric phantoms made of PMMA.

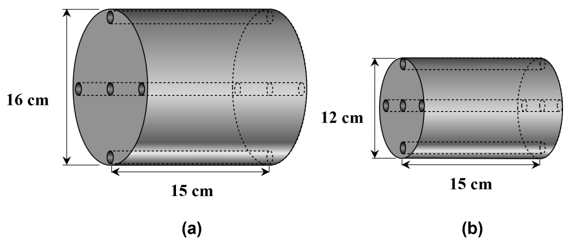

Figure 2. Head phantoms dimensions: (*a*) Adult standard; and *(b)* pediatric.

Dose measurements have been performed by positioning the head phantom in the isocenter of the gantry and aligning the openings like as the positions 3, 6, 9 and 12 of an analog clock, through the help of the CT scanner lasers. The phantom openings are filled with PMMA rods which must be removed one by one for the positioning of the pencil ionization chamber, targeting the dose measurements in the five positions.

A pencil ionization chamber RADCAL ACCU-GOLD model 10X6-3CT was used to measure the CT air kerma in PMMA ($C_{k,PMMA,100}$) in each opening of both phantoms. The ionization chamber was calibrated in the LABPROSAUD - Laboratory of Health Products - Calibration Laboratories Service - Ionizing Radiations. First, a scout was made in order to check the correct alignment of the phantoms as well as to demarcate the central slice position. Furthermore, the central slice of the phantoms was irradiated successively. For each chamber positioning, 5 measurements were performed, getting a minimum of 25 measurements for each protocol and for each phantom. In the central slice irradiations, the remaining openings were filled using PMMA rods. From these results, the CT Dose Index values, weighted and volumetric ($CTDI_w$, $CTDI_{vol}$), were obtained for 10 cm scans of the central region of the head phantoms, in helical mode (14,15).

The $CTDI_w$ and $CTDI_{vol}$ were calculated according to the Equations (1) and (2):

$$CTDI_w = \frac{1}{3}.(CTDI_{100,central} + \frac{2}{3}.CTDI_{100,per}) \quad (1)$$

$$CTDI_{vol} = \frac{CTDI_w}{pitch} \quad (2)$$

where $CTDI_{100,central}$ is the dose index value obtained at the central role and $CTDI_{100,per}$ is the average dose index value at the peripheral roles, in a 100 mm central axial region around the center position of the head phantom. The scans were performed using different voltage values (80, 100 and 120 kV) and charge (mA.s). To obtain the CT Dose Index (CTDI) values from the air kerma values the measurements were adjusted using a conversion factor (F_c) air/PMMA. The Fc used were 1.0418, 1.0324, and 1.0106 for the X-ray beam generated with 120, 100 and 80 kV, respectively (15,16).

The protocol for irradiation of the phantom central slice, in axial mode, used the following parameters: current of 100 mA, charge of 100 mA.s, tube rotation time of 1 s, beam thickness of 10 mm and three voltage values (120, 100 and 80 kV).

Helical scans of 10 cm in length were also performed in the central region of the head phantoms, aiming to define a current value adjusted by the equipment's automatic exposure control (auto mA), using the different voltage values. Usually, in the initial slices of the scan there is an adjustment in the current value (mA) in the first slices irradiated and after these adjustments the current stabilizes, since all the slices of the phantom have the same size. Head acquisition protocols often use a constant current value (mA), as the axial section of the head does not have large diameter variations.

With the current reference value defined based on the current recorded in the central slice, new scans were made to test fixed current values, lower than the value suggested by the automatic current control scan. For each current value tested, pixel noise value was calculated in the image of the central slice and the best current value was determined for each phantom and voltage.

The protocols used in the scans of the central region of the phantom used pitch values closest to 1, that is available in the CT equipment. Table 1 shows the CT head scanning protocol used in the service routine, regardless of the patient's size or age.

Table 1. Routine protocol of the CT scanner.

Voltage (kV)	Current (mA)	Charge (mA.s)	Time (s)	Pitch
120	73.7	110.5	1.5	1.0625

Source: The Author (2023).

Dose reduction in patient's CT scans was performed by increasing the pitch value to close to 1, thus decreasing patient re-irradiation and varying the charge value (mA.s). Three different values of available voltages were tested and keeping the reconstructed image in 1.25 mm, already defined in the routine protocol of the service. Both increasing the pitch and decreasing the mA.s promote an increase in the pixel noise of the image [17,18].

Unlike human organs, which are composed by the association of different tissues, PMMA is homogeneous; on the Hounsfield scale, PMMA has a value around 118.7 for images generated with an X-ray beam of 120 kV. As it is a homogeneous material it is possible to evaluate the variation of pixel noise in the images generated by different acquisition protocol tested. In acceptance tests of CT equipment during installation, the pixel noise must be less than 1% for tests with a PMMA phantom [17,18,19].

In order to validate the quality of the CT images, a noise analysis of the central slice image was performed in each helical CT scan, aiming at maintaining the diagnostic quality of the images. The noise value had its maximum acceptable limit of 1%, considering that the phantom is homogeneous [19,20]. This noise limitation, using a homogeneous material, implies in the generation of diagnostic images of the human body. Then, as a control parameter for testing new protocols, it was defined that the noise threshold in the central slice image should be 1% to guarantee the diagnostic quality of the patient's image. This value is recommended by the manufacturer when testing for acceptance of CT equipment after installation [18,19,20,21].

Four regions of interest (ROI) were selected in the image and were analyzed. The noise (N) was calculated as the percentage value of the standard deviations in relation to the average value of the Hounsfield scale (HU) through Eq.3.

$$N\% = \frac{SD}{\overline{HU}+1000}.100 \quad (3)$$

3. Results

3.1. Dose Measurements

Table 2 shows the average values and standard deviations of punctual and weighted air *kerma* in PMMA ($C_{k,100,PMMA}$ and C_w) and weighted CT Dose Index ($CTDI_w$) that were obtained from $C_{k,100,PMMA}$ measured in the five positions of the phantoms, using the parameters defined in Table 1 with the charge fixed in 100 mA.s.

Table 2. The Values of C_w and $CTDI_w$ in mGy for head phantoms.

Phantoms	Voltage (kV)	C_w (mGy)	$CTDI_w$ (mGy)
Adult (16 cm)	120	18.48±0.32*	19.25±0.33
	100	11.07±0.16	11.54±0.17
	80	5.36±0.10	5.59±0.10
Pediatric (12 cm)	120	20.65±0.23	21.51±0.24
	100	12.49±0.10	13.02±0.11
	80	6.15±0.06	6.40±0.06

*Standard deviations
Source: The Author (2023).

The protocol using the voltage of 120 kV has the highest absorbed dose value recorded of 19.25 mGy in the adult phantom and 21.51 mGy on the pediatric phantom. The minimum value happened in the adult and pediatric phantoms with the 80 kV voltage, with the values of 5.59 mGy and 6.40 mGy respectively.

Analyzing the measurements obtained, it is verified that with the pediatric phantom the values are always the highest, since the other parameters used were the same; the volume of the pediatric phantom is smaller than the adult, promoting a higher dose deposition.

3.2. Optimized CT Scan Protocols

Table 3 shows the results of volume CT Dose Index ($CTDI_{vol}$) obtained when the routine and optimized protocols were used in both phantoms with different voltage values and optimized charge in the X-ray tube during the scans of the central region of the phantoms. In optimized protocols, the optimized charge value (mA.s) was adjusted to the point where the noise in the central slice was less than 1%. The other parameters: pitch, tube time, thickness beam and image reconstruction were the same of the routine protocol (Table 1).

Table 3. Routine and optimized protocols.

Phantoms	Protocol	Voltage (kV)	Charge (mA.s)	$CTDI_{VOL}$ (mGy)
Adult (16cm)	Routine	120	110.5	20.02 ± 0.34*
	Opt. 1	120	35	6.34 ± 0.11
	Opt. 2	100	60	6.51 ± 0.09
	Opt. 3	80	130	6.83 ± 0.12
Pediatric (12cm)	Routine	120	110.5	22.87 ± 0.39
	Opt. 4	120	25	5.06 ± 0.06
	Opt. 5	100	40	4.90 ± 0.04
	Opt. 6	80	90	5.43 ± 0.05

*Standard deviation
Source: The Author (2023).

In Table 3 it is possible to observe the variation of the absorbed dose values for both phantoms for the analysis of the protocol that presents the lowest dose for the patient, maintaining the image quality. In the adult head phantom, the absorbed dose in the routine protocol had a higher dose of 20.02 mGy and with the optimized protocols smaller doses were obtained. The optimized protocol Opt.1 with 120kV had the lowest value of 6.34 mGy with a reduced dose of 68.33% in relation with the routine protocol.

On the other hand, the pediatric head phantom presented a significant variation in the absorbed dose values. The absorbed dose in the routine of the pediatric phantom had a higher dose than the adult phantom with a dose of 22.87 mGy that is 14.23% higher. The optimized protocol Opt. 5 with 100kV reduced the dose in the pediatric phantom in 78.6% in relation with the routine protocol. Figure 4 shows a graphic with the $CTDI_{vol}$ values for adult and newborn phantoms obtained according with the average current and pitch.

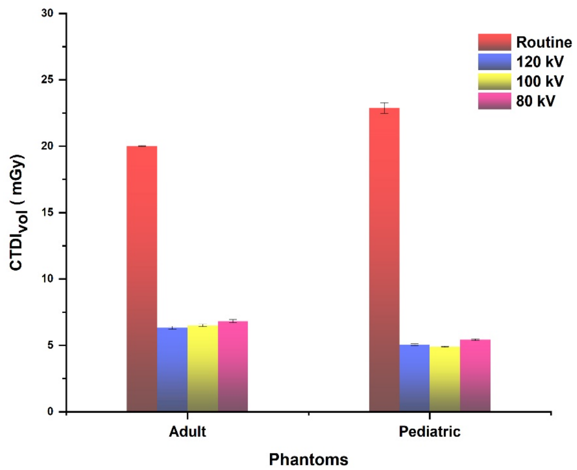

Figure 4. $CTDI_{vol}$ values for adult and pediatric head phantoms obtained with routine and optimized protocols.

Observing the absorbed dose values obtained for the tested protocols, it is verified that the pediatric phantom had a better CT scan with the voltage of 100 kV. The optimized protocols selected with the low absorbed dose obtained noise values below 1%, being a good alternative to be used aiming the reducing of absorbed dose of the patient and maintaining the diagnostic quality of the image.

It is also worth noting that the tested protocols showed in Table 3 were selected among several others tested with the variation of the mA.s value until a noise lower than 1% was obtained in the analysis of the image of the central slice. The mA.s and pitch variation cannot be chosen randomly, since there are discrete values in the CT equipment menu that are possible to be tested.

5. Conclusion

The absorbed dose index values were determined during head CT scans with the standard adult and pediatric PMMA phantoms.

This work made it possible to highlight relevant information on dose reduction in head CT scans in adults and children, which is of great importance to argue for the adoption of optimized protocols without loss of diagnostic image quality. In addition, the use of optimized protocols increases the useful life of the CT X-ray tube, generating less expenses for the radiodiagnosis service.

Dose values were significantly higher in the pediatric phantom using the same routine protocol than the adult. In the generation of images with the same diagnostic objective, the volumetric dose index showed a higher dose value in the pediatric phantom, corresponding to a head with smaller volume, compared to the value measured in the standard head phantom.

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