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Optimization in the relation between image quality and patient dose in head CT

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Thirty-two head CT scans were acquired employing an anthropomorphic phantom containing lesions in the posterior fossa, using 2 scanners: Siemens Sensation with 64 slices and Philips Brilliance with 6 slices. Parameters as tube current (mA), slice thickness (mm), collimation (mm), tube potential (kVp) and dynamic range were changed during studies, looking for the optimal acquisition/processing conditions which permit both good lesion detectability and the lowest dose. The CT air kerma index (mGy) was measured with a pencil ionization chamber. Image quality was analyzed by 5 radiologists using a 5 points-scale criteria (1=poor, 2=fair, 3=good, 4=very good, 5=excellent) and also using 5 figure of merit in the spatial and frequency domains: Contrast (C [%]), Contrast to Noise Ratio (CNR), Signal to Noise Ratio (SNR), Normalized Mean Square Error (NMSE) and Spectral Distance (SD). Objective and subjective results were correlated. We observed that doses could be reduced by up to 25% respect to the usual practice with both scanners, mainly reducing the mAs, without affecting lesion detection. As a result, we propose an optimized protocol for each scanner as follow: 250 mAs, 120 kVp and the collimation of 6 slices x 1.50 mm per rotation the same reconstructed slice thickness to detect the lesions in the posterior fossa with good image quality for the Philips Brilliance 6, while 150 mAs, 100 kVp, collimation of 30 x 1.2 mm and reconstructed slice thickness of 3.0 mm were needed with the Siemens Sensation 64.
Keywords: Computed tomography; image quality; dosimetry; optimization.

Otimização na relação entre a qualidade da imagem e a dose paciente em CT de crânio

Trinta e duas tomografias computadorizadas (CT) de cabeça foram adquiridas utilizando um fantoma antropomórfico contendo lesões na fossa posterior, utilizando 2 tomógrafos: Siemens Sensation com 64 cortes e Philips Brilliance com 6 cortes. Parâmetros como corrente do tubo (mA), espessura de corte (mm), colimação (mm), tensão do tubo (kVp) e faixa dinâmica foram alterados durante os estudos, com o objetivo de determinar as melhores condições de aquisição e processamento, que permitam uma boa detecção de lesões e doses menores. O índice de kerma no ar em CT (mGy) foi medido com uma câmara de ionização lápis. A qualidade da imagem foi analisada por 5 radiologistas utilizando critérios de qualidade em uma escala de 5 pontos (1=pobre, 2=razoável, 3=bom, 4=muito bom, 5=excelente) e utilizando 5 medidas nos domínios especial e das frequências: Contraste (C [%]), Razão contraste-ruído (CNR), Razão sinal-ruído (SNR), Erro médio quadrático normalizado (NMSE) e Distância espectral (SD). Os resultados objetivos e subjetivos foram correlacionados. Observamos que as doses podem ser reduzidas a até 25% em relação à prática usual com ambos tomógrafos, reduzindo o mAs sem afetar a detecção de lesões. Como resultado, propomos um protocolo otimizado para cada tomógrafo, como segue: 250 mAs, 120 kVp e colimação de 6 cortes x 1,50 mm, com espessura reconstruída igual, para detectar as lesões na fossa posterior com boa qualidade para o Philips Brilliance 6; e 150 mAs, 100 kVp, colimação de 30 x 1,2 mm e espessura de reconstrução de 3 mm foram necessários com o Siemens Sensation 64.
Palavras-chave: Tomografia computadorizada; qualidade da imagem; dosimetria; otimização.

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1. INTRODUCTION

The radiation exposure during a CT scan depends on the acquisition parameters such as the tube current and potential, rotation time and the beam collimation, among others [1,2]. In order to improve image quality, some CT studies require the use of high mAs, for example, resulting in images with less noise. In the head CT scan, it is especially important for the slices situated in areas as posterior fossa, typically affected by noise and so many artifacts [3,4] for improving the lesion detection. Nevertheless, this condition produces high absorbed doses for patients, contributing in more than 40% to the effective collective dose for most of the countries [5].

The above problem makes important the need of optimizing the relationship between image quality and patient dose. The implementation of good acquisition / reconstruction protocols is the correct way to develop this optimization, especially for paediatric studies. Some works reported results under the above framework in the last years [6,11]. The present paper shows some new results with the same approach, using a modern analysis of image quality.

2. MATERIALS AND METHODS

In this work, 13 axial head CT scans were acquired using a Philips Brilliance 6 scanner (scanner 1) and 19 with a Siemens Somatom Sensation 64 (scanner 2), employing an anthropomorphic head phantom, model RS-250, made by RSD (Figure 1a). The phantom contains small structures in the posterior fossa, which simulate cranial lesions (Figure 1b). The acquisition parameters selected at both scanners are presented at the Table 1 and are typically used in the evaluated institutions for head scans. The tube current selected at scanner 1 varied in steps of 50 mA, from 100 to 350 mA. At scanner 2, the currents were 100, 120, 150 and 200 mA. The automatic exposure control was not used. Figure 1c shows an acquisition example.

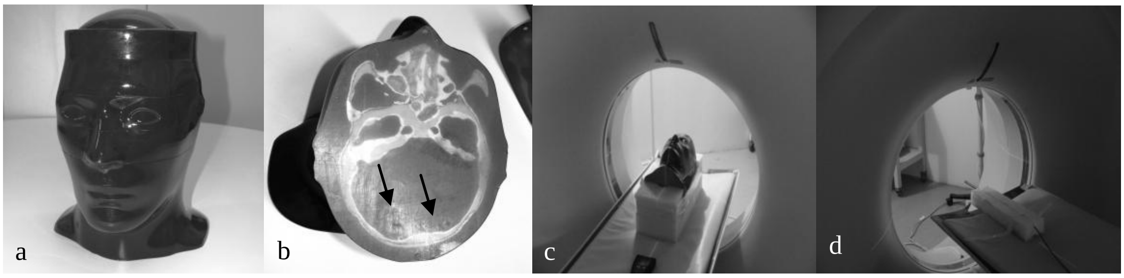

Figure 1: a) RS-250 Head head phantom; b) posterior fossa phantom section, pointing to the lesions; c) phantom positioned in the CT scanner; d) air kerma in air measurement with a pencil ionization chamber.

Table 1: Acquisition parameters selected at each CT scanner.

CT Scanner	(1) Philips 6	(2) Siemens 64
Acquisition mode	Axial	Axial
Tube potential (kVp)	120	100 / 120
Rotation time - T_{rot} (s)	1.167	0.50 / 1.00
FOV* (mm)	250	250
Tube current (mA)	100–350	100–200
# slices per rotation	4 / 6	24 – 30
Slice thickness (mm)	0.75 / 1.50	0.60 / 1.20
Reconstructed slice thickness (mm)	0.75 / 1.50	2.40 / 3.00

* FOV – field-of-view.

A pencil ionization chamber with 100 mm length, made by PTW, was used for the dosimetric measurements. It was positioned in the center of the CT gantry for both scanners (Fig. 1 d). The CT air kerma index ($C_{a,100}$) was measured using the same acquisition combinations than for the phantom experiment. The $C_{a,100}$ was calculated using the following equation (1):

$$C_{a,100} = \frac{1}{n.T}\int_{-50}^{+50} K_a(z)dz = \frac{P_{KL,ar}}{n.T} \quad (1)$$

Where *n.T* is the beam collimation used, $\int_{-50}^{+50} K_a(z)(dz)$ is the integral of the air kerma through the parallel line to the z axis of the scanner with 100 mm length and $P_{KL,ar}$ is the air kerma-length product, measured with a pencil ionization chamber in air.

Slices corresponding to the posterior fossa region were used to analyze the image quality. They were shown to five specialists who graded the image quality on a 5-point scale: *Excellent (5)*, *Very Good (4)*, *Good (3)*, *Fair (2)* or *Poor (1)*. Five objective quality metrics were also calculated for the same purpose and using Regions of Interest (ROI) in with 30 x 30 pixels. Three of these metrics were calculated globally: Contrast (C), Contrast to Noise Ratio (CNR) and Signal to Noise Ratio (SNR), while the other two were relative to the maximum dose condition at each scanner (condition with the highest mAs value): the Normalized Mean Square Error (NMSE) and the Spectral Distance (SD) [12]. All the objective metrics were calculated for a fixed window width (WW) of 150 HU (hounsfield units) and three window levels (WL): = 25; 35; and 45 HU.

3. RESULTS AND DISCUSSION

Figure 2 shows the behavior of normalized univariate metrics (SNR, C and CNR) with mAs for both scanners. All the metrics improved slightly with the mAs increment for both equipment but the differences among values are not significant (p>0.05), especially between 250 and 350 mAs for Philips Brilliance 6 and between 150 and 200 mAs for Siemens Sensation 64.

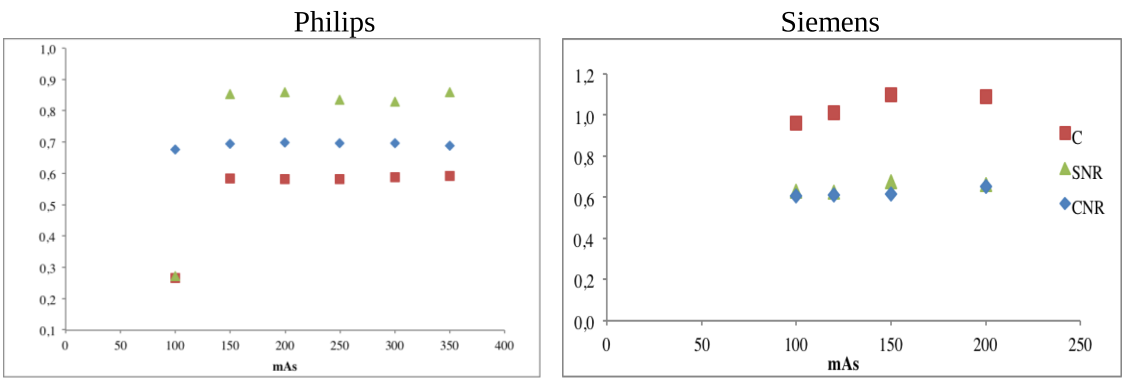

Figure 2: Univariate metrics vs. mAs for both scanners.

Figure 3 shows how the above results are reproduced when slice thickness is taken into account for both scanners, from the point of view of SNR. The conditions with larger acquisition slice thickness presented a lower noise contribution and consequently, a higher SNR. This was expected, since the image noise is inversely proportional to the size of the X-ray photons sample, which is higher for a larger slice.

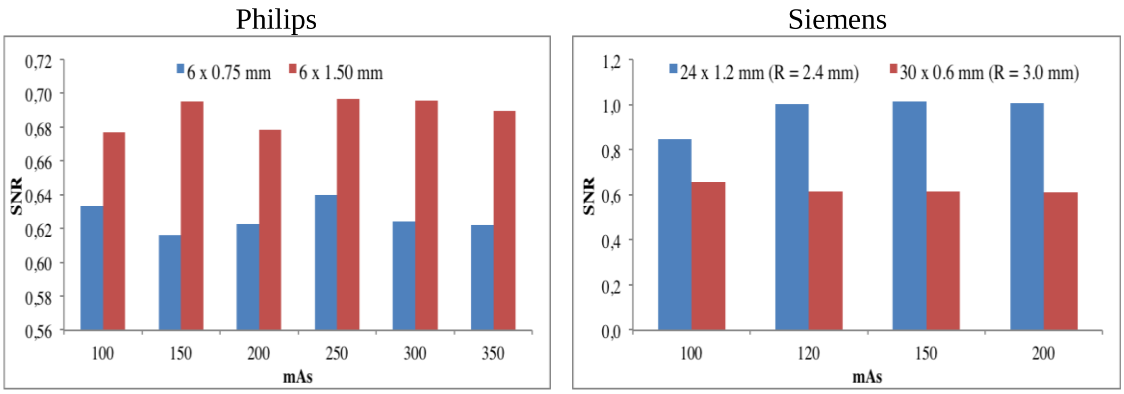

Figure 3: Influence of slice thickness on the signal to noise ratio with both scanners. For the Philips scanner, the slice thickness was equal to the reconstructed thickness; for the Siemens, the reconstructed slice thickness is slightly larger.

On the other hand, the resolution loss produced with the increment of the slice thickness did not affect the visibility of the lesions in the posterior fossa for both equipment, following the visual expert opinion, while noise diminish considerably from one protocol to another. Figure 4 shows an example of this aspect for one of the both equipment.

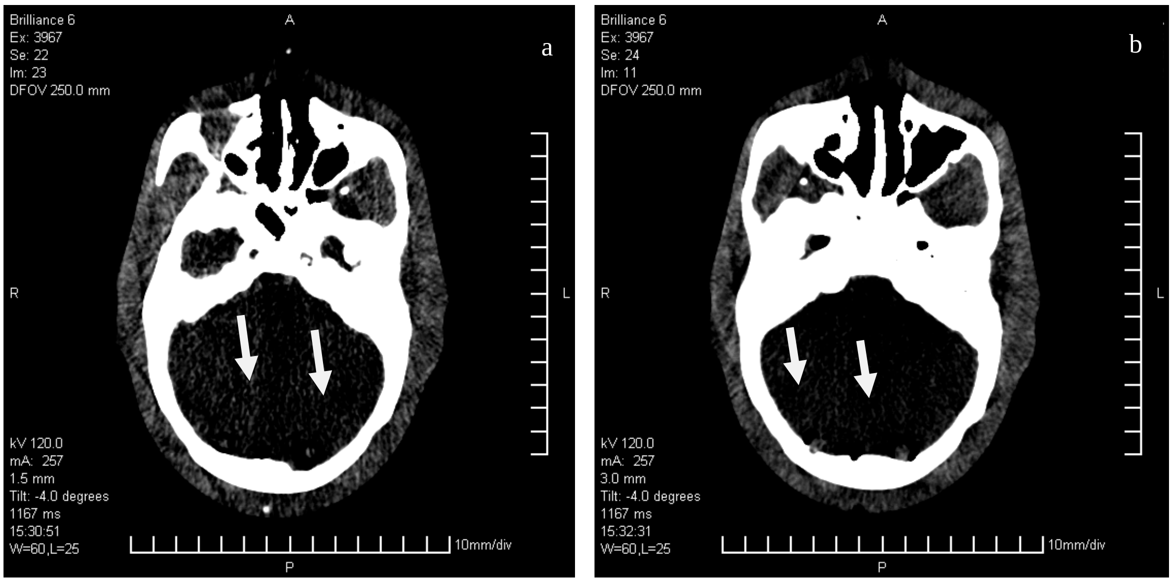

Figure 4: Levels of noise and spatial resolution for two different reconstruction slice thickness at the same mAs and kVp conditions. a) 1.5 mm; and b) 3.0 mm

Bi-variate metrics, as NMSE and SD, diminish with mAs increment for both scanners (see Figure 5). Nevertheless, the differences are not significant between 250 and 350 mAs for Philips Brilliance 6, and between 150 and 200 mAs for Siemens Sensation 64 ($p>0.05$).

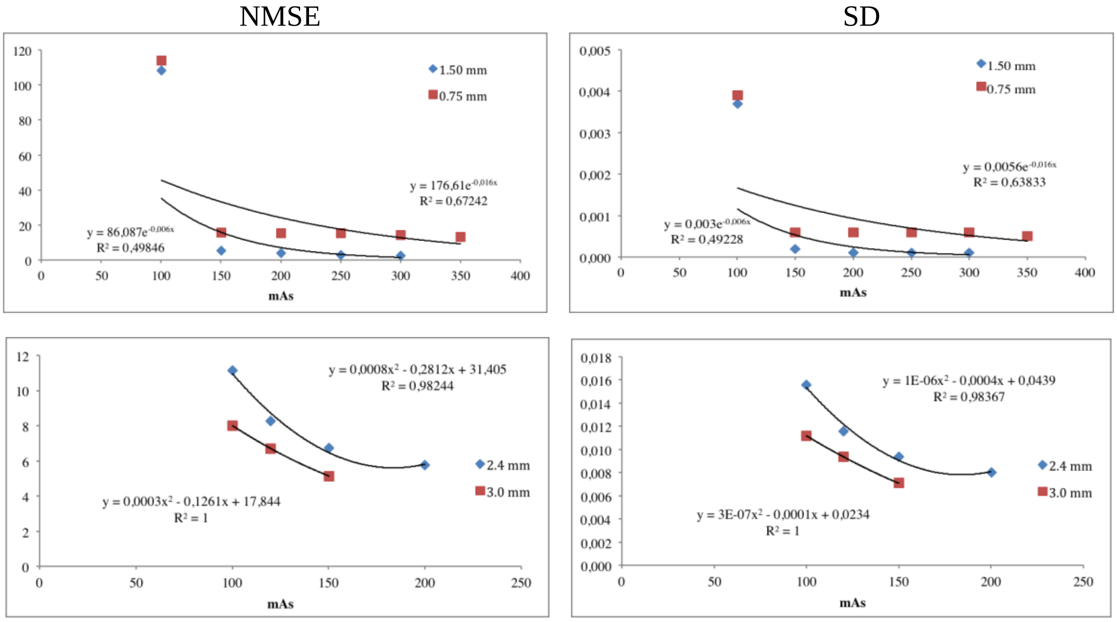

Figure 5: Bi-variate metrics vs. mAs for both scanners (Philips – up; Siemens – bottom).

The results are reproducible for other windowing conditions, but the window level of 35 HU seems to be the most adequate to visualize slices from posterior fossa from both scanners (see Figure 6) from the point of view of Image Contrast.

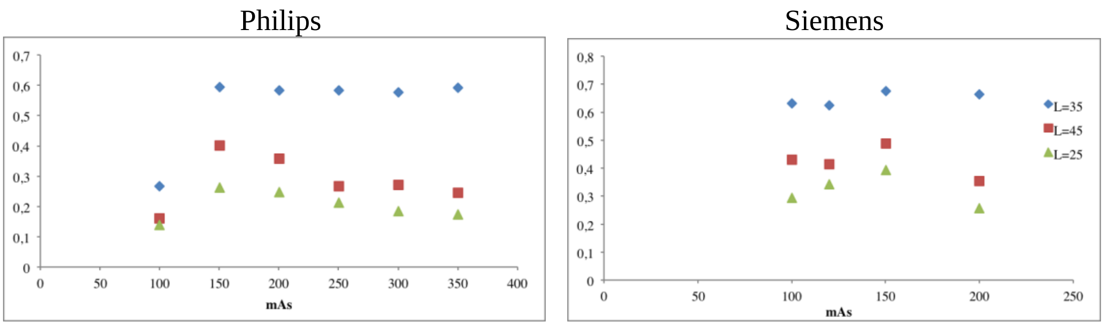

Figure 6: Image contrast vs. mAs with different visualizing window levels for both scanners.

The increment of the kVp diminishes the Image Contrast. Table 2 shows the results for the Siemens Sensation 64.

Table 2: Behaviour of Image Contrast with kVp at different mAs.

kVp	mAs	Contrast (%)
100	100	34.42
100	200	35.04
120	100	23.10
120	200	25.77

The correlation between objective and subjective results was fair. Table 3 shows some results of the Pearson Coefficient (r) and its signification (p). The main aspect with influence between both evaluations is that objective metrics only take into account noise levels and spatial resolution while aspects as the typical presence of artifacts in the fossa region is also included in the observer opinion. These incongruences between objective and subjective metrics have been deeply discussed by Avcibaş et al. [13].

Table 3: Correlation between objective and subjective Image quality analysis.

Coefficients	Contrast-Subj	SNR-Subj	CNR-Subj
r	0.471	0.405	0.477
p	0.042	0.085	0.039

On the other hand, $C_{a,100}$ shows a very strong linear behavior with the increment of mAs for both scanners, as it can be seen in the Figure 7. It indicates the importance of developing optimization studies for each scanner taken into account the best relationship between image quality and patient dose [14].

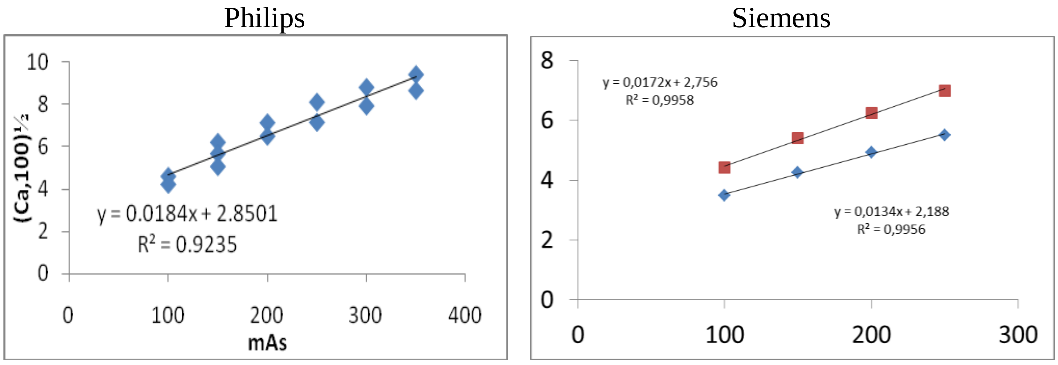

Figure 7: CT air kerma index ($C_{a,100}$) vs. mAs for both scanners.

From the above image quality and air kerma index values we can see that the use of 250 mAs, 120 kVp and collimation of 6 slices x 1.50 mm per rotation for the Philips Brilliance 6 scanner allows the lesions detection in the posterior fossa with good image quality and a 25% of dose reduction than using 350 mAs. The mAs increment produces an unnecessary dose increment while image quality doesn't improve in a significant way. On the other hand, the reduction of the slice thickness or mAs value beyond to the recommended in this study especially for the posterior fossa increases the noise level. Similar results were obtained for the Siemens Sensation 64, using 150 mAs, 100 kVp and reconstruction slice thickness of 3 mm. The Figure 8 shows slices from the posterior fossa with both scanners, acquired with the optimized conditions. Good image quality is guaranteed from the subjective and objective points of view in both cases.

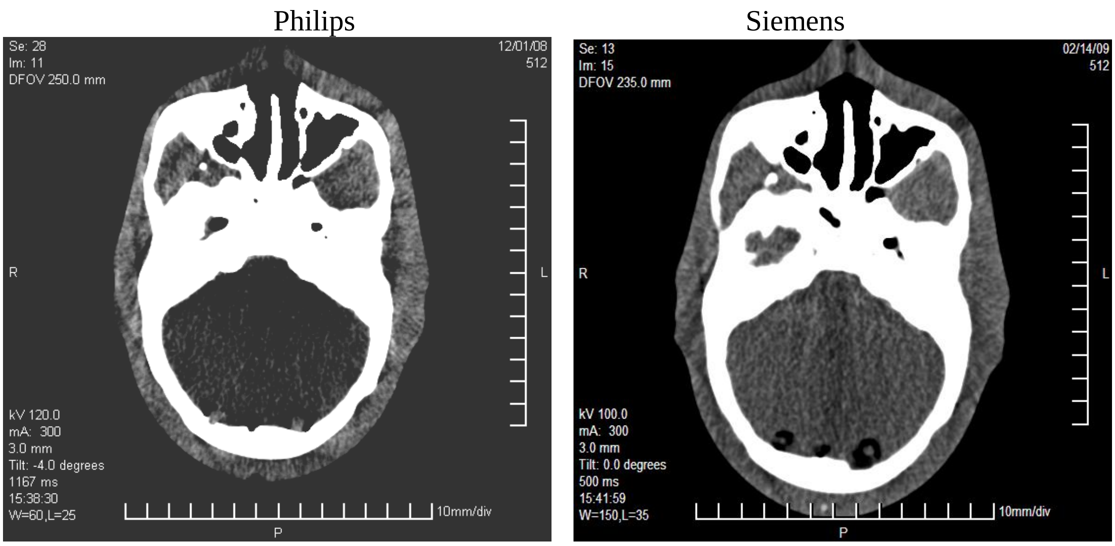

Figure 8: Posterior fossa CT slices obtained with both scanners using the optimized protocols.

The mAs suffers many variation among countries, technologies or regions around the world, found in this and other CT studies [10,11]. This behaviour implies that the dose variation must be correspondingly high for head CT scans [7,11].

4. CONCLUSION

The present paper shows the possibility to reduce doses with two different technologies in this type of studies without affecting image quality for diagnosis. We concluded that it is adequate to use 250 mAs, 120 kVp and collimation of 6 slices x 1.50 mm per rotation for the tested Philips Brilliance 6. These parameters permit the correct detection of all lesions in the phantom posterior fossa with good image quality. In the case of the Siemens Sensation 64, we found that the optimized parameters are 150 mAs, 100 kVp and slice thickness of 3 mm. With the above protocols we can obtain a 25% reduction in the air kerma index with respect to the usual practice in these hospitals with both technologies.

5. ACKNOWLEDGEMENTS

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