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Radiation Dose to the Radiologist's Hand During Continuous CT Fluoroscopy-Guided Interventions

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Abstract

Computed tomography fluoroscopy (CT fluoroscopy) enables real-time image control over the entire body with high geometric accuracy and, for the most part, without significant interfering artifacts, resulting in increased target accuracy, reduced intervention times, and improved biopsy specimens [1–4]. Depending on the procedure being used, higher radiation doses than in conventional CT-supported interventions might occur. Because the radiologist is present in the CT room during the intervention, he is exposed to additional radiation, which is an important aspect. Initial experience with CT fluoroscopically guided interventions is from the work of Katada et al. in 1994 [5] and only relatively few reports on radiation aspects in CT fluoroscopy are found in the literature [1, 2, 6–11]. To date, there are no reported injuries to patients and radiologists occurring with CT fluoroscopy. The time interval since the wide use of CT fluoroscopy is too short to have data on late effects to the operator using CT fluoroscopy on a daily basis. In addition, the spectrum of CT fluoroscopically guided interventional procedures will expand and more sophisticated procedures requiring longer fluoroscopy times will be performed. Thus, effective exposure reduction is very important. The purpose of our study was to assess the radiation dose to the operator's hand by using data from phantom measurements. In addition, we investigated the effect of a lead drape on the phantom surface adjacent to the scanning plane, the use of thin radiation protective gloves, and the use of different needle holders.

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Materials and Methods

Technology

As a result of a repetition frequency of 8–12 images/sec, a CT scanner with continuous rotation presents images on an additional monitor without the sensory perception of a windshield wiper effect. When performing an intervention, it is important that the delay time between object action (e.g., the movement of the needle tip) and display on the monitor is as small as possible. Short image reconstruction periods of 83 msec minimize the delay using a special real-time processor. The CT scanner used was a four-slice Aquilion Multi equipped with CT fluoroscopy (Toshiba Medical Systems, Nasu, Japan).

The CT fluoroscopy image is displayed in the examination room on a monitor. There are several ways to display the fluoroscopy image. Most scanners work with a single image display. With our CT scanner unit, a maximum of three simultaneous image slices can be shown on the monitor, with the two middle slices of the four-slice detector being combined into one slice. This simultaneous display of three slices has the advantage that the needle guidance can be controlled in the outer images and that deviation from the target slice plane will be immediately noticed in the outer slices. After a scan stop, the last images are shown again. A mobile operating unit in the examination room is used with a panel for operating the gantry and laser beam, controlling the vertical and horizontal table motion, as well as adjusting the CT table position in millimeter steps to exactly follow the needle tip.

The tube voltage was 120 kV, the tube current was 50 mA, and the tube rotation time was 0.5 sec.

Fluoroscopy Method

The study was performed using real-time fluoroscopy. The biopsy or aspiration needle is inserted using a needle holder, especially designed for this purpose, to keep the operator's hand outside of the primary beam. The needle is advanced into the target during CT fluoroscopy: The radiologist steps on the foot pedal while adjusting

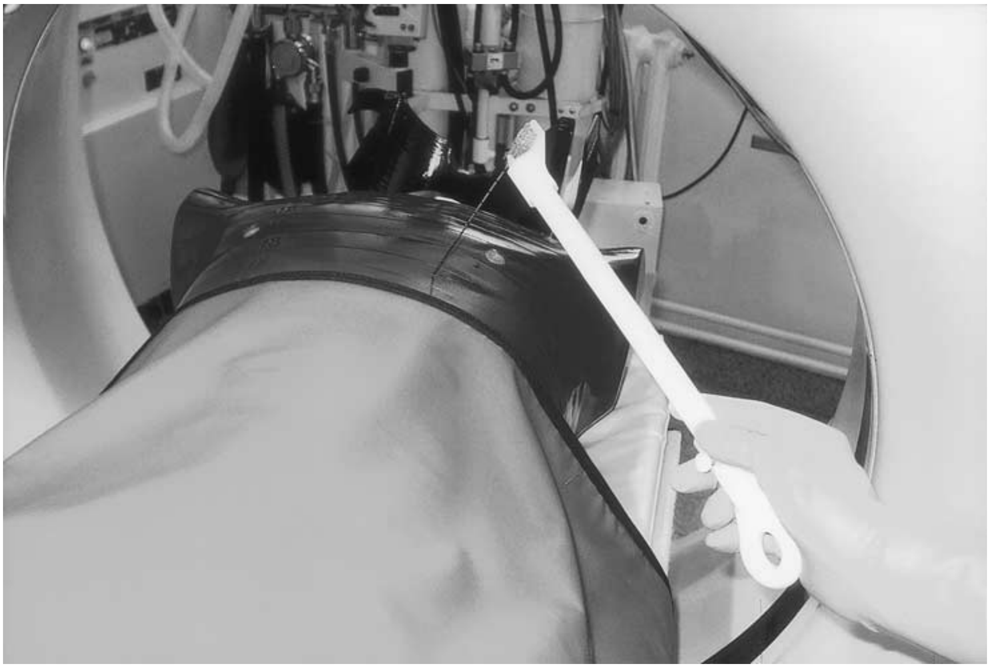

Fig. 1. Measurement of radiation dose to the radiologist's hand by using the Alderson phantom. Radiation protection tools with placement of lead drape 2 cm caudally from the central plane and use of radiation protection gloves and long needle holder.

the table position by using the free nonpunctating hand to follow the needle tip. When the needle tip is in the lesion, the foot pedal is released.

Devices for Radiation Dose Measurements

Alderson Radiation Therapy Phantom

The radiation dose was measured using the Alderson Radiation Therapy (ART) Phantom (The Phantom Laboratory, New York, NY). The ART phantom is molded of tissue equivalent material and follows the standards of the International Commission of Radiation Units and Measurements (ICRU, Report No. 44). The male ART was used representing a 175-cm-tall and 73.5-kg male.

Radiation Dosimeter

A digital dosimeter was used to assess the radiation dose of the radiologist's hand, which was attached directly to the back of the punctating hand (model EPD1; Siemens Plessey Control Limited, Dorset, UK). The minimum reliable dose of the dosimeter is 0.01 μGy. The dose rate is 5 μGy/h to3Gy/h. The sampling rate is 10–15 impulses/sec. For measurements with gloves, the dosimeter was secured under the gloves.

Radiation Protection Devices

The potential for high radiation doses to the radiologist's hand during CT fluoroscopy prompted us to investigate devices for reducing the radiation dose.

Radiation Protection Gloves

For radiation protection of the radiologist's hand, thin latex radiation protection gloves made of bismuth (0.4-mm lead equivalent; Paul Hartmann AG, Heidenheim, Germany) were used.

Lead Drapes

The lead drapes were 60 cm in length and 90 cm in width (Mavig GmbH, Munich, Germany). The lead cover placed on the surface of the phantom was of 0.5-mm lead equivalent; the one positioned under the phantom was of 1.0-mm lead equivalent. Thus, the phantom was covered with the heavier lead drape beneath and the lighter on top. The drape was positioned with its end 2 cm caudally from the scanning plane (Fig. 1).

Needle Holders

Short needle holder: The needle holder is made of acrylate (CBC Corporation, Tokyo, Japan; Fig. 2). It is 15 cm in length and keeps a distance of 10 cm between the handle and the X-ray beam.

Long needle holder: The needle holder is made of polyoxymethylene (Somatex GmbH, Rietzneuendorf, Germany; Fig. 2). It is 35 cm in length and keeps a distance of 30 cm between the handle and the X-ray beam.

Monte Carlo Simulation

Monte Carlo simulations are conducted to estimate the distribution of scatter radiation in the examination room during CT fluoros-

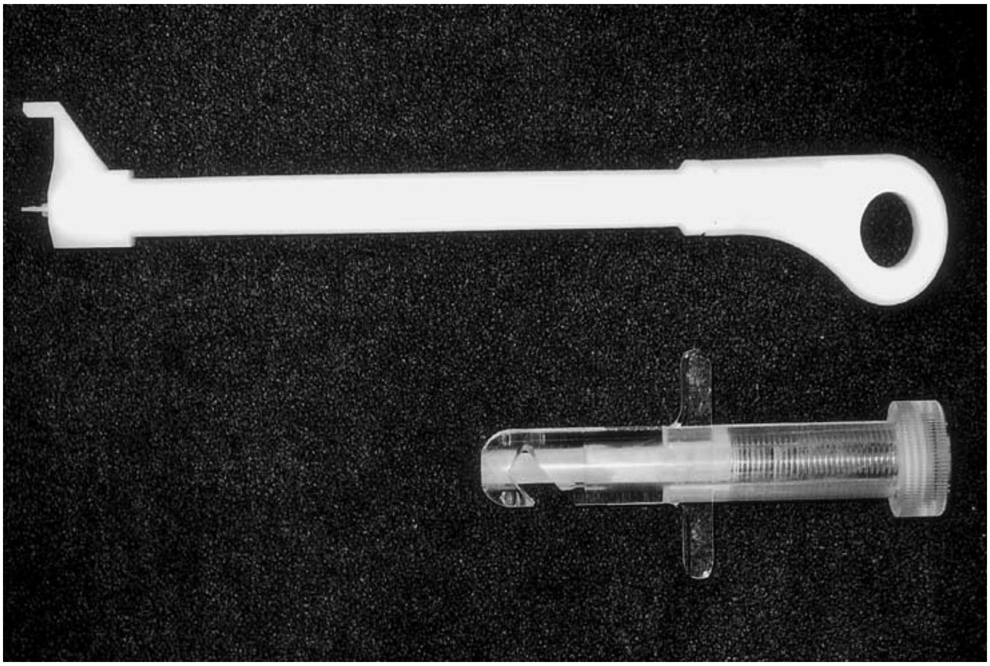

Fig. 2. Long and short needle holders.

Table 1. Radiation dose to the radiologist's hand during continuous CT fluoroscopy with and without radiation protection devices

Group	Needle holder Length (cm)	Lead drapes[a]	Radiation protection gloves	Radiation dose[b] (μGy)			Dose rate (μGy/sec)
				5 sec	10 sec	20 sec	
A	15	−	−	240	360	690	39.5
B	15	−	+	34	112	195	9.3
C	15	+	−	16	32	63	3.2
D	15	+	+	6	13	20	1.2
E	35	−	−	80	120	230	13.2
F	35	−	+	20	30	60	3.3
G	35	+	−	2	3	7	0.4
H	35	+	+	1	2	3	0.2

[a] "+" = with; "−" = without.
[b] Radiation dose values are an average from the measurements taken at the three times for the 5-, 10-, and 20-sec fluoroscopy times.

copy. Using EGS-Ray, a program for visualization of Monte Carlo calculations, the trajectories and distribution of the scattered photons during CT fluoroscopy can be visualized [12]. The Monte Carlo program EGS-Ray can simulate the CT scanner with its X-ray spectrum at 120 kV tube voltage. In this way, the scatter radiation occurring during CT fluoroscopy can be graphically imaged 2 cm away from the central beam with and without a lead drape (1-mm lead equivalent; length: 60 cm; width: 90 cm) wrapped around the phantom.

Scatter Radiation Dose

Radiation doses were assessed during CT fluoroscopy using the ART phantom. The radiation dose to the radiologist's hand was measured with the digital dosimeter, which was attached directly to the back of the operator's hand with and without latex radiation protection gloves as well as with and without placement of the lead drapes on and beneath the phantom 2 cm caudally from the central plane.

All measurements were made for 5-, 10-, and 20-sec fluoroscopy times and repeated three times. The dose values from the three measurements for each radiation protection arrangement and each fluoroscopy time period (5, 10, and 20 sec) were averaged. We calculated the dose rate by dividing the radiation dose by the fluoroscopy time (5, 10, and 20 sec).

The reduction of the radiation dose was determined by comparing the radiation dose values and exposure rate values with and without the lead drapes in place, with and without the use of the protective gloves. Each measurement was performed with the short and the long needle holder. In addition, the radiation dose was determined for a combination of lead drapes, radiation protection gloves, and long needle holder.

Results

Radiation Dose

The results are summarized in Table 1. Radiation dose rates of the operator's hand ranged from 0.16 to 39.5 μGy/sec. The long needle holder decreased the dose rates by 30%. Lead drapes reduced the dose rates up to 97.3%. The lead

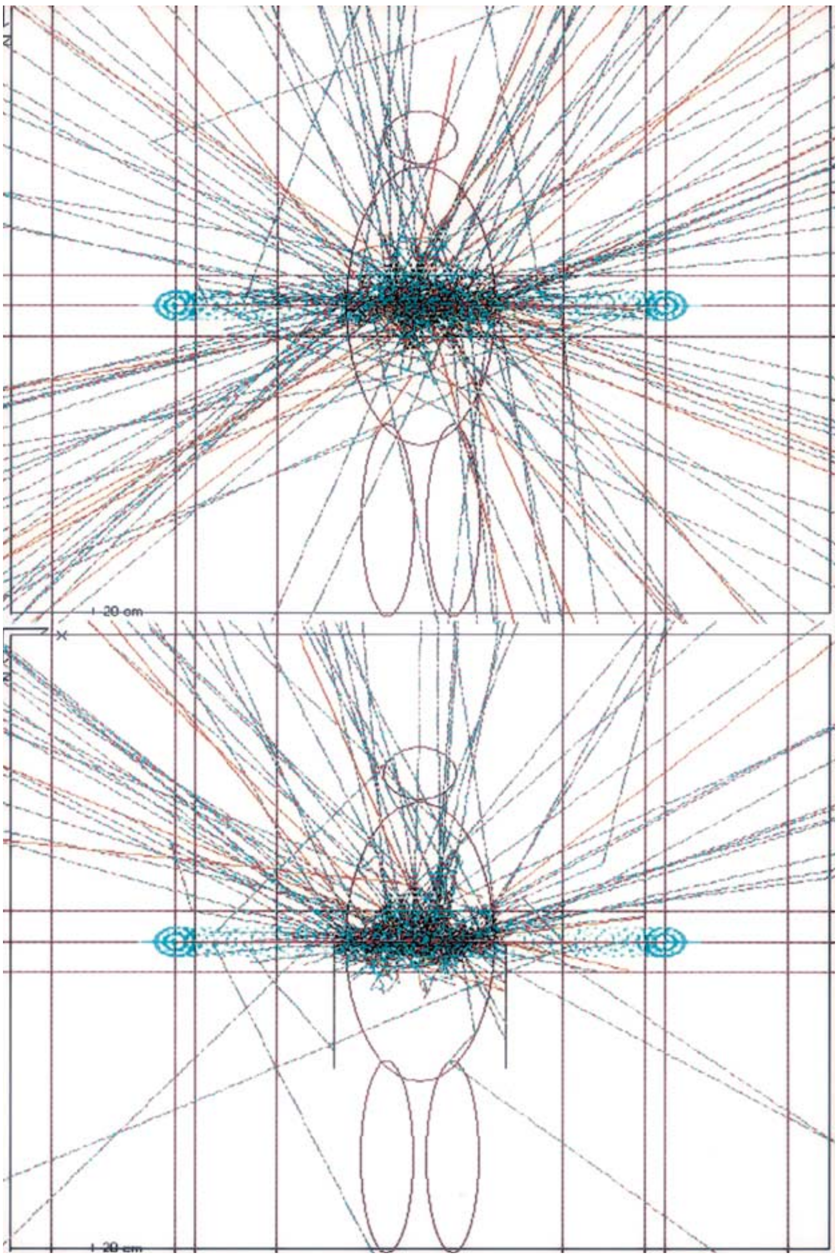

Fig. 3. Using EGS-Ray for visualization of Monte Carlo calculations, the distribution of scatter radiation during CT fluoroscopy can be graphically visualized with the patient (red), the CT gantry (light blue), and the primary radiation/central beam (red line). The lines to the right and left of the phantom's body in the bottom image represent the lead drape wrapped around the phantom. Scatter radiation is demonstrated by lines of various colors (Compton radiation, blue and red dotted lines; Raleigh radiation, orange lines). In the top image, there is scatter radiation in all directions without the use of a lead drape around the phantom. In the bottom image, there is markedly reduced scatter radiation caudally to the central plane with the lead drape in place.

shield is more effective with the long needle holder than with the short needle holder. Radiation protection gloves resulted in a 76.6% dose reduction. The combination of lead drapes, protective gloves, and long needle holder decreased the dose rates by 99.6%.

Monte Carlo Simulation

Figure 3 shows graphically the scatter radiation during CT fluoroscopy by means of a Monte Carlo simulation. In the top image, without the use of a lead drape, scatter radiation in all directions around the phantom is seen. The interventional radiologist standing next to the gantry is exposed to a marked amount of scatter radiation from the phantom's body. In the bottom image, with the lead drape wrapped around the patient, there is markedly reduced scatter radiation caudally to the central plane where the radiologist stands.

Discussion

Sonography, conventional X-rays, conventional CT, CT fluoroscopy, and magnetic resonance imaging (MRI) are available for percutaneous radiological interventional procedures. CT is superior to the other methods because it can be applied to soft tissue, fluid- and air-filled structures, as well as bones. Furthermore, CT provides good reproducibility, a large variable image field with high geometric precision, and easy patient access. In conventional methods, respiratory motions and the patient's restricted ability to cooperate might reduce target accuracy while increasing complication rates and examination times. CT fluoroscopy overcomes these disadvantages through image reconstruction and display on a monitor in real time.

As a result, the indications for CT fluoroscopically controlled diagnostic interventions are clearly expanded compared to conventional CT-supported procedures. The real-time method is advantageous for small or deep targets because the operator can trace the needle insertion throughout and make adjustments. This method is preferred when targeting small lesions. It is also helpful in cases in which an angled approach to the target is required. As expected with the real-time method, however, higher doses to the patient and personnel are implied.

Radiation Dose

In our study, we measured radiation doses ranging from 1 to 690 μGy and calculated radiation dose rates ranging from 0.16 to 39.5 μGy/sec, respectively. In the literature, radiation dose estimates are expressed in various ways [1, 2, 6–10]. For this reason, the values reported might vary widely, and it is not always clear what was measured. Unfortunately, the terms "radiation dose," "radiation exposure," and "dose equivalent" are sometimes used interchangeably [13]. The radiation measurements for the operator's hand from literature reports are partly given as radiation doses (Gy) and partly as dose equivalent (Sv). As dose equivalent values weighted for X-rays do not differ from the radiation exposure values, the data can be compared. Measurements for the operator's hand from the works of Irie et al. [8] and Silverman et al. [2] range between 0.06 and 2.7 mSv. The radiation exposure on the fingertips is even higher because the fingertips are located closer to the CT plane. Irie et al. tried to measure the dose eqivalent on the fingertips [8]. However, attachment of the thermoluminescence ring on the fingertip disturbed control of the needle holder.

With these measurements, it might happen that the radiologist is restricted to a certain number of interventions per year, which, in the worst case, might be not more than 185, considering a dose limitation of 20 mSv/year for the whole body and 500 mSv/year for the hands.

Radiation Protection

However, there are a number of options for reducing the radiation dose of patients and radiologists. The tube power can be reduced to minimize the dose. Usually, a tube current of 30–50 mA is sufficient [1]. In contrast, others report higher milliampere values of up to 90 mA [2, 14, 15]. Other factors in dosage reduction are a low tube voltage of 120 kV and a collimation of 1–3 mm [1, 2, 8]. In our study, the tube current was 50 mA, the tube voltage was 120 kV, and the collimation was 3 mm.

Our results show a significant reduction of the radiation dose for the radiologist by only using thin latex radiation protection gloves, which reduced the dose to the operator's hand by 77%. There are various models of latex radiation protection gloves available made of different materials, such as lead or bismuth, and with slightly differing lead equivalents. Our staff uses the shielded gloves without loss of tactile feedback of the fingertips and freedom of action, which was mentioned as drawbacks in some studies [16].

Another tool for radiation protection is the placement of lead drapes underneath and on top of the patient adjacent to the scanning plane. Use of a lead drape was already reported to reduce scatter radiation dose to the physician's hand [10]. A drape was positioned over the patient immediately caudal to the cutaneous access site. Our lead drapes arrangement is distinct from others in that we used a lighter 0.5-mm lead equivalent lead drape on top of the phantom and another 1-mm lead equivalent lead-10 cm drape underneath the phantom. Thus, a more effective 1-mm lead equivalent drape prevents scatter radiation from the posterior chest wall of the phantom. The described arrangement of the two drapes is more comfortable for the patient in our daily interventional routine. With the use of the two drapes, scatter radiation was reduced by a maximum of 97%. Compared with the dose measurements using gloves alone, the lead drapes have a significantly greater protective effect than the gloves. Another advantage of using lead drapes is that it will not only protect the operator's hand but also reduce the radiation dose to radiation-sensitive tissue such as the lens and the thyroid.

A combination of the lead drapes and the bismuth gloves combined with the long needle holder was most effective, with a dose reduction of nearly 100%. With these exposures, to exceed the 500-mSv hand dose per year, a radiologist would have to perform many thousands of real-time CT fluoroscopic interventions per year.

Needle holders keep the hands away from the central beam. The space between the tomographic plane and the hand is a very important factor in determining the scatter radiation. The longer the needle holder, the less the radiation dose to the hand. Therefore, the lead shield is more effective with the long needle holder than with the short needle holder. However, not in all cases can the long needle holder be effectively used due to difficulties in maneuvering the needle, especially in rather firm tissues and tumors, when insufficient inward force is exerted, or to target deep lesions. Silverman et al. reported that towel clamps can be effective and inexpensive for holding and guiding the needle [2]. However, there are limitations in that the needle might become dislodged from the clamp and maneuvering is reduced.

Furthermore, procedure times are dependent on the operator's experience. There is a learning curve for CT fluoroscopically controlled interventions. After 200–250 interventions using CT fluoroscopy, the fluoroscopy period is reduced by about 50% [11].

Monte Carlo Simulation

Monte Carlo simulation calculations are conducted to estimate the distribution of scatter radiation in the examination room during CT fluoroscopy. Using EGS-Ray, a program for visualization of Monte Carlo calculations, both the CT with its X-ray spectrum and the phantom or patient with and without placement of a lead drape is graphically simulated [12]. This way, the scatter radiation to the radiologist can be visualized with the lead drape at different distances from the central beam. As our results show, there is marked reduction of scatter exposure to the interventional radiologist with the use of a lead drape. It should be discussed whether other personnel in the CT room, like patients on a respirator with the anesthesiologist standing at the patients' head close to the gantry, should be protected by a mobile lead shield.

The radiation dose to the radiologist occurring during CT fluoroscopy can be reduced to an extremely low level. This is the first report on a combination of several radiation protection devices to minimize the dose on the operator's hand. Based on the results in our study, we suggest limiting fluoroscopic time, which might decrease with the interventionalist's experience, increasing the distance from the primary beam by using long needle holders whenever possible, combined with placing lead drapes on top of and underneath the patient. The addition of radiation protective gloves is strongly recommended if their use does not prolong the procedure.

References

1. Paulson EK, Sheafor DH, Enterline DS, et al. (2001) CT-fluoroscopy-guided interventional procedures: techniques and radiation dose to radiologists. Radiology 220:161–167
2. Silverman SG, Tuncali K, Adams DF, et al. (1999) CT-fluoroscopy-guided abdominal interventions: techniques, results, and radiation exposure. Radiology 212:673–681
3. Irie T, Kajitani M, Yoshioka H, et al. (2000) CT fluoroscopy for lung needle biopsy: a new device or needle placement and a phantom study. J Vasc Intervent Radiol 11:359–364
4. de Mey J, Op de Beeck B, Meysman M, et al. (2000) Real-time CT fluoroscopy: diagnostic and therapeutic applications. Eur J Radiol 32:32–40
5. Katada K, Anno H, Takeshita G, et al. (1994) Development of CT fluoroscopy using fast CT. Nippon Act Radiol 54:1172–1174
6. Kato R, Katada K, Anno H, et al. (1996) Radiation dosimetry at CT fluoroscopy: physician's hand dose and development of needle holders. Radiology 201:576–578
7. Katada K, Kato R, Anno A, et al. (1996) Guidance with real-time CT fluoroscopy: early clinical experience. Radiology 200:851–856
8. Irie T, Kajitani M, Yuji I (2001) CT fluoroscopy-guided intervention: marked reduction of scatter radiation dose to the physician's hand by use of a lead plate and improved I-I device. SCVIR 12: 1417–1421
9. Teeuwisse WM, Geleijns J, Broerse JJ, et al. (2001) Patient and staff dose during CT guided biopsy, drainage and coagulation. Br J Radiol 74:720–726
10. Nawfel RD, Judy PF, Silverman SG, et al. (2000) Personnel exposure during CT fluoroscopy-guided interventional procedures. Radiology 216:180–184
11. Gianfelice D, Lepanto L, Perreault P, et al. (2000) Effect of the learning on procedure times and radiation exposure for fluoroscopy-guided percutaneous biopsy procedures. J Vasc Intervent Radiol 11:1217–1221
12. Kleinschmidt C (2001) EGS-Ray, ein Programm zur Visualisierung von Monte-Carlo-Rechnungen in der Strahlenphysik. Z Med Phys 11:119–123
13. Morin RL, Gerber TC, McCollough CH (2003) Radiation dose in computed tomography of the heart. Circulation 107:917–922
14. Froelich JJ, Saar B, Hoppe M, et al. (1998) Real-time CT fluoroscopy for guidance of percutaneous drainage procedures. J Vasc Intervent Radiol 9:735–740
15. Daly B, Krebs TL, Wong-You-Cheong JJ, et al. (1999) Percutaneous abdominal and pelvic interventional procedures using CT-fluoroscopic guidance. J Vasc Intervent Radiol 173:637–644
16. Mack MG, Straub R, Eichler K, et al. (2001) Nadelhalter zur Reduktion der Strahlenbelastung für den Untersucher bei einer CT-gesteuerten Punktion. Radiologe 41:927–929