



## Dosimetry Study in Head and Neck of Anthropomorphic Phantoms in Computed Tomography Scans

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Received 03 January 2020; Accepted 19 February 2020

### Abstract

**Objectives:** To determine the CT absorbed dose profiles for routine adult scan parameters in adults, using male and female anthropomorphic phantoms. Compare the levels of absorbed dose of the phantoms and perform image quality analysis by making noise percentage measurements on the CT images obtained. **Methods:** Radiochromic film strips were introduced in the central region of the phantoms for to record the dose profile in head and neck in order to determine the amount of the dose deposited along the central axis of the phantoms. The scans were performed on a 64 - channel CT scanner (General Electric), programmed in helical scanning mode. In addition to the routine acquisition protocol with fixed current value, it was performed other three scans with the voltage of 80, 100 and 120 kV, using automatic exposure control. **Results:** Absorbed dose values were found between 15.54 to 24.38 mGy on average for anthropomorphic male phantom and values of 13.13 to 21.49 mGy for anthropomorphic female phantom. Noise analysis was performed, finding that all are acceptable diagnostic parameters according to ministerial order 453/98 of the Brazilian Ministry of Health. The acquisition parameters of CT images were found that deposited on average less doses in the head and neck for both phantoms, maintaining the image quality for diagnosis.

**Keywords:** Dosimetry; Computed Tomography; Anthropomorphic Phantom.

## 1. Introduction

Since ionizing radiations began to be used in medical applications for the diagnosis and treatment of diseases, the doses to which the population has been exposed are increasingly higher. In 2008, in the United States, the diagnostic technique that showed the highest dose deposition in the population was CT scans. Studies carried out in the Unified Health System of Brazil (*SUS*) reported that, between 2001 and 2011, authorized CT head scans for inpatients and outpatients had increased 14.7% and 17.5%, respectively [1-3].

The use of anthropomorphic phantoms in CT dosimetry studies has been a great help in proposing to optimize image quality in new acquisition protocols. The female and male Alderson Rando anthropomorphic phantoms have physical properties similar to that of a patient, such as geometry, weight and equivalent materials to human body tissues. The use of radiochromic films in anthropomorphic phantoms has allowed obtaining absorbed dose profiles in different places considered as radiosensitive organs [4-9].

The radiochromic films are calibrated for different energy intensities separately, due to their energy dependence. Studies carried out with PMMA cylindrical head phantom and ionization chambers determined the calibration curves for radiochromic films GAFCHROMIC XR-AQ2 for different voltages of CT X-ray tube [10, 11].

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 <http://dx.doi.org/10.28991/SciMedJ-2020-0201-6>

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## 2. Materials and Methods

### 2.1. Materials

The materials and equipment used for the development of this dosimetry study were:

- Anthropomorphic male and female phantoms, Anderson Rando model
- Radiochromic film strips, GAFCHROMIC XR-AQ2 model
- GE CT scanner with 64-channels, model VCT

### 2.2. Methods

The male and female anthropomorphic phantoms were positioned in isocenter of the CT scanner gantry. Radiochromic film strips with dimensions of 0.5 x 32 cm<sup>2</sup> were inserted in the longitudinal axis section of anthropomorphic male and female adult phantoms. The CT scanner was setting in helical mode for head scans to realize acquisitions with the voltages of 80, 100 and 120 kV, using the automatic exposure control to make scans of 30 cm, performing 12 phantom slices, from the top of the skull just the phantom slice number 12 (vertebra T2.. Another CT scan was performed using the routine protocol with voltage of 120 kV with a fixed current of 200 mA. The scans were performed with a tube time of 0.5 s, pitch of 0.984, image reconstruction of 1.25 mm and thickness beam of 40 mm. Figure 1 illustrates a frontal scouts of anthropomorphic phantoms.

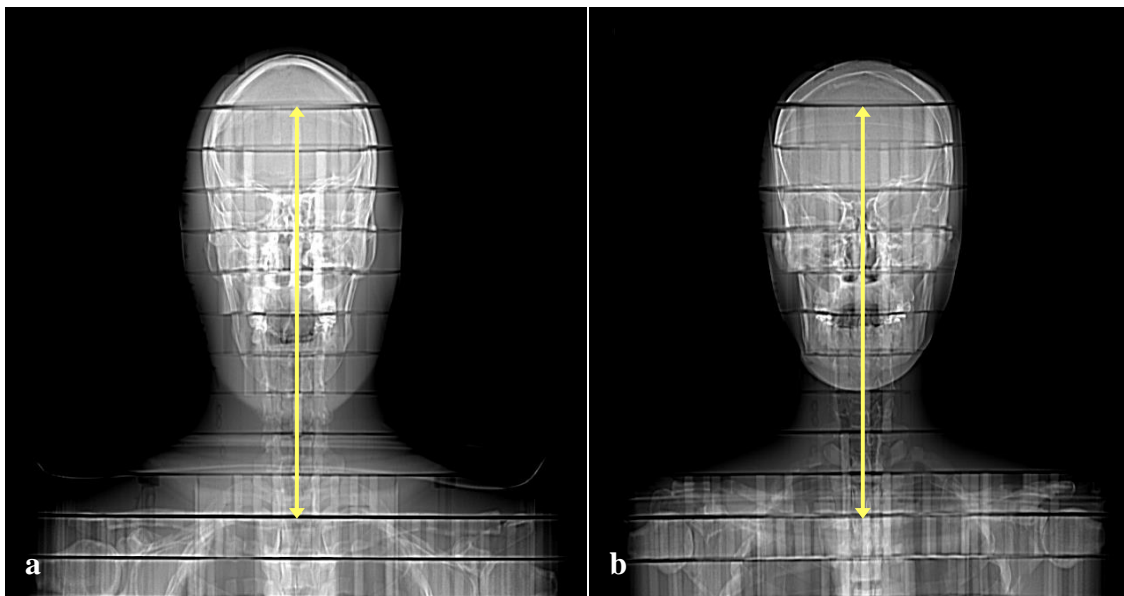


Figure 1. Scout of male (a) and female (b) anthropomorphic phantoms

The exposed film strips were stored of 24 hours, with temperature and humidity control. They were digitized using a HP Photosmart C4480 scanner in reflective mode and these images processed using ImageJ software to obtain the pixel intensity values of the scanned strips images with 25 cm in length, including the phantom slice 2 just to slice 12. The pixel intensity values was obtained making the RGB color split channels and the red channel was elected because it presents better response to X-ray energy variations. The red channel images were the greyscale inverted to have the intensity values. The pixel intensity values for film strips none irradiated it was considered 0 mGy (zero miligrays).

The absorbed dose values are obtained from the pixel intensity values using calibration curves for each voltage value to get air kerma values [10]. The conversion factors used to determine the dose profile for each protocol in the anthropomorphic phantoms. The calibration curves are meeting the following mathematical model: The absorbed dose values are obtained from the pixel intensity values using calibration curves for each voltage value to get air kerma values [8]. The conversion factors used to determine the absorbed dose profile for each protocol in the anthropomorphic phantoms were 1.0106, 1.0324, and 1.0418 for 80, 100 and 120 kV [12]. The noise analysis was performed electing a CT axial image in the brain using the RadAnt software of the phantom slice number 3. Four ROI's were selected in each image and the average noise percentage calculated. Equation 1 was used to calculate the noise values.

$$y=(A e^{-x^B}+y_0) \times FC \tag{1}$$

Where  $A$ ,  $B$  and  $Y_0$  are proportionality constants for each energy,  $X$  is the intensity pixel value,  $FC$  is the conversion factor from NIST [12] and  $Y$  is the adsorbed dose value. The proportionality constants values are shown in Table 1. The noise analysis was performed electing a CT axial image in the brain using the RadAnt software of the phantom slice number 5. Four ROI's were selected in each image and the average noise percentage calculated. Equation 2 was used to calculate the noise values.

$$\text{Noise \%} = 100 \times (\text{SD}) / (\text{HU}_{\text{average}} - \text{HU}_{\text{air}}) \tag{2}$$

Where  $SD$  is the standard deviation,  $HU_{\text{average}}$  is the HU average value of the ROI and  $HU_{\text{air}}$  is the HU value of the air (-1000).

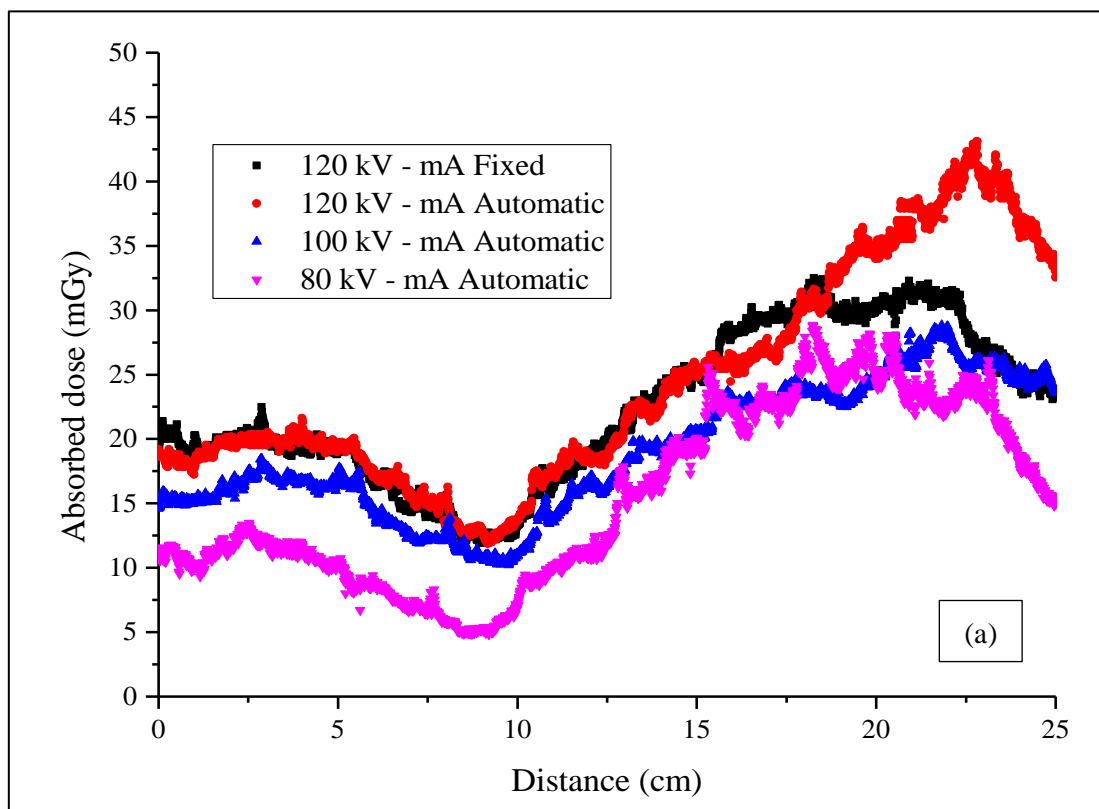
**Table 1. Proportionality constants for calibration films**

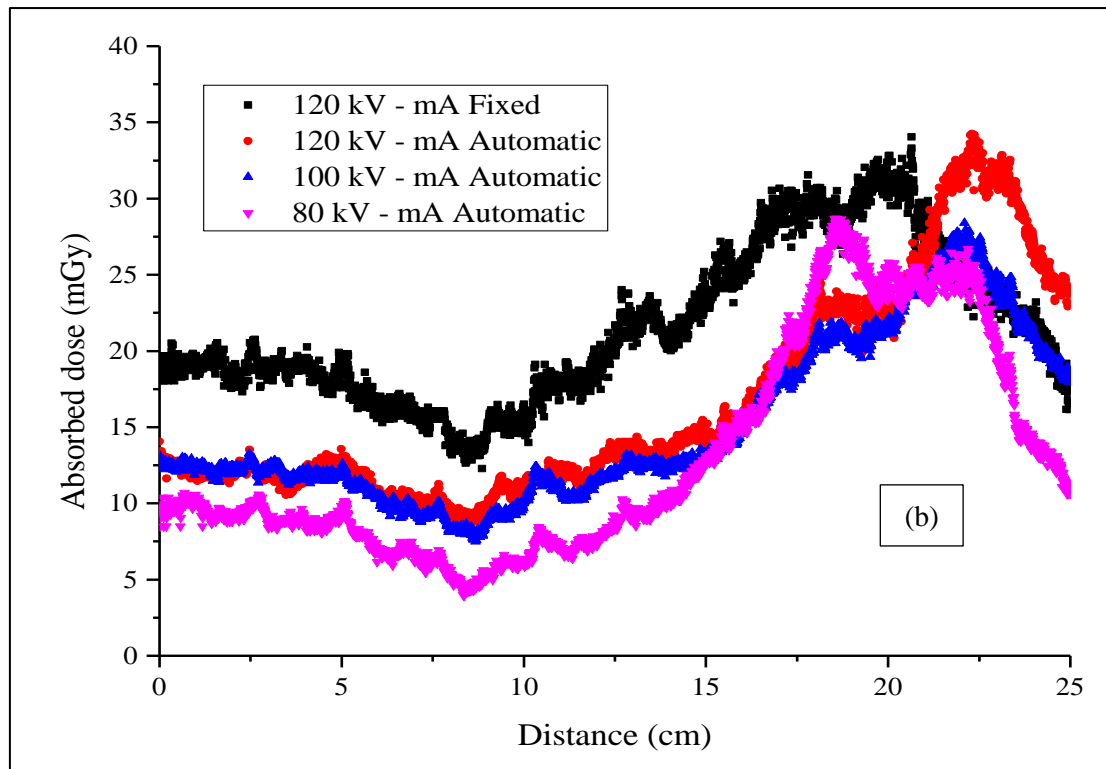
kV	120	100	80
A	4.45	5.10	0.93
B	48.46	53.18	27.89
$y_0$	9.88	10.64	3.69
FC	1.10	1.01	1.09

### 3. Results

The curves in the graphs of the Figure 2 shown the dose variation in the central area of the phantoms for the four scans using different parameter in acquisition protocol. These scans start in the brain (0) just to the up of the lungs (25 mm). The absorbed dose in the region referring to the brain, presents little variation because there are small variations in density in the materials which the phantom was manufactured. The data recorded in the mandible region were the lowest for the image acquisition protocols used in this study. The image acquisition protocol that registered the lowest absorbed dose values in the head and neck areas was the one that used 80 kV.

As the X-ray beam begins to scan the chest region, greater attenuation is evident by the materials present in this region, causing the scanner to deposit more energy, producing a higher absorbed dose in the chest. The protocol that recorded a higher peak of absorbed dose in the chest region was 120 kV with automatic exposure control.





**Figure 2. Dose profile in head and neck CT scans in anthropomorphic male phantom (a) and anthropomorphic female phantom (b)**

For scans in anthropomorphic male phantom, the lowest average dose was observed for the protocol with voltage of 80 kV and automatic exposure control. Compared to the routine protocol (120 kV and fixed current), the reduction observed was of 30.62%. Figure 2a shows the absorbed dose profiles for each protocol used. The average values of absorbed dose for 100 kV had a 15.26% reduction and 120 kV with automatic exposure control had an increase of 8.66%, compared to the routine CT head scan.

For scans in anthropomorphic female phantom, the lowest average absorbed dose was observed for voltage of 80 kV and automatic exposure control, followed by protocol with voltage of 120 kV and fixed current. Figure 2b represents the absorbed dose profiles for each protocol used. The average values of absorbed dose for 80 kV and automatic exposure control had a 38.90% to reduction compared to the routine CT head scan. For voltage 100 and 120 kV used automatic exposure control, they had 29.97% and 22.61% to reduction of absorbed dose compared to the routine CT head scan.

The absorbed dose curves for the four protocols used in this study show similar variations between them. However, the registered mean dose values vary according to the acquisition parameters with which the scanner was programmed. The average values of absorbed dose and their standard deviation (SD) for phantoms and different image acquisition parameters are shown in the Table 2.

**Table 2. Average absorbed dose in mGy for anthropomorphic female and male phantoms**

	80 kV		100 kV		120 kV		120 kV*	
	Absorbed dose (mGy)	SD	Absorbed dose (mGy)	SD	Absorbed dose (mGy)	SD	Absorbed dose (mGy)	SD
Female	13.13	7.02	15.05	5.39	16.63	6.86	21.49	5.03
Male	15.54	6.95	18.98	5.09	24.38	8.52	22.40	5.95

\* With fixed current.

Significant differences in absorbed dose were found by comparing the two types of phantoms. The male phantom with higher absorbed dose values in all the protocols used in this study. Comparing the two phantoms, average absorbed dose difference of 15.51%, 20.71%, 44.09% and 4.06% were found for 80, 100, and 120 kV with automatic exposure control and 120 kV with fixed current respectively.

The absorbed dose peak recorder every 2.5 cm are the product of the interaction of the x-ray beam with the air present between the phantoms slices.

Noise analyzed was made for TC images of slice number 5 of the phantoms for each of the protocols used. The ROI's selected shown the Figure 3. The values in percentage of noise found in the images are shown in Table 3.

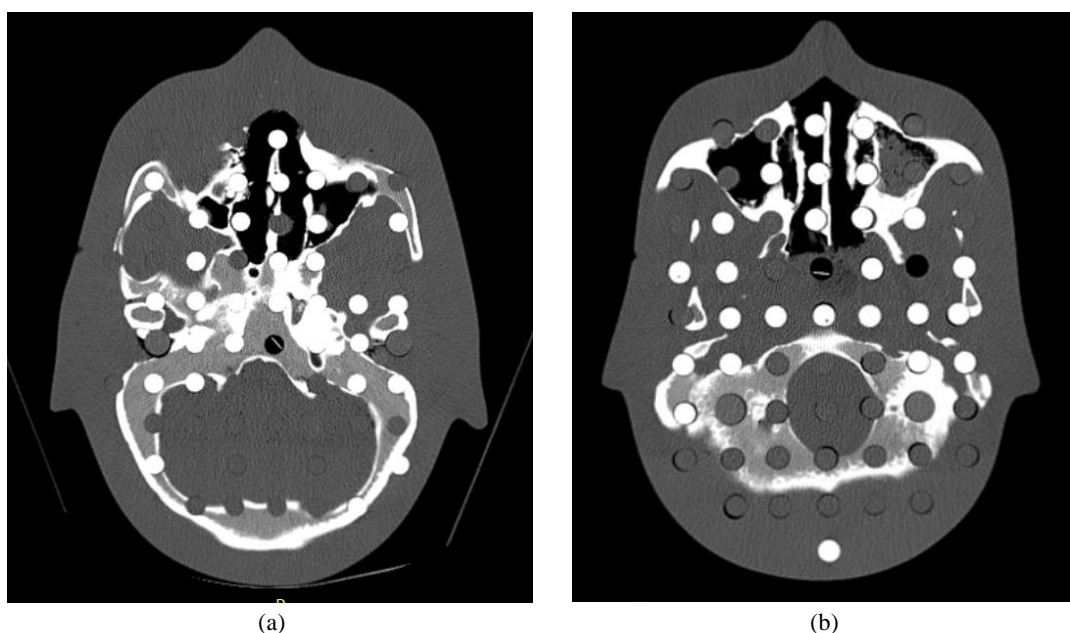


Figure 3. CT head images of (a) male and (b) female anthropomorphic phantoms

Table 3. Noise percent from CT images of anthropomorphic phantoms

Phantom	Noise %			
	80 kV	100 kV	120 kV	120 kV*
Female	8.43	6.03	7.10	6.12
Male	1.42	1.29	1.62	1.68

The noise indexes in the CT images of anthropomorphic phantoms did not exceed 8.5%, which reached a value greater than 10%. The female phantom CT images have higher noise percentages than those found in the male phantom CT images.

#### 4. Conclusion

The dose profile variations showed the presence of small peaks due to the air layer between the phantoms slices. The highest dose values were recorded in the chest and the lowest values near the mouth area, for all tested acquisition protocols. The use of radiochromic films as absorbed dose recording devices allows, with the recording of the dose profile, to consider the contribution in the dose of secondary radiation in CT scans. Dosimetry studies carried out with phantoms of identical characteristics, using thermo luminescent dosimeters (TLDs) located in regions close to the region where this study was conducted, and recorded lower dose values than those recorded with radiochromic films due to the use of different parameters of acquisition of CT images. The images acquisition parameters than deposited the lowest dose values in the two phantoms used were voltage 80 kV and automatic exposure control. The use of this protocol means an optimization in head and neck CT scans. The recorded absorbed dose values are lower than values suggested by the order 453/98 [13] of the Brazilian Ministry of Health that is of 50 mGy for CT head scans. The percentage of noise found in the CT images in the female phantom was higher because there is evidence of a difference in materials with which it was manufactured when compared to the CT images obtained with the male phantom.

#### 5. Funding and Acknowledgements

The authors are thankful to CAPES, FAPEMIG for their support of developing this study and CDTN/CNEN for

the loan of the phantoms. The funds provided for development of this study were made available by CAPES and FAPEMIG in the form of scholarship and research projects.

## 6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## 7. Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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