Dose reduction at abdominal CT imaging: reduced tension (kV) or reduced intensity (mAs)?

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Résumé
Diminuer la dose en tomodensitométrie abdominale : baisser la tension (kV) ou la charge (mAs) ? J Radiol 2004;85:375-80

Objectif. Étudier 2 protocoles de réduction de dose d’environ 50 % en scanographie abdominale chez les patients de faible corpulence, l’un réduisant la tension et le second la charge.

Matériel et Méthodes. Cinquante patients dont l’exploration tomodensitométrique abdominale prévoyant une série sans injection et dont le poids était inférieur à 55 kg ont été inclus prospectivement. Les images du protocole standard (120 kV, 200 mAs) ont été comparées à celles obtenues par quatre coups supplémentaires, 2 réalisées avec un protocole de diminution de tension (100 kV, 200 mAs) et 2 avec un protocole de diminution de charge (120 kV, 100 mAs). La qualité d’image a été comparée suivant des critères subjectifs (notation par 2 radiologues en fonction d’une liste de points à apprécier) et des critères objectifs (mesure de l’écart type des coefficients d’atténuation d’une zone du foie).

Résultats. Il est apparu que les images réalisées avec le protocole de réduction de dose par la tension étaient meilleures selon ces 2 critères que celles réalisées en diminuant la charge.

Conclusion. En tomodensitométrie abdominale, chez le patient de faible corpulence ou l’enfant, la réduction de dose par diminution de la tension constitue donc une alternative à la diminution de la charge. Elle est facile à mettre en œuvre et peut être utilisée conjointement avec les logiciels de réduction de dose.

Mots clés : Irradiation, exposition. CT. Irradiation, dose. Irradiation, protection.

Abstract
Purpose. To compare low-dose protocols using either reduction of the tension (kV) or reduction of the intensity (mAs) at abdominal CT imaging, with reference to image quality.

Materials and Methods. Fifty adult patients, weighing less than 55kg, were prospectively included among patients referred for abdominal CT examination when the protocol required a noncontrast study. The images obtained with the standard protocol (120kV, 200mAs) were compared to 4 additional test images, two obtained with low intensity (120kV, 100mAs) and two obtained with low tension (100kV, 200mAs). Two senior radiologists blindly reviewed all images using both subjective (itemized list) and objective criteria (measure of standard deviation for density measurements obtained of the liver parenchyma).

Results. The image quality of the low kV protocol was better than the image quality of the low mAs protocol for both subjective and objective criteria.

Conclusion. For abdominal CT imaging of standard to thin adult patients or children, dose reduction using a low kV protocol may be an alternative to a protocol using a low intensity. This can easily be implemented and can be used in conjunction with a dose reducing software.

Key words: Irradiation. Scanographic. Réduction de dose. Dosimétrie.

To cite the present paper, use exclusively the following reference. Dion AM et al. Diminuer la dose en tomodensitométrie abdominale: baisser la tension (kV) ou la charge (mAs) ? (full text in english on www.e2med.com/jr). J Radio 2004; 85: 375-80.
considered. The benefit expected from diagnostic imaging studies requires that image quality must be acceptable. Protocol optimization necessitates an empirical approach on each CT unit in order to reach an acceptable compromise between exposure and image quality and experience shows that this seldom is performed.

With CT, the technologist can modify the dose for each image by modifying the parameters of acquisition. The technical parameters are the intensity or tube current x time (mAs) and the tension or beam energy (kV). In practice, the intensity is reduced by decreasing the tube current (mA). Direct selection of beam energy or kV is now routinely possible with a typical range of 100-140kV, and sometimes 80-140kV. Reducing kV is usually not recommended for all patients and is typically possible for thinner patients in order to avoid over attenuation of lower energy photons. This can easily be achieved for thin individuals, especially children. We have prospectively evaluated two dose reduction protocols (about 50% reduction), one with low mAs and the other one with low kV. Image quality was evaluated using objective and subjective criteria. This study was performed on adult patients, because of the resultant low increase in radiation exposure, but its results are applicable to the pediatric population.

Materials, patients and methods

All examinations were performed using a single detector CT unit (HiSpeed Advantage, GE Medical Systems). Fifty adult patients, weighing less than 55kg, were prospectively included among patients referred for abdominal CT examination when the protocol required a noncontrast study. The indication for the examination was not a selection criterion. Informed consent, with signed consent form, was obtained from all patients after written and verbal information was provided with regards to radiation exposure. Since the requested CT examinations in all enrolled patients included about 50 slices, the addition of 4 CT images, at a dose reduction of about 50%, corresponded to an added exposure of only about 4%.

Noncontrast images were acquired using a helical technique with collimation of 5mm and pitch factor of 1.5. Two additional acquisitions were then obtained at the supramesocolic level using similar collimation and pitch factor. The technical parameters for the standard acquisitions were 120kV and 200mAs (200mA with gantry rotation time of 1sec) (fig. 1a). A second acquisition of 2 slices was obtained at 120kV and 100 mAs (low mAs protocol) (fig. 1b). A third acquisition of 2 slices was obtained at 100 kV and 200mAs (low kV protocol) (fig. 1c). The dose variation for each slice can be estimated by comparing the computed tomography dose index or CTDI displayed at the console for each acquisition. The index was 7.49mGy for the standard protocol, 3.75mGy for the low mAs protocol (50%
Results

Descriptive analysis (table I)

The distribution of scores from the qualitative assessment by two radiologists is reported in table I. All images were considered to be of acceptable diagnostic quality.

Qualitative criteria

Inter-observer agreement (table II)

The difference between the scores from both radiologists (difference = score from radiologist 1 – score from radiologist 2) was calculated for all 300 images. This corresponded to the mean of the observed difference compared to the value 0 (theoretical value if both radiologists gave the same score).

From a total of 300 recorded scores, the difference between 230 scores (77%) for both radiologists was between –1 and +1. The mean difference between the scores from both radiologists was 0.24. This was statistically different from 0 (p = 0.002, student t-test for paired samples). Radiologist 1 usually recorded a score that was higher than the one recorded by radiologist 2. The difference in scoring was observed for each protocol: evaluation of the difference for each group was performed by comparing the mean difference between the scores and the value 0. There was a difference for both low kV (p = 0.034, student t-test for paired samples) and low mAs (p = 0.044) protocols but there was no statistically significant difference for the standard protocol (p = 0.27) (table II).

A difference of recorded scores was observed between the 3 protocols. However, the difference in scores recorded by both radiologists was not significantly different between the 3 protocols (Kruskal-Wallis test, p = 0.67) indicating that the standard deviation observed between the scores recorded by both radiologists do not differ based on the protocol.

Mean scores for both radiologists

Because the scores attributed by both radiologists were different, the mean of both scores was selected to evaluate all 300 images. The mean score was calculated as follows: (score from radiologist 1 + score from radiologist 2) / 2. The mean value for all 300 mean scores was 7.44±0.97.

Correlation between mean scores (qualitative data) and noise (quantitative data)

The correlation coefficient was equal to −0.54 (p < 10^-4, student t-test) and significantly different from 0. Therefore, both criteria are not independent. When the mean score increases, the amount of noise decreases.

Reproducibility of the technique (2 images performed using the same protocol) (table III)

Reproducibility was evaluated by comparing the difference between the mean scores from both radiologists for each pair of images obtained using a same acquisition protocol as well as the difference between the standard deviations from density measurements.

Results show that there was no difference between both series of images for the mean scores of both radiologists (p = 0.90) and their distribution (student t-test).

Comparison of image quality as a function of exposure.

Comparison of image quality between the standard and both low dose protocols (table IV)

Images obtained using the standard protocol (200mAs, 120kV) were of better quality than those obtained with both low dose protocols (low-kV and low-mAs) (p < 10^-4, student t-test).

Comparison of image quality between the low kV and the low mAs protocols (table V)

A significant difference was also noted for noise measurements (p = 7.1×10^-4). The standard deviations for density measurements were larger with the low mAs protocol than with the low kV protocol.

Global image quality was superior for images obtained using the standard protocol compared to images obtained with either of the low dose protocols (p < 10^-4).
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There was a significant difference between the mean scores of the low kV and low mAs protocols. The images obtained using the low kV protocol were better rated than those obtained using the low mAs protocol (p = 8.6 x 10^{-5}). However, none of the images was rated as being of inadequate diagnostic quality (score < 5).

### Discussion

Optimization of radiation exposure, especially at CT and for pediatric patients, now is a legal obligation in France following the implementation of EURATOM directive 97/43 (3). This need to evaluate and optimize radiation exposure is further heightened by the increasing availability of multi-detector row CT (MDCT) units. Unless the technical parameters are reduced, the dose from MDCT is higher than the dose from a single detector CT (4). Our study involved CT imaging of the abdomen, a body area usually requiring relatively high effective doses (5). Our standard protocol was already optimized for an adult population. Indeed, acquisition parameters of 120kV and 200mAs are relatively low compared to other centers using 140 kV and 240-300mAs (6). Our results indicate that image quality and diagnostic value remain acceptable by further decreasing the dose in thinner patients (weight < 55 kg). We elected to choose a threshold based on weight as a compromise only because of its simplicity. Using the body mass index would have been optimal but complicated. Dose reduction protocols must remain simple and easy to implement. Dose reduction with the low mAs protocol (~50%) was slightly more compared to the low kV protocol (~40%) but image quality was qualitatively inferior and noise was quantitatively higher. Both tested protocols did not result in a strictly identical degree of dose reduction, but both were easy to implement using already available parameters. At CT, the reduction of beam energy does not result in a relative increase of dose as with conventional radiography. Indeed, at conventional radiography, increasing beam energy results in a relative decrease in patient exposure because the number of photons reaching the film increases relative to the number of photons absorbed by the patient. The increased sensitivity of digital...
CT detectors results in a decreased dose when beam energy is decreased and all other parameters remain unchanged, as confirmed by CTIDT values. Giraud et al. (7) reported that the radiation dose at a specific point of a water phantom increased by 72% when increasing kV from 120 to 140. Some authors have suggested that kV values for thinner and pediatric patients be limited at a maximum of 100kV because dose is proportional to the square of kV (8). Image quality was inferior for both studied low dose protocols compared to the standard protocol but none of the images was considered non-diagnostic (grade<3). Dose reduction thus implies that the esthetic appearance of the image will be reduced while the diagnostic nature will be preserved. For our thinner patients, and presumably for pediatric patients, images were considered diagnostic for both the low mAs and low kV protocols. The first original feature of our study is that we have compared image quality using a double grading system. First, a subjective set of criteria was used that closely approximates daily clinical practice of radiology, as evaluated by two independent reviewers. Results showed very mild dispersion of qualitative scores (the mean difference between scores for both radiologists was 0.24). Second, an objective criteria based on quantitative measurement of image noise. Results showed that subjective and objective scores showed similar trends for variations. Indeed, when image noise increased, image quality scores decreased. The second original feature of our study was to have compared two different low dose protocols. In order to reduce dose by about 50%, two options are available: reduce mAs by 50% or reduce beam energy by about 20%. The first option is usually selected by most. Several authors (6, 9) have compared protocols with standard mAs and 50% reduced mAs (240-300mAs versus 120-150mAs) and have concluded that the diagnostic value was satisfactory with the low mAs protocols using image contrast and diagnostic information criteria. Other authors have studied the impact of reduced beam energy and increased pitch factor (10). Only a few published studies reported the value of decreased kV for low dose protocols (11, 12).

The comparison of low mAs and low kV protocols has, to our knowledge, not previously been reported. Our study was performed on adult patients because it would not be appropriate in pediatric patients due to the increased dose (even though the increase is less than 5% based on our protocols). Still, our results can be applied to the pediatric population. In addition, reduced beam energy protocols can be combined with software that self-adjust beam intensity based on the scanned body area, while it is not possible to preset mAs while using this same type of software. Our results indicate that reducing beam energy has a lesser impact on image quality than reducing beam intensity for a similar degree of dose reduction for patients less than 55kg. Therefore, it would appear that low dose protocols for thinner and pediatric patients should preferentially take advantage of decreased beam energy since these can easily be implemented compared to low mAs protocols. Standard fixed high dose protocols should no longer be blindly used for all patients, irrespective of age and size (5). Another advantage of the low kV protocol would be the increased contrast of iodinated contrast material, but this was not evaluated in our study. This is one of the inherent weaknesses of CT dosimetry studies since they can only be performed using noncontrast images. The amount of contrast induced by a specific quantity of iodinated contrast material is related to the qualitative nature of the x-ray beam. Usually, the contrast between structures with high Z values and surrounding water density structures is higher for low-energy photon beams, i.e. for radiation with lower beam energy. The contrast between a calcified renal calculus and surrounding tissues of the contrast from iodinated contrast material is increased when the mean beam energy is near the k-edge of iodine (13). The optimal attenuation occurs at a beam energy of about 80kV, seldom usable for CT imaging. However, attenuation difference is better at 100kV than at 120 or 140kV. For daily practice, a standard CT protocol could use a kV of 120 while a kV of 100 would be used for thinner or pediatric patients and a kV of 140 would be used for larger patients. Again, low kV protocols can be combined with adaptive mAs software.

**Conclusion**

The need for dose optimization at abdominal CT imaging will require a compromise with regards to image quality while maintaining an acceptable diagnostic quality. Our results indicate that dose reduction can be achieved for thinner adults, and presumably for pediatric patients, by using a low kV protocol, seldom proposed, as well as a low mAs protocol, usually proposed. Results also indicate that image quality is superior with a low kV protocol compared to a low mAs protocol. In addition, a low kV protocol

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**Table V**

Comparison of the average grade and the measure of noise between 2 protocols of dose reduction.

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Images</th>
<th>Mean</th>
<th>Median</th>
<th>Min.</th>
<th>Max.</th>
<th>SD*</th>
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* standard deviation.
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References