Eur Radiol (2005) 15: 1898–1905
DOI 10.1007/s00330-005-2720-2

COMPUTER TOMOGRAPHY

Jessen Gurung
M. Fawad Khan
Adel Maataoui
C. Herzog
R. Bux
H. Bratzke
Hanns Ackermann
Thomas J. Vogl

Multislice CT of the pelvis: dose reduction with regard to image quality using 16-row CT

Received: 8 October 2004
Accepted: 15 February 2005
Published online: 2 April 2005

J. Gurung and M.F. Khan contributed in equal measure to this study

J. Gurung (✉) · M. F. Khan · A. Maataoui · C. Herzog · T. J. Vogl
Institute for Diagnostic and Interventional Radiology,
Johann Wolfgang Goethe University,
Theodor-Stern-Kai 7,
60590 Frankfurt am Main, Germany
e-mail: jessen.gurung@gmx.de
Tel.: +49-69-63017277
Fax: +49-69-63017258

H. Ackermann
Institute for Epidemiology and Medical Statistics,
Johann Wolfgang Goethe University,
Frankfurt am Main, Germany

R. Bux · H. Bratzke
Institute for Forensic Medicine,
Johann Wolfgang Goethe University,
Frankfurt am Main, Germany

Abstract To optimize examination protocols of 16-row multi-detector CT (MDCT) of pelvis for dose reduction with regard to image quality. MDCT of pelvis was performed on 12 cadaver specimens with stepwise reduction of tube current from 160 mA (113, 80, 56, 40, 28) to 20 mA at 120 kV. Scan parameters were 16×1.5 mm collimation. Reconstructions of axial and coronal images were used for evaluation of cortex, trabeculum, image quality, image noise, acetabulum and iliosacral (ISJ) joints. After data were blinded, evaluation of images was done by three radiologists according to 5-point Likert scale. Accuracy of the observers in sorting films according to dose reduction was determined with kappa coefficient. Mean values of image evaluation were determined. Pronounced deterioration of image quality for all criteria was observed between 80 and 28 mA. Adequate image quality was obtained at 40 mA [effective dose (E): 2.2 mSv, $CTDI_w$: 2.8 mGy] for criterion detailed definition of acetabulum and ISJ and at 80 mA (E: 4.4 mSv, $CTDI_w$: 5.6 mGy) for remaining criteria. Moderate agreement was observed between the three observers (kappa coefficient: 0.31). All observers were excellent in arranging images according to decreasing dose. Using 16-row MDCT image quality of pelvis is acceptable at 80 mA and 120 kV. This translates into a dose reduction of 33% of average value of the nationwide survey of the German Roentgen Society (1999) for this type of examination.

Keywords 16-row MDCT · Dose reduction · Image quality · Pelvis

Introduction

Although computed tomography comprises only 4% of the total radiological investigations carried out, it contributes up to 35% of the collective effective dose.

The CT therefore has the largest amount of radiation exposure caused medically [1].

In the last few years, technical developments have further increased the sensitivity of the detector system in order to be able to bring about possible reduction in radiation. However, faster and better imaging with higher resolution and thinner slices have led to higher radiation dose from one CT generation to the next [2].

The CT scan of the pelvic bones offers an overlap-free description of the clinical condition in comparison to conventional X-ray. For the frequently asked question about pelvic fracture, it is possible to describe the fracture better with CT especially the posterior ring [5, 6]. Multiplanar reconstruction (MPR) with slice thickness between 2 and 4 mm allows us to describe the fracture in detail [5, 6, 14]. The nationwide survey of the German Roentgen Society (1999) for CT exposition shows a relative high radiation exposure with CT examination of the pelvic bones [7]. Because there are radiation sensitive organs especially in the pelvis and also in view of the frequent young patients, reduction in radiation exposure is desirable.

With this background, a detailed evaluation of every CT generation is necessary with the aim to optimise investigation protocols to lower irradiation doses and simultaneously be able to produce a diagnostically sufficient image quality.

Especially suited for a dose reduction are tissues with high density differences, the so-called object-contrast, like the one found in lung and bone tissue.

A nationwide study done by Galanski et al. showed a relatively high dose value for CT examinations of the pelvic bones [3]. The authors believe that this was because the examinations of the soft tissues and bones performed were not requirement oriented, that for both CT examinations the same CT protocol was used. Conclusively, the possibility of dose reduction in high object-contrast was seldom made use of.

Hence this study is carried out to work on an ALARA principle (as low as reasonable achievable) and simultaneously maintain an adequate image quality in a 16-row MDCT with the purpose to optimise the dose for CT examination of the pelvic bones.

Materials and methods

MDCT examinations

All examinations of the pelvic bones were carried out on a Somatom Sensation (Siemens Medical Solutions, Forchheim, Germany), 16-row multidetector computer tomograph with 120 kV. The tube current was set at seven gradations starting from 160 to 20 mA. The following mA values were used: 160, 113, 80, 56, 40, 28, 20 mA keeping the exposure time constant. The other investigation parameters are shown in Table 1.

Table 1 The parameters for MDCT examination of the pelvic bones

Tube voltage (kV)	120
Tube current (mAs)	160–20
Collimation (mm)	16×1.5
Table feed/rotation (mm)	24
Pitch	1.0
Rotation time (ms)	420
Scan length (cm)	21–23

Table 2 Age, height and weight of the 12 cadavers used for MDCT examination

Patient	Age	Height (m)	Weight (kg)
1	93	1.55	63
2	27	1.71	60
3	81	1.62	58
4	46	1.76	72
5	90	1.60	66
6	61	1.69	82
7	98	1.50	56
8	55	1.80	90
9	68	1.68	90
10	55	1.60	47
11	59	1.80	60
12	69	1.83	78

As the image noise changes proportional to the reciprocal value of the square root of the milliampere product, it results in tube current grade of about factor $1/\sqrt{2}=0.71$ in logarithmic form. Thus the resultant logarithmic grade for image noise is calculated to be at factor 1.19. All examinations were conducted upon 12 cadavers.

A total of seven examinations were conducted upon every cadaver with the above mentioned tube current levels. The average age of the cadavers was 66.8 years. Age, height and weight of every cadaver are listed in Table 2.

Image reconstructions

Two reconstructions were done out of the raw data for every examination: 5 mm and 1.5 mm thick axial slices. Both reconstructions were done with a kernel of “B70f” which is a “very sharp” filter used for bone window. The increment for reconstruction was 5 mm for 5 mm thick slices and 0.75 mm for 1.5 mm thick slices. The 1.5 mm thick slices were used for coronal multiplanar reconstruction (MPR). The slice thickness and image distance for the MPR was 3 mm.

For the purpose of evaluation two axial images of 5 mm slice thickness and two coronal images of 3 mm slice thickness were printed. Both axial images were filmed through the acetabulum. Out of the two coronal images, one was made through the iliosacral joint (ISJ) and the other through the acetabulum. Altogether four images were taken in a film sheet for every milliampere gradation so that there were seven films for each patient for evaluation (Fig. 1). All examination parameters that would lead to identification of the image or dose level were blinded. The films were blinded with an alphabetical code so that the observer could later sort them according to milliampere product and film. The coding or blinding was done with the help of a technical assistant.

Fig. 1 Example of a film with four images that were available to the radiologists for evaluation

Evaluation of images

The coded films, which were arranged in a random order, were evaluated by three radiologists (J.G, M.F.K, A.M.) who noted their findings, according to given assessment criteria, in a form. There were five criteria for every film and every criteria had a 5-point Likert scale for evaluation: cortical contours, trabecular structure, subjective image quality, image noise, detailed definition of acetabulum and ISJ.

The assessment criteria were evaluated as follows (Likert scale): 1—very good; 2—good; 3—average; 4—sufficient; 5—suboptimal/poor.

The evaluation was made from simultaneous assessment of both axial and MPR images. At the end, all the three observers were asked to sort out the seven films of each patient in a descending order according to the impression of dose reduction.

Statistical evaluation

The correlation of the three observers in the evaluation of the five criteria was adjudged with the multi-rater-coefficient. The accuracy of the observers in correctly sorting out the coded films in descending order in respect to the irradiation doses was determined with the square deviation of the sorted position from the true order. The image quality was established from the mean value for every seven different dose gradations. In this way, a mean value of the score given by the three observers for the five criteria was established. This was done for each dose levels for every patient. Thus a diagnostically sufficient image quality was defined to be at an average point value of two (1.5–2.49) [4].

The statistical evaluation was done with BiAS software programme for Windows, Version 8.01, 1989–2004 Epsilon (http://www.bias-online.de).

The CT Expo software programme serves for all seven dose levels in each case the effective dose (millisievert) which computes the effective and weighted CTDI (CTDIeff or $CTDI_w$), dose length product (DLP) and their relative values with regards to the 1999 survey were determined. The 1999 survey of CT exposition by Galanski et al. serves as a basis for the establishment of German CT reference values. A proportional comparison of our dose results with

Table 3 The five criterias were evaluated on a 5-point scale by three observers

Criterias	Kappa-coefficient
Cortical contours	0.19
Trabecular structure	0.25
Subjective image quality	0.22
Image noise	0.33
Detailed definition of acetabulum and ISJ	0.22

The correlations between the assessments of the three observers were established by multi-rater-kappa coefficient

the results of the nationwide survey is possible with this program.

Results

The correlation of the three observers concerning the five criteria was only moderate. The multi-kappa-rater coefficient was in the average of k=0.24 and the confidence interval was 95% with kappa coefficient of 0.20–0.30. The kappa coefficients are shown in detail in Table 3. The best correlation was shown by image noise with a kappa coefficient of 0.33.

Table 4 The mean values from the 5-point scale evaluation by the three observers for every seven dose gradations

Patients	160 mA			113 mA			80 mA			56 mA			40 mA			28 mA			20 mA		
	J.G.	M.F.K.	A.M.	J.G.	M.F.K.	A.M.	J.G.	M.F.K.	A.M.	J.G.	M.F.K.	A.M.	J.G.	M.F.K.	A.M.	J.G.	M.F.K.	A.M.	J.G.	M.F.K.	A.M.
1	1.8	1.6	2.6	1.4	2.4	2.6	2.8	2.6	2.6	2.2	2.4	3	2.2	3.6	2.8	2.8	3.8	2.2	3	4.2	3.4
2	1.6	1.6	1.8	2.8	1.4	1.6	3	2	2.4	2.8	2.8	2.2	3.6	3.8	2.8	3.4	3.8	2	4	3.8	3.8
3	2	1.8	2.4	1.2	2	2.8	1.8	3.2	2.6	2.4	3.2	2.2	2.8	3.8	2.6	4	3.2	3.2	4	4	3.6
4	1	1.4	2.2	2.2	1.6	1.6	2	2.8	2.2	1.8	3	2.2	2.6	3.4	2.2	3	3.6	3.4	4	4.4	2.6
5	1	1.4	1.8	1.2	1.6	2	1.2	2.4	1.6	2.4	3	2.8	3.4	4.2	2.6	3.6	4	3.2	4.2	4.2	3.2
6	2.2	1.4	1.2	1.8	1.6	1.2	1.2	2.4	1.2	2.4	3.2	2.6	4.4	4.2	2.8	4	4	2.8	4.4	3.8	3
7	2.4	1.6	2.2	2.6	2	2.6	3.6	2.8	2.8	3.6	3.4	2.4	4.2	2.8	3.2	3.8	4.4	3.8	4.6	5	4.4
8	2	2.2	1.2	1.6	1	1.4	2.8	2.6	1.2	2.2	2	2.2	2.4	3.6	2	2.4	2.2	2	3.6	3.2	3.2
9	1.8	2.2	1.8	1.4	3	4.2	1.6	2.8	3.2	2.6	3.4	3	3	5	4.2	3.4	4.8	5	3.8	4.6	4.8
10	1.6	4	2.2	1	1	1.2	1	1.8	2.2	2.2	2	2	2	1.8	1.6	2.2	2.8	2	3	2.8	3.2
11	1.2	2	2	2	1.8	2	1.8	2.8	2.2	2.4	2	2.8	2	3.6	3.6	3.4	2.8	3.6	3.8	4.4	4.6
12	1.8	3.2	2.6	1	1	1.4	2	1.8	2	2.2	2	2.2	2.2	4.6	2.8	3	4.2	3.6	3.6	4	3.8
Mean	1.7	1.7	2	1.68	1.84	2.05	2.06	1.92	1.92	2.45	2.45	2.04	2.9	2.12	2.12	3.25	2.20	3.06	3.83	2.3	3.63

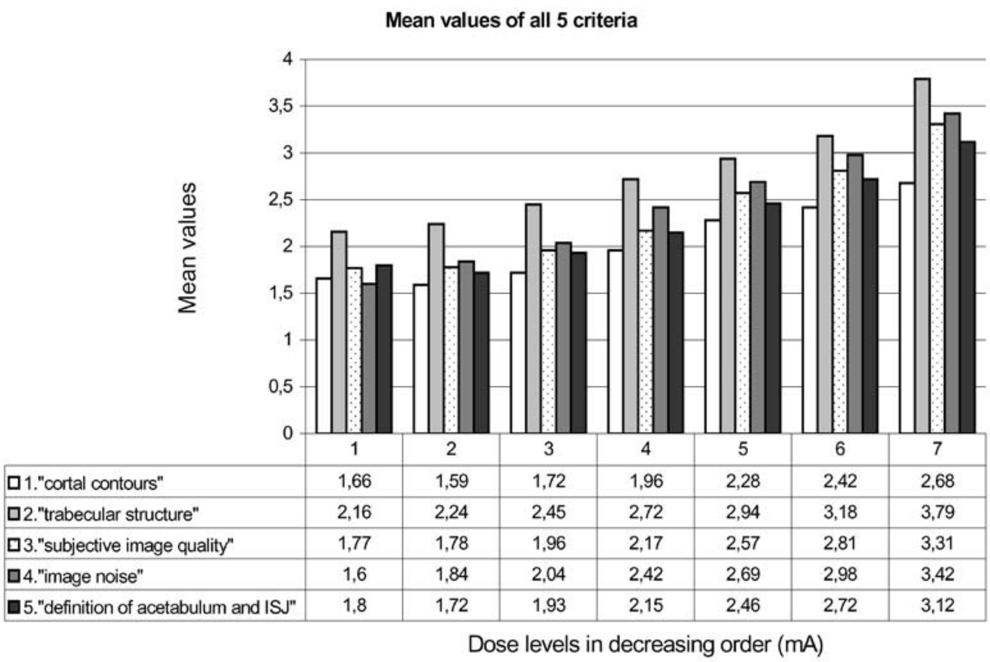

Fig. 2 Graphic representation of all mean values for every criteria

Fig. 3 **a** Coronal and axial images at 80 mA and 120 kV. Cortex, trabecular structure and image quality are adequate. Only minimal image noise was noticed. **b** Coronal and axial images at 40 mA and 120 kV. Acetabulum and iliosacral joints can still be well defined. Note the increase in image noise here

The three observers were very good in sorting out the images in an ascending order of dose reduction. Of the 36 times (three observers for 12 patients) that every seven films were required to be sorted out in the right order, the observers were able to sort out the films 22 times in an exact ascending order. The films could not be arranged in the right order 14 times. Eight times were more than one film arranged in the false order.

The mean values from the 5-point scale evaluation are shown in Table 4 and Fig. 2.

The average values showed an increase with a poor image quality with increasing dose reduction. The mean value for the maximum dose level (160 mAs/120 kV) was calculated to be from 1.7 to 2.0 for every single evaluation criteria. In contrary to that, the mean value for the minimal dose level (20 mA/120 kV) was found to be between 2.3

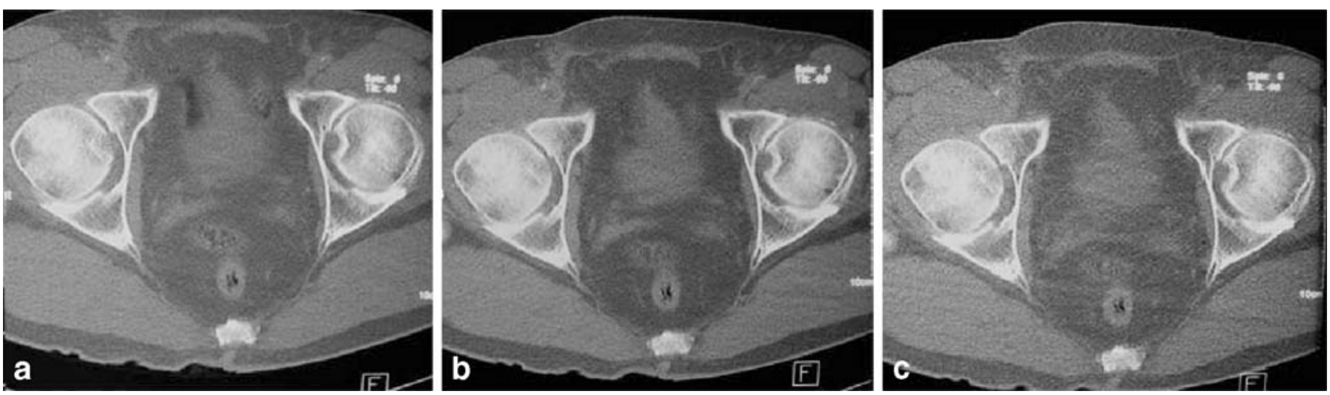

Fig. 4 Coronal images at 40, 28 and 20 mA showing increased image noise which compromises image quality

Table 5 The dose value for CTDI eff, $CTDI_w$, DLP, effective dose (millisievert) and the relative values to 1999 survey for the seven dose gradations using CT-Expo software programme

	Dose value				Relative value (%)			
Doses (mA)	CTDI eff (mGy)	$CTDI_w$ (mGy)	DLP (mGy*cm)	E (mSv)	CTDI eff	$CTDI_w$	DLP	E
160	11.2	11.2	515	8.7	56	48	81	81
113	7.9	7.9	364	6.2	39	34	57	58
80	5.6	5.6	258	4.4	28	24	41	41
56	3.9	3.9	180	3.1	20	17	28	29
40	2.8	2.8	129	2.2	14	12	20	20
28	2	2	90	1.5	10	8	14	14
20	1.4	1.4	64	1.1	7	6	10	10

and 3.8. A clear difference in the evaluation values was found to be for a dose reduction from 80 to 56 mA.

A variation of dose levels was felt to be necessary for every evaluation criteria to achieve an adequate image quality.

An adequate image quality could be achieved for the criteria—cortical contours, trabecular structure, subjective image quality and image noise with a dose level of 80 mAs/120 kV. Only for the criteria—detailed definition of acetabulum and ISJ, an adequate image quality could be achieved with a low dose level of 40 mA (Fig. 3).

Dose levels of 40, 28 and 20 mA did not produce an adequate image quality (Fig. 4).

The calculated value for the CTDI eff, $CTDI_w$, DLP and the effective dose (mSv) and the relative values to 1999 survey for the seven dose levels done with the CT Expo software programme are shown in Table 5.

An effective dose [*E*) of 4.4 mSv ($CTDI_w$=5.6 mGy] and 2.2 mSv ($CTDI_w$=2.8 mGy) was calculated for the dose gradations of 80 mAs/120 kV and 40 mAs/120 kV, respectively. In comparison to the 1999 survey, the relative values were calculated to be 41 and 20% for effective dose and 24 and 12% for $CTDI_w$, which means that it is possible to reduce the dose levels up to one-third of the reference values, despite maintaining adequate image quality.

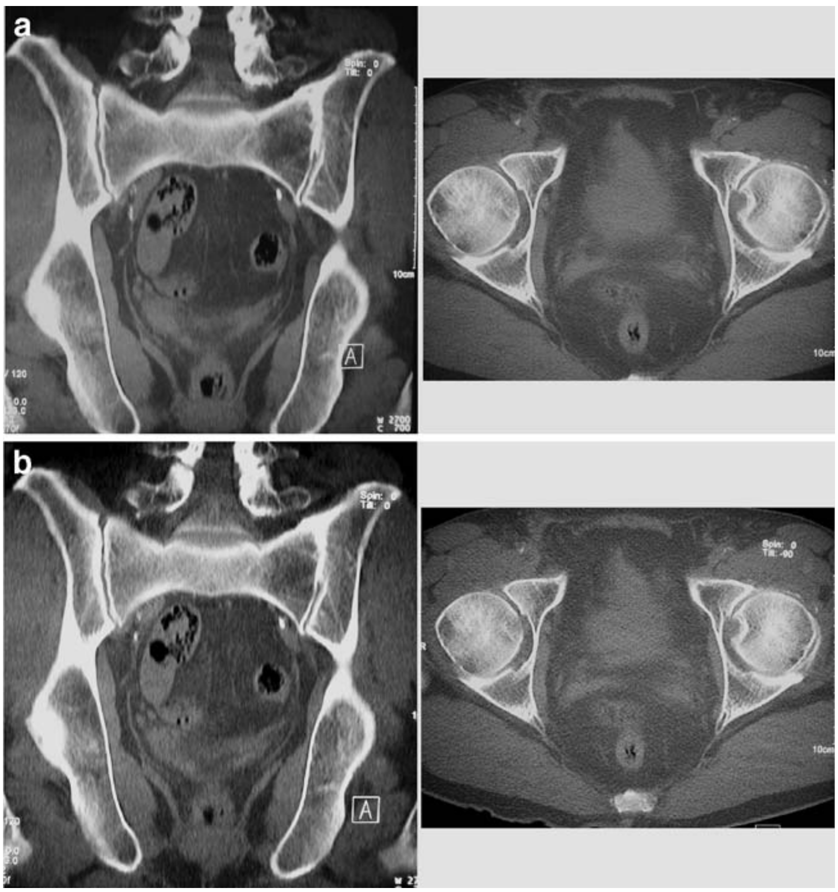

Fig. 5 **a** Coronal and axial images at 160 mA and 120 kV. Minimal or no image noise can can be seen here. **b** Coronal and axial images at 28 mA and 120 kV. Increased image noise in the images

Discussion

Our study shows that it is possible to achieve a clear reduction in doses in the examination of pelvic bones by simultaneously maintaining an adequate image quality. Although the various dose levels showed different evaluation criteria as adequate, a conclusion concerning the accuracy of the diagnosis of a fracture can be made. Description of the cortex, the trabecular structure as well as details of the acetabulum and ISJ plays a major role in the diagnosis of fractures. They allow definite diagnosis of a fracture.

Although image noise was strongly reported with increasing dose reductions, there was no obvious difference for other criteria especially for the cortical contour and trabecular structure (Fig. 5). Image noise plays an important role in the quality of image. Techniques such as multidimensional adaptive filtering (MAF) which improved image quality by reducing image noise as described by Baum et al. offers better perspectives for further dose reduction [18].

Considering the different priorities of the individual criteria in the diagnosis of a fracture, a dose level of 80 mA and 120 kV can be regarded as adequate for CT scan of the pelvic bones. In our study, it was possible to obtain a diagnostically adequate image quality at 80 mA for criteria–cortical contours, trabecular structure, subjective image quality and image noise with a weighted CT dose ($CTDI_w$) of 5.6 mGy and an effective dose of 4.4 mSv.

As the tube current is directly proportional to dose, a decrease in tube current leads to decreased radiation exposure. Contrast-rich tissues such as the lungs and the bones are better suitable for dose reduction than tissues poor in contrast. Studies have been performed to obtain a reasonable compromise between image noise and dose reduction in CT examinations of children [16]. Various studies relating to detection of the lung nodules show that a tube current reduction of up to 30% from the standard is diagnostically sufficient [8–10].

Cohen et al. reported a possible dose reduction of up to 40% for CT examination of the skull [11]. A dose reduction of up to 46% of nationwide average was possible for four-row MDCT with adequate image quality [4].

Although all the observers gave a bad note for the various criteria of image quality with increasing dose reduction, only little co-relation could be noticed in overall evaluation. It was proved that exact evaluation of the criteria was difficult especially with low dose gradations (56, 40, 28, 20 mA).

Prasad et al. describes a better co-relation (0.59); however, in his study there were only two observers instead of three and only two dose gradations instead of seven were studied [12]. Kamel et al. shows that a substantial dose reduction can be achieved in a paediatric pelvic CT at 80 mA without recognisable deterioration of diagnostic image quality [13]. Although this does not fit as a low dose protocol in children, the study supports our theory of the possibility of dose reduction in CT examinations while at the same time maintaining good image quality. Greess et al. in their study show that a substantial reduction of dose in MDCT examinations of children can be achieved by online modulation of tube current [17].

The good results in arranging the films in descending order of dose gradations nevertheless hint towards a good film analysis. In summary, this shows that a parameter adjustment of 80 mA and 120 kV for CT examination of the pelvic bones in a 16-row MDCT offers an optional compromise between dose reduction and image quality. This leads to a definite reduction in dose levels and nevertheless a good detectability of bone structures. The $CTDI_w$ and DLP values serve as a guide for comparison with equipments from other vendors who do not have the same milliampere values, filtrations or DQE for the detectors.

All examinations were conducted on 12 cadavers that were provided by the Institute of Forensic Medicine, Johann Wolfgang Goethe University, Frankfurt, Germany.

References

1. Bernhardt J, Veit R, Bauer B (1995) Erhebung zur Strahlenexposition der Patienten bei der Röntgendiagnostik. Z Med Phys 5:33–39
2. Nagel ND, Strahlenexposition in der Computertomographie. Grundlagen, Einflussfaktoren, Dosisermittlung, Optimierung, Zahlenwerte, Begriffe. CTB Publications, Hamburg (Info:ctb-publications@gmx.de)
3. Galanski M, Nagel ND, Stamm G (2001) CT- Expositionspraxis in der Bundesrepublik Deutschland. Ergebnisse einer bundesweiten Umfrage im Jahre 1999. Fortschr Röntgenstr 173:R1–R66
4. Wedegartner U, Lorenzen M, Lorenzen J, Nolte-Ernsting C, Weber C, Dieckmann C, Cramer M, Schoder V, Adam G (2004) Mehrzeilen Spiral CT (MSCT) des Beckenskelettes: dosisoptimierung unter berücksichtigung der bildqualität. Fortschr Röntgenstr 176:106–112
5. Rommens P, Gielen J, Broos P (1992) Die bedeutung der CT für diagnostik und therapie der frakturen des beckenrings. Unfallchirurg 95:168–173
6. Montana M, Richardson M, Kilcoyne R, Harley J, Shuman W, Mack L (1986) CT of sacral injury. Radiology 161:499–503

7. Wedegärtner U, Thurmann H, Schmidt R, Adam G (2003) Strahlenexposition bei der Mehrschicht Spiral CT (MSCT) von Kopf; Mittelgesicht und Beckenskelett: Vergleich mit dem Einzeilen Spiral CT (SSCT). Fortschr Röntgenstr 234–238
8. Ravenel JG, Scalzetti EM, Huda W, Garrisi W (2001) Radiation exposure and image quality in chest CT examinations. Am J Roentgenol 17:279–284
9. Rusinek H, Naidich D, McGuiness G, Leitmann B, McCauley D, Krinsky G, Clayton K, Cohen H (1998) Pulmonary nodule detection: low-dose versus conventional CT. Radiology 209:243–249
10. Diederich S, Lenzen H, Windmann R et al. (2000) Pulmonary nodules: experimental and clinical studies at low-dose CT. Radiology 213:289–298
11. Cohnen M, Fischer H, Hamacher J, Lins E, Kötter R, Mödder U (2000) CT of the head by use of reduced current and kilovoltage: relationship between image quality and dose reduction. Am J Neuroradiol 21:1654–1660
12. Prasad SR, Wittram C, Shepard JA, McLoud T, Rhea J (2002) Standard-dose and 50% reduced-dose chest CT: comparing the effect on image quality. Am J Roentgenol 179:461–465
13. Kamer IR, Hernandez RJ, Martin JE, Schlesinger AE, Niklason LT, Guire KE et al. (1994) Radiation dose reduction in CT of the pediatric pelvis. Radiology 190(3):683–687
14. Herzog C, Ahle H, Mack MG, Maier B, Schwarz W, Zangos S, Jacobi V, Thalhammer A, Peters J, Ackermann H, Vogl TJ et al. (2004) Traumatic injuries of the pelvis and thorac and lumbar spine: does thin-slice multidetector-row CT increase diagnostic accuracy? Eur Radiol 14(10):1751–1760. Epub 2004 Aug 05
15. Brix G, Lechel U, Veit R, Truckenbrodt R, Stamm G, Coppenrath EM, Griebel J, Nagel HD et al. (2004) Assessment of a theoretical formalism for dose estimation in CT: an anthropomorphic phantom study. Eur Radiol 14(7):1275–1284. Epub 2004 Mar 19
16. Verdun FR, Lepori D, Monnin P, valley JF, Schnyder P, Gudinchet F et al. (2004) Management of patient dose and image noise in routine pediatric CT abdominal examinations. Eur Radiol 14 (5):835–841. Epub 2004 Jan 13
17. Greess H, Lutze J, Nomayr A, Wolf H, Hothorn T, Kalender WA, Bautz W et al. (2004) Dose reduction in subsecond multislice spiral CT examination of children by online tube current modulation. Eur Radiol 14(6):995–999. Epub 2004 Mar 30
18. Baum U, Anders K, Steinbichler G, Lell M, Greess H, Riedel T, Kachelriess M, Kalender WA, Bautz WA et al. (2004) Improvement of image quality of multislice spiral CT scans of the head and neck region using a raw data-based multidimensional adaptive filtering (MAF) technique. Eur Radiol 14 (10):1873–1881. Epub 2004 Aug 24