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Radiation dose in computed tomography – scanning parameters affecting patient dose

Since its introduction in 1972, x-ray computed tomography (CT) has evolved into an essential diagnostic imaging tool for a continually increasing variety of clinical applications. Despite the introduction of alternative examination techniques, such as sonography, magnetic resonance imaging (MRI) and endoscopy, the number of x-ray examinations has altogether increased. The frequency of some types of x-ray examinations was very strongly increasing, i. e. CT, angiography and mammography. The frequency of chest and abdomen radiographic examinations remained practically constant. Other examination types were markedly decreasing, i. e. mainly those of the GI tract (8, 15).

Improvements in image quality, acquisition speed, and patient throughout have resulted from recent technical developments in helical and, more recently, multi-row detector technologies (18). CT was always considered a "high dose" technique, but recent technological developments have conspired to make it more so as a consequence both of changes in the technology and the changes in practice that it has allowed (3).

The purpose of the study is to present scanning parameters affecting radiation dose for patients undergoing CT study and methods of reducing the patient effective dose.

DISCUSSION

In 1980 CT accounted for about 2% of all radiologic examinations delivered about 5% of the collective radiation dose from all radiologic procedures. Currently CT examinations constitute about 6% of all x-ray examinations, they cause more than 40% of the exposure due to medical x-ray applications (7, 15).

Significant growth has been noted in CT procedures in the period between 1991–2002, including a 235% growth rate in vascular CT procedures, 145% rise in cardiac CT, 25% growth rate in abdominal CT, and 27% increase in pelvic CT scanning. Indeed, between 1980 and 1998, CT scanning increased by up to 800% and up to 100% during the last decade of the 20th century (12). It is assumed that the number of CT procedures will still continue to increase at the rate of 10% per year (11).

A recent survey suggests that about 93 million CT examinations are performed globally on an annual basis, corresponding to a frequency of 16 examinations per 1,000 inhabitants. About 90% of these scans are conducted in the western world at a rate of 57 examinations per 1000 population. Up to 11% of CT examinations are performed in children less than 18 years old, with 17% of these children being between 0 and 5 years of age (12).

It is estimated that about 30% of CT examinations have questionable indications. CT scanning is associated with significantly higher radiation exposure compared with other radiation-based medical examinations, including conventional radiography and nuclear medicine studies (12). Table 1 shows some absorbed radiation doses (in mGy) and effective radiation doses (in mSv) for radiography and CT examination of different parts of the body (9, 12, 20, 23). The data found in the literature are different, which may result from different scanning protocols for different CT scanners.

Table 1. The table shows examples of absorbed radiation dose and effective radiation doses for the examination of different parts of the body

Part of the body	Plain radiograms		CT		
	mGy	mSv	CTDI (mGy) [mediana]	DLP (mGy•cm) [mediana]	mSv [mediana]
Head	1.5–5	0.03–0.1	45–66 [54]	250–1 400 [700]	0.6–4.1 [1.6]
Chest	0.1–1.6	0.02–0.1	14–30 [19]	160–1 000 [490]	1.9–16 [7.6]
Abdomen	5	0.4–0.7	14–35 [21]	160–1 320 [450]	2.3–20 [7.0]
Pelvis		0.3–1.3	14–35 [22]	160–2 000 [440]	2.9–35.1 [7.8]
Lumbar spine	1.2–4.8	0.3–1.5	30–42 [36]	49–500 [275]	0.9–11.6 [4.7]
Urography		5.4–15.1			9.2–18.8 [14.8]
Mammography	1–3				
Fluoroscopy of the alimentary tract: 35–61 mGy/min					
Annual per person effective dose equivalent for the world population from natural background radiation: 2.4–3 mSv					

Consequently, CT scanning now contributes most man-made radiation exposure to the population, being second only to natural background radiation (12). Whereas the annual per person effective dose equivalent for the world population from natural background radiation is 2.4–3.0 mSv, medical radiation procedures deliver 0,4–1 mSv, with almost 65% of the radiation dose from medical sources attributable to CT scanning (9, 12, 16, 20, 23). With continued developments in CT technology and its expanding uses and applications, radiation dose contributions from CT scanning are likely to increase further (12).

The radiation dose from CT remains a major concern, because of the potential carcinogenic effects of relatively low levels of ionizing radiation exposure (21).

The estimated lifetime cancer mortality risks from a single full-body CT examination are about 8×10^{-4} (about one in 1,250) for a 45-year-old adult and about 6×10^{-4} (about one in 1,700) for a 65-year-old adult. To put these values in perspective, the odds of an individual dying in a traffic accident in the U.S. during the year 1999 were about one in 5,900. The risk estimates for multiple CT examinations are correspondingly higher (1).

Radiation dose for patients undergoing CT study is affected by several scanning parameters such as beam energy (tube voltage), tube current time product (mAs), section thickness, number of sections and pitch (21) and the body region being scanned. The patient dose is directly proportional to the selected mAs value and the scan length. For example, reducing either the mAs or the scan length by 25% reduces the patient effective dose by 25%. The relationship between patient dose and x-ray tube voltage is more complicated, and the dose increases in a supra-linear manner with increasing kVp. The dose to patients undergoing spiral CT scans also depends on the pitch ratio PR (the incremental movement of the table per 360° rotation of the x-ray tube divided by the section thickness) (10, 11). Faster table speed for a given collimation, resulting in a higher pitch, is associated with a reduced radiation dose because of shorter exposure time, whereas the narrow collimation with slow table speed, resulting in a longer exposure time, is associated with a higher radiation dose. Although scanning at a higher pitch is generally more dose efficient, it also tends to cause helical artifacts, degradation of the section-sensitivity profile, and decrease in spatial resolution (14).

The radiation dose from CT remains a major concern and therefore there are attempts to reduce radiation dose in CT scanning. The dose and the image quality in CT are closely linked. Reducing patient dose by reducing x-ray exposure has the inevitable consequence of increasing noise and decreasing contrast in the images. It is very important to identify the minimum x-ray exposure, which means the lowest image quality, required for a given examination and pathology (2).

Research efforts are being directed towards establishing the appropriate amount of radiation that is required to generate an optimum clinical CT image. Because of increasing diagnostic meaning of multislice CT, it is the joint responsibility of the radiological community to ensure that patients are scanned in a manner that ensures optimal image quality and the lowest patient doses. This requires the image quality to be sufficient to achieve a satisfactory clinical diagnosis (11). There is still no consensus about optimal tube current for clinical examination CT protocols. In most cases, tube currents are chosen arbitrarily without assessing impact on image quality, lesion detectability (19) and delivered to the patient radiation dose.

The most important factor for reducing radiation exposure is an adaptation of the dose to the patient's size and weight. An approach that is finding increased implementation in clinical practice is anatomic tube current modulation. The overall aim is to achieve a more consistent level of image quality from patient to patient and also to optimize the use of x-rays, thereby reducing dose. Systems which automatically adapt the overall tube current based on actual patient attenuation remove the guesswork from selecting the appropriate mA setting. With this technique, tube output is adapted to the patient geometry during each rotation of the scanner to compensate for strongly varying x-ray attenuation in asymmetric body regions such as the shoulders and pelvis. Automatic mA adjustment requires prior knowledge of the attenuation characteristics of a patient. The attenuation information to adapt the mA for patient size is obtained from the planning scan projection radiograph (ScoutView, Scanogram or Topogram), or is determined online by evaluating the signal from a detector row. With this technique, dose can be reduced by 15%–35% without degrading image quality, depending on the body region (4–7, 12, 13, 17, 22).

In the past, manufacturers and radiologists tended to look at CT in terms of the aesthetic quality of the examination. Doses were set higher than necessary because there was no downside in image quality, while lower doses produced a less aesthetic, noisier images (21). Additional there was a general tendency to increase the coverage area and include regions beyond the area of actual interest. This increases the effective radiation dose to the patient (14). The patient dose remains a major concern, especially in pediatric applications, because of the potential carcinogenic effects of relatively low levels of ionizing radiation exposure. With future advances in scanner technology, the number of CT examinations will likely continue to increase as will the collective medical radiation dose to the population (21).

The variety of imaging protocols used in clinical practice also affect the resultant value of effective dose. The radiographic technique in CT (i.e., mAs setting) should be no higher than that required to keep the radiographic noise to a level that will not adversely affect the diagnostic interpretation. Additional images or multi-phased contrast examinations should only be performed when these series are pertinent to the clinical question. The patient benefit should always exceed any estimate of the corresponding radiation risk (11).

CONCLUSIONS

Tomography (CT) has evolved into an essential diagnostic imaging tool for a continually increasing variety of clinical applications. CT scanning is associated with significantly higher radiation exposure compared with other radiation-based medical examinations, including conventional radiography and nuclear medicine studies. Therefore it is essential to draw the attention of referring physicians, radiologist, and even manufacturers to dose consequences and to establish scanning protocols that restrict the examination to what is absolutely essential. The optimum technique factor will generally depend on the specific task at hand.

REFERENCES

1. Brenner D. J., Elliston C. D.: Estimated radiation risks potentially associated with full-body CT screening. Radiology, 232, 735, 2004.
2. Britten A. J. et al.: The addition of computer simulated noise to investigate radiation dose and image quality in images with spatial correlation of statistical noise: an example application to X-ray CT of the brain, Br. J. Radiol., 77, 323, 2004.
3. Cohnen M. et al.: CT of the head by use of reduced current and kilovoltage: relationship between image quality and dose reduction, AJNR Am. J. Neuroradiol., 21, 1654, 2000.
4. Dawson P.: Patient dose in multislice CT: Why is it increasing and does it matter?, Br. J. Radiol., 77, S10, 2004.
5. Flohr T. G. et al.: Multi-detector row CT systems and image-reconstruction techniques. Radiology, 235, 756, 2005.
6. Fox S. H., Toth T.: Dose reduction on GE CT scanners. Pediatr. Radiol., 32, 718, 2002.
7. Gies M. et al.: Dose reduction in CT by anatomically adapted tube current modulation. I. Simulation studies. Med. Phys., 26, 2235, 1999.
8. Greess H. et al.: Dosage reduction in computed tomography by anatomy-oriented attenuation-based tube-current modulation: the first clinical results, Rofo, 170, 246, 1999.
9. Hart D., Wall B. F.: UK population dose from medical X-ray examinations. Eur. J. Radiol., 50, 285, 2004.
10. Hidajat N. et al.: Survey of conventional and spiral CT doses. Radiology, 218, 395, 2001.
11. Huda W.: Dose and image quality in CT. Pediatr. Radiol., 32, 709, 2002.
12. Huda W. et al.: How do radiographic techniques affect image quality and patient doses in CT?, Semin. Ultrasound CT MR, 23, 411, 2002.
13. Kalra M. K. et al.: Clinical comparison of standard-dose and 50% reduced-dose abdominal CT: Effect on image quality, Am. J. Roentgenol., 179, 1101, 2002.
14. Kalra M. K. et al.: Radiation exposure and projected risks with multidetector-row computed tomography scanning: clinical strategies and technologic developments for dose reduction. J. Comput. Assist. Tomogr., 28, S46, 2004.
15. Kalra M. K. et al.: Sixteen-detector row CT of abdomen and pelvis: study for optimization of z-axis modulation technique performed in 153 patients. Radiology, 233, 241, 2004.
16. Kalra M. K. et al.: Strategies for CT radiation dose optimization, Radiology, 230, 619, 2004.
17. Kaul A. et al.: Effective doses to members of the public from the diagnostic application of ionizing radiation in Germany, Eur. Radiol., 7, 1127, 1997.

18. Koller C. J. et al.: Variations in radiation dose between the same model of multislice CT scanner at different hospitals. Br. J. Radiol., 76, 798, 2003.
19. Lewis M.: Radiation dose issues in multi-slice CT scanning, ImPACT technology update, 3, 1, 2005.
20. Mahesh M.: Search for isotropic resolution in CT from conventional through multiple-row detector, Radiographics, 22, 949, 2002.
21. Scheck R. J. et al.: Radiation dose and image quality in spiral computed tomography: multicentre evaluation at six institutions, Br. J. Radiol., 71, 734, 1998.
22. Schulze D. et al.: Radiation exposure during midfacial imaging using 4-and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac. Radiol., 33, 83, 2004.
23. Siegel M. J. et al.: Radiation dose and image quality in pediatric CT: Effect of technical factors and phantom size and shape, Radiology, 233,515, 2004.
24. Sohaib S. A. et al.: The effect of decreasing mAs on image quality and patient dose in sinus CT, Br. J. Radiol., 74, 157, 2001.
25. Toth T. L.: Dose reduction opportunities for CT scanners. Pediatr. Radiol., 32,261, 2002.
26. Yates S. J. et al.: Effect of multislice scanners on patient dose from routine CT examinations in East Anglia. Br. J. Radiol., 77, 472, 2004.

SUMMARY

Since its introduction in 1972, x-ray computed tomography (CT) has evolved into an essential diagnostic imaging tool for a continually increasing variety of clinical applications. Despite the introduction of alternative examination techniques, such as sonography, magnetic resonance imaging (MRI) and endoscopy, the number of x-ray examinations has altogether increased. The frequency of some types of x-ray examinations was very strongly increasing, i. e. CT, angiography and mammography. CT scanning is associated with significantly higher radiation exposure compared with other radiation-based medical examinations, including conventional radiography and nuclear medicine studies. Currently CT examinations constitute about 6% of all x-ray examinations, they cause more than 40% of the exposure due to medical x-ray applications. The purpose of the study is to present scanning parameters affecting radiation dose for patients undergoing CT study and methods of reducing the patient effective dose. Radiation dose for patients undergoing CT study is affected by several scanning parameters such as beam energy (tube voltage), tube current time product (mAs), section thickness, number of sections and pitch. The radiation dose from CT remains a major concern and therefore, there are attempts to reduce radiation dose in CT scanning. The dose and the image quality in CT are closely linked. Reducing patient dose by reducing x-ray exposure has the inevitable consequence of increasing noise and decreasing contrast in the images. It is very important to identify the minimum x-ray exposure, which mean the lowest image quality, required for a given examination and pathology. Therefore, it is essential to draw the attention of referring physicians, radiologist, and even manufacturers to dose consequences and to establish scanning protocols that restrict the examination to what is absolutely essential. The optimum technique factor will generally depend on the specific task at hand

Dawka promieniowana w tomografii komputerowej – parametry skanowania wpływające na jej wielkość

Od czasu wprowadzenia w roku 1972 tomografia komputerowa stała się jednym z podstawowych obrazowych badań diagnostycznych o ciągle rosnącej różnorodności zastosowań klinicznych. Pomimo wprowadzenia alternatywnych metod diagnostyki obrazowej, niewykorzystujących promieniowania rentgenowskiego, takich jak ultrasonografia, rezonans magnetyczny, endoskopia, liczba wykonywanych badań radiologicznych, a szczególnie tomografii komputerowej, stopniowo wzrasta. Badanie TK jest powiązane z wielokrotnie większym narażeniem na promieniowanie w porównaniu z innymi badaniami radiologicznymi. Według najnowszych danych badania TK stanowią obecnie około 6% badań radiologicznych, powodując przekazanie ponad 40% całkowitej dawki promieniowania. Celem pracy jest przedstawienie parametrów badania TK wpływających na wielkość dawki promieniowania pochłoniętej przez pacjenta i w trakcie badania oraz metod jej redukcji. Dawka promieniowania przekazana podczas badania tomograficznego powinna być zawsze brana pod uwagę ze względu na potencjalne szkodliwe działanie, i powinno się dążyć do jej minimalizacji. Na poziom dawki promieniowania w badaniu tomografii komputerowej ma wpływ wiele parametrów skanowania, spośród których najważniejsze są: natężenie prądu lampy (mA), napięcie prądu lampy (kV), grubość warstwy, ilość warstw, pitch. Dawka promieniowania i jakość obrazowania są ze sobą ściśle powiązane. Obniżając dawkę promieniowania, stopniowo podwyższa się szum uzyskiwanych obrazów oraz obniża się rozdzielczość kontrastową. Ważnym wyzwaniem jest określenie właściwej jakości obrazowania, tj. optymalnego poziomu szumu oraz rozdzielczości kontrastowej dla danego badania, wystarczających do uzyskania wartościowych diagnostycznie obrazów przy użyciu minimalnej dawki promieniowania. W wielu przypadkach możliwa jest znaczna redukcja natężenia prądu lampy bez negatywnego wpływu na wartość diagnostyczną obrazowania. Dlatego istotne staje się zwrócenie uwagi na potencjalne konsekwencje narażenia pacjenta na promieniowanie. Ważną sprawą jest racjonalne wykorzystanie wszechstronnego narzędzia obrazowania, jakim jest spiralny tomograf komputerowy, oraz opracowanie protokołów badań minimalizujących ekspozycje pacjenta na promieniowanie jonizujące. Optymalna technika skanowania zależy głównie od wiedzy lekarza badającego i znajomości urządzenia, na którym przeprowadzane jest badanie.