Estimation of MSAD values in computed tomography scans using radiochromic films*

Estimativa dos valores de MSAD em procedimentos de tomografia computadorizada utilizando filmes radiocrômicos

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Abstract **Objective:** To evaluate the feasibility of using radiochromic films as an alternative dosimeter to estimate the multiple scan average dose on the basis on kerma profiles. **Materials and Methods:** The radiochromic films were distributed in cylinders positioned in the center and in four peripheral bores of a standard abdominal phantom utilized for computed tomography dosimetry. **Results:** Values for multiple scan average dose values corresponded to 13.6 ± 0.7, 13.5 ± 0.7 and 18.7 ± 1.0 mGy for pitch of 0.75, 1.00 and 1.50, respectively. **Conclusion:** In spite of results showing lower values than the reference level for radiodiagnosis (25 mGy) established by the Brazilian regulations for abdominal studies, it is suggested that there is room to optimize procedures and review the reference level for radiodiagnosis in Brazil.

Keywords: Kerma profiles; Computed tomography; Radiochromic films; MSAD.

Resumo **Objetivo:** Verificar a viabilidade de filmes radiocrômicos como um dosímetro alternativo para estimativa da dose média em cortes múltiplos a partir dos perfis de kerma. **Materiais e Métodos:** Os filmes foram distribuídos em cilindros posicionados no centro e nas regiões periféricas de um objeto simulador padrão de abdome utilizado para dosimetria em tomografia computadorizada. **Resultados:** Os valores de dose média em cortes múltiplos calculados foram 13,6 ± 0,7, 13,5 ± 0,7 e 18,7 ± 1,0 mGy para os valores de passo (*pitch*) de 0,75, 1,00 e 1,50, respectivamente. **Conclusão:** Apesar de os resultados mostrarem valores menores que o nível de referência de radiodiagnóstico de 25 mGy estabelecido pela legislação brasileira para exames de abdome, eles sugerem que há espaço para otimização dos procedimentos e uma revisão do valor para o nível de referência de radiodiagnóstico brasileiro.

Unitermos: Perfis de kerma; Tomografia computadorizada; Filmes radiocrômicos; MSAD.

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INTRODUCTION

The main objective of patient dosimetry in computed tomography (CT) is determining the dosimetric quantities for the establishment and utilization of the diagnostic reference levels (DRL) in addition to risk assessment. In many situations it is desirable to make measurements directly; however, it is preferable to utilize a patient phantom[1].

In the clinical practice, the doses to patients are specified on the basis of measurements performed on standard phantoms for CT dosimetry. The kerma index ($C_{a,100}$) and the weighted kerma index (C_W) are the basic dosimetric quantities utilized in CT. The $C_{a,100}$, measured in the air for a single rotation of the CT X-ray tube, is the quotient of the integral of air kerma along a line parallel to the rotation axis for a length of 100 mm and the nominal slice thickness. The notation $C_{PMMA,100}$ is utilized for measurements performed within polymethylmethacrylate (PMMA) phantoms. The C_W combines the values of $C_{PMMA,100}$ measured in the center with the mean value of the four peripheral positions of the phantom. The C_W is utilized in combination with the scanning parameters to calculate volumetric kerma index (C_{VOL}), which provides a better mean value of the volume. The air kerma length product ($P_{KL,CT}$) is determined for a complete CT scan, and is analogous to the dose length product introduced by the European Commission[2]. Multiple scan average dose (MSAD) has also been utilized for dosimetry in Brazilian CT apparatuses, and is intimately related to C_{VOL}[1].

In compliance with international recommendations[4], the Brazilian regulations have included DRL in terms of MSAD. The following values are adopted: 50 mGy for the head, 35 mGy for the lumbar spine and 25 mGy for the abdomen in a typical adult[3]. The DRLs must be utilized for quality control of CT apparatuses in order to optimize the procedures as the doses exceed the specified values[3].

The relevance of improving the methods of dosimetry and radiological protec-

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tion has been object of a number of recent studies published by Brazilian authors in different areas of knowledge[5–11]. In CT, measurements of dosimetric quantities are performed by means of a calibrated pencil-type ionization chamber. Previous studies have also suggested the utilization of thermoluminescent dosimeters (TL)[12,13] and radiochromic films[12,14–16] in order to obtain kerma profiles and calculate the MSAD values from such alternative materials for dosimetry in CT. Several other studies[17–20] have established the response to the dose and to the energy dependence of the radiochromic films, XR-CT model, designed for measurements in CT.

The present study proposes estimating the MSAD of three standard imaging protocols for CT abdomen studies, with different pitch values, in order to verify the viability of radiochromic films as an alternative to ionization chamber and TL dosimeters. Results for MSAD calculated from kerma profiles were compared with the values established by the Brazilian regulations, with the purpose of undertaking a critical analysis of such DRL.

MATERIALS AND METHODS

The measurements were performed with Gafchromic XR-CT radiochromic films in 100 mm × 9 mm strips, in a four-channel GE Bright Speed apparatus located at a hospital in the city of Belo Horizonte, MG, Brazil. The metrological reliability of radiochromic films was demonstrated by means of tests of homogeneity and repeatability and by their calibration at a specific CT reference radiation (RQT9), reproduced in the Calibration Laboratory of Centro de Desenvolvimento da Tecnologia Nuclear (CDTN/CNEN).

The film calibrations and measurements were obtained in an abdomen PMMA phantom with 320 mm in diameter and 150 mm in length, with five parallel bores (one in the center and the others peripherally located, at 3h00, 6h00, 9h00 and 12h00 positions. For the calibration, radiochromic film strips were inserted into the chamber cap[16] and positioned inside the phantom bores, reproducing exactly the position of the 10X5-3CT 100 mm pencil-type ionization chamber (Radcal Corporation) calibrated according to the established procedures[21]. The obtained results were compared with the purpose of obtaining the respective calibration coefficients. The phantom with the inserted radiochromic films was positioned at the isocenter of the CT apparatus (Figure 1).

A topogram (scout view) was acquired with the purpose of verifying the materials positioning and limiting the irradiation area to the length of the phantom. A single scanner rotation was selected and the irradiation was performed according to the standard protocol for adult abdomen in the center of the chamber cap, i.e., where the sensitive region of the ionization chamber would be. The following parameters were utilized: 120 kV, 4 × 2.5 mm slices and 242.4 mA.s.

For the measurements, the chamber cap was replaced by new radiochromic film strips positioned along the PMMA cylinders (Figure 2) and distributed in the center and four peripheral bores of the phantom, according to the following parameters: I) 120 kV, 4 × 2.5 mm slices, 242.4 mA.s and 0.75 pitch; II) 120 kV, 4 × 2.5 mm slices, 240.0 mA.s and 1.5 pitch; III) 120 kV, 2 × 0.625 mm slices, 80.0 mA.s and 1.00 pitch. Such parameters were based on a study developed in the hospital itself aimed at changing imaging protocols in order to reduce the radiation dose, and to utilize a pitch equal to 1.00.

The exposed films were digitized with a Microtek ScanMaker 9800XL scanner in the reflection mode. Digitization parameters were the following: RGB color mode (48 bits per color) and 300 dpi. The red channel was selected for calibration because such radiochromic films have a main absorption peak in the red region of the visible spectrum (636 nm). The MSADs were calculated from the values of the defined integrals obtained in the center of the phantom for the three protocols with different pitch values. The utilized integration limits corresponded to the length of the radiochromic films (100 mm).

RESULTS

All measurements were converted into kerma values in the PMMA, utilizing the ratio between the attenuation coefficients of air and of the PMMA, corresponding to approximately 1.07[22]. The radiochromic films presented homogeneity of 6.9% and repeatability of 4.3%. Their calibration coefficients in terms of air kerma for RQT9 (120 kV) are shown in Table 1.

The kerma profiles along the longitudinal axis, in the five regions where the cyl-

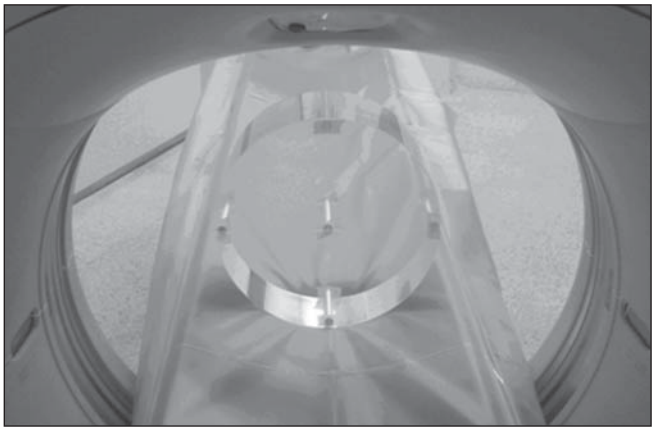

Figure 1. Positioning of the phantom at the isocenter of the CT scanner.

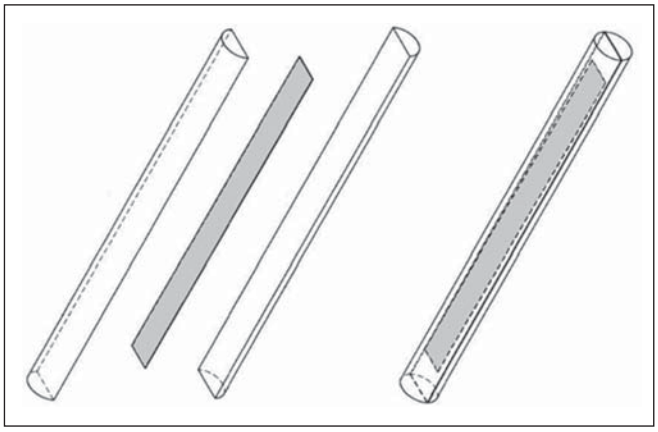

Figure 2. Positioning of the radiochromic film in the PMMA cylinder.

inders were inserted in the phantom's bores, utilizing three different scanning parameters, are shown in Figures 3 to 7. The relative expanded uncertainty (k = 2.03) for the measurements utilizing radiochromic films is approximately 5.2%. The calculated MSAD values were 13.6 ± 0.7, 13.5 ± 0.7 and 18.7 ± 1.0 mGy for the three imaging protocols with pitch values of 0.75, 1.00 and 1.50, respectively.

Table 1 Calibration coefficients.

Regions	Integral	Kerma (mGy)	Calibration (mGy.gray scale^{-1})
12h00	13.6	31.5	2.3
3h00	13.8	30.5	2.2
6h00	12.5	24.6	2.0
9h00	13.5	30.1	2.2
Central	8.0	14.4	1.8

DISCUSSION

The Gafchromic XR-CT radiochromic films constitute a good alternative in dose evaluations. Such films are not sensitive to visible light and darken as exposed to ionizing radiation, the change in the color tone being associated with the radiation dose[15,20]. Such characteristic facilitates the visualization of irradiation regions, on account of different pitch values utilized in the standard imaging protocols.

Oscillatory curves with pulse heights of up to 10 mGy were observed in the peripheral measurements at the phantom, depending upon the pitch value utilized in the protocols. The peripheral regions of the phantom presented higher kerma values than the central region, because of the high attenuation of the X rays through the phantom. The region at 6h00 presented the lowest dose, as compared with other peripheral

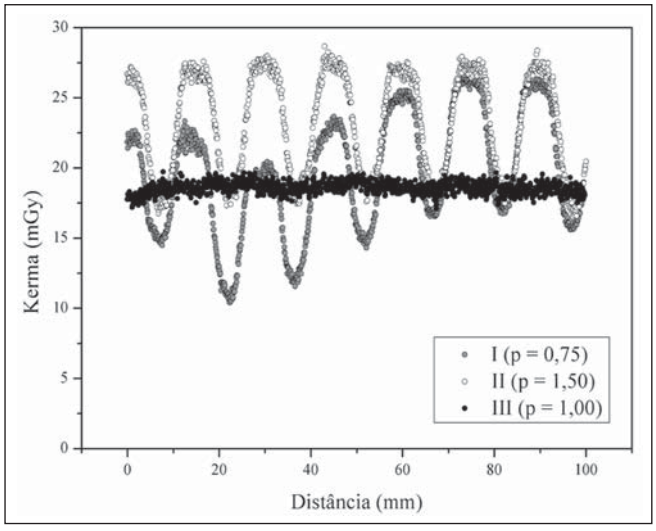

Figure 3. Kerma profiles of the 12h00 region for three different parameters.

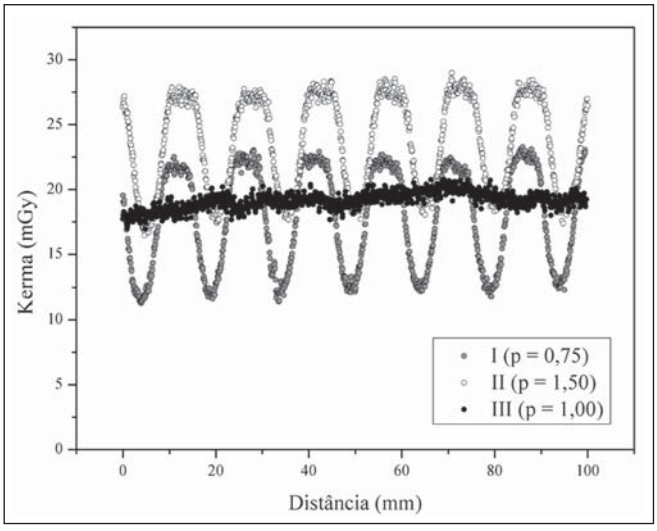

Figure 4. Kerma profiles of the 3h00 region for three different parameters.

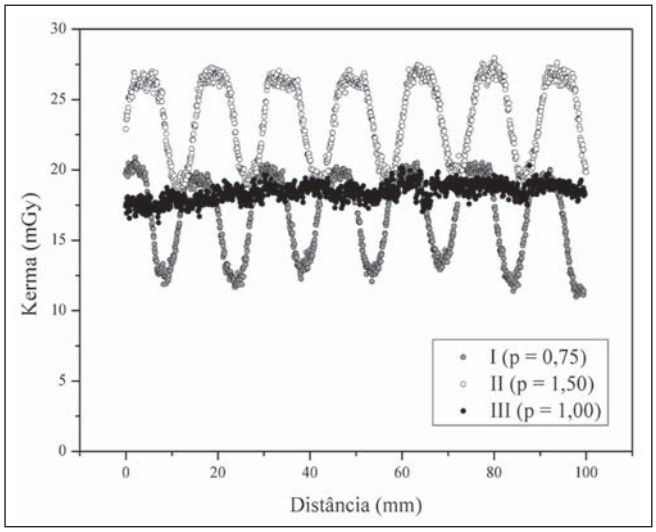

Figure 5. Kerma profiles of the 6h00 region for three different parameters.

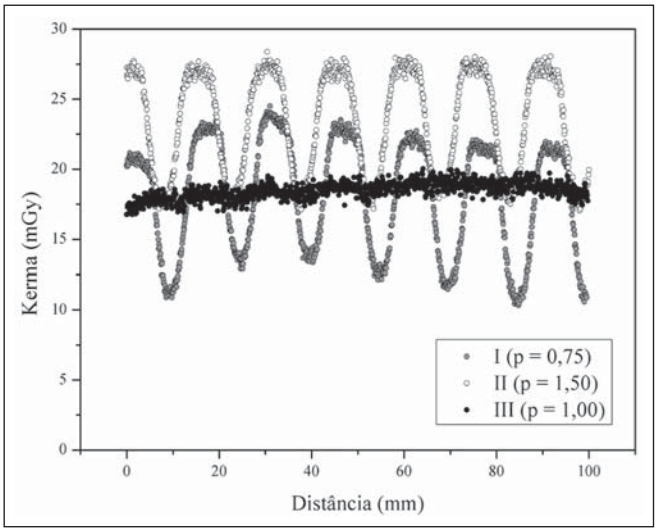

Figure 6. Kerma profiles of the 9h00 region for three different parameters.

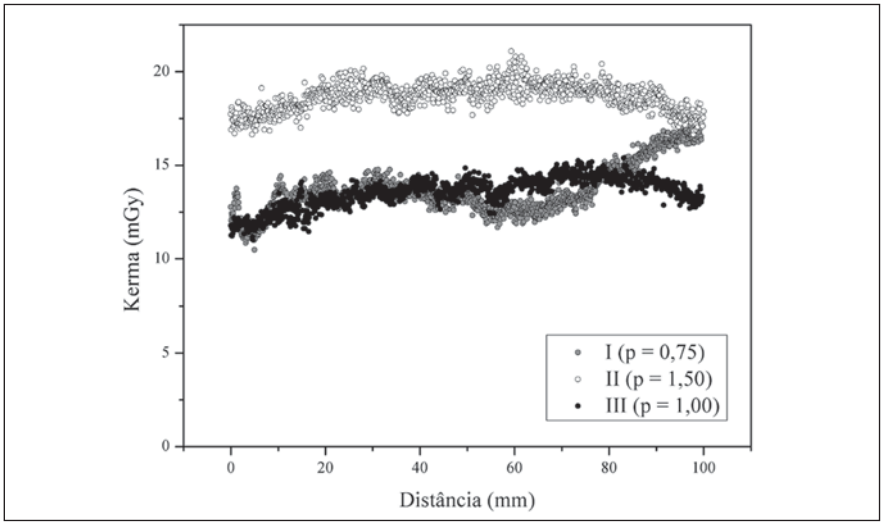

Figure 7. Kerma profiles of the central region for three different parameters.

regions, due to the beam attenuation caused by the table of the CT scanner.

The MSAD values are associated with the characteristics of the apparatuses, besides their specific performances in the quality control tests and protocols adopted in each service[23]. The obtained MSADs demonstrate that a dose reduction occurs as the protocol I is adopted instead of protocol II, mainly due to the utilized pitch value (pitch = 0.75). As the protocol III was adopted, the dose value decreases a little further on account of the new pitch value (pitch = 1.00) and mainly on account of the tube loading value, extending the X-ray tube useful life, thus reducing costs for the institution[24].

It is clear that CT scan protocols should utilize reduced values for voltage and tube loading, provided the image quality is maintained to allow a safe medical diagnosis utilizing dose values as low as reasonably achievable[3,25]. In spite of the fact that the calculated MSAD values resulted < 25 mGy for DRL established by the Brazilian regulations for abdomen studies[3], it is suggested that there is room for procedure optimization, also considering the need for an appropriate evaluation of image quality for each protocol.

CONCLUSIONS

The advantages of the radiochromic films for measurements of kerma profile are the following: continuous reading, which facilitates the observation of the oscillatory curves on account of different pitch values; ease of manipulation, which decreases the need for long interruptions in analyses of the clinical practice; and the acceptable uncertainty (~ 5.2%). Therefore such materials seem to be appropriate for CT quality control, in spite of their high cost and non-reusability. The obtained MSAD values suggest the need for reviewing the DRL for abdomen studies, as its value is very high and it is possibly not representing the reality of the practice in Brazil.

The MSAD values also suggest that it would be better to adopt a standard imaging protocol with a pitch value equal or close to 1 (one) and reduced tube loading values in order to reduce the doses, avoid differently irradiated regions and increase the X-ray tubes useful life. It would be more appropriate to adopt, together with the established MSAD values, the DRLs in terms of the other CT dosimetric quantities. The knowledge of such values would be important for the optimization of clinical procedures, besides facilitating the comparison with internationally recommended values. Considering the relevance of optimization, in addition to the calculation of dosimetric quantities, an evaluation of the image quality for each protocol should be made. As radiochromic films have not yet been utilized for dosimetry in radiology in Brazil, the present study contributes to the dissemination of the procedure for calculation of the MSADs from kerma profiles measured with radiochromic films among hospitals and radiologists.

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