CT Fluoroscopy–guided Interventional Procedures: Techniques and Radiation Dose to Radiologists

PURPOSE: To determine the radiation dose to radiologists who perform computed tomographic (CT) fluoroscopic interventional procedures by using a quick-check method and a low-milliampere technique.

MATERIALS AND METHODS: Two hundred twenty CT fluoroscopy–guided interventional procedures were performed in 189 patients. Procedures included 57 spinal injections, 17 spinal biopsies, 24 chest biopsies, 20 abdominal aspirations, 44 abdominal biopsies, and 58 abdominal drainages. Procedure details were prospectively recorded and included site, depth, target diameter, milliampere value, kilovolt peak, fluoroscopic time, and CT technique (continuous CT fluoroscopy, quick-check method, or a combination of these techniques). An individual collar and finger radiation detector were worn by each radiologist during each procedure to determine the dose per procedure.

RESULTS: The quick-check technique was performed in 191 (87%) of 220 procedures. Four procedures were performed with continuous CT fluoroscopy, and a combination technique was used for 25 (11%) procedures. The overall mean CT fluoroscopic time was 17.9 seconds (range, 1.2–101.5 seconds). The mean milliampere value was 13.2 mA (range, 10–50 mA). The overall mean radiologist radiation dose per procedure was 2.5 mrem (0.025 mSv) (whole body). Individual procedure doses ranged from 0.66 to 4.75 mrem (0.007–0.048 mSv). The finger radiation dose was negligible.

CONCLUSION: By using a low-milliampere technique and the quick-check method, CT fluoroscopic time and radiation exposure can be minimized.

Computed tomographic (CT) fluoroscopy is a technical advance resulting from slip-ring technology, x-ray tubes with improved heat capacity, high-speed array processors, and partial reconstruction algorithms (1,2). The images can be reconstructed at a rate of approximately 6 frames per second, allowing near real-time visualization similar to that of ultrasonography (US). A promise of this technology is to facilitate interventional procedure guidance by means of combining the localizing strengths of CT with the real-time advantages of US.

Findings of recent clinical studies (3–6) have shown that CT fluoroscopy is a safe and effective guidance tool for percutaneous interventional procedures in the chest, spine, abdomen, and pelvis. With this technology, procedures are performed more quickly than with traditional CT (7). CT fluoroscopy is particularly useful for procedures involving deep structures, such as retroperitoneal masses, or for procedures involving organs prone to physiologic motion, including the liver and lungs (3,6).

One of the concerns with the use of CT fluoroscopy is the high radiation exposure (4,5,8). In contrast with conventional fluoroscopy in which the patient dose is on the order of centigrays per minute of exposure, with CT fluoroscopy, patient doses may be on the order of centigrays per second. An additional concern is the scattered exposure to the hands and body of radiologists, since they may be close to the x-ray source during the manipulation of the needle (9).

During the next few years, the number of procedures performed with CT fluoroscopy...
May increase. Because a greater number of physicians use CT fluoroscopy, it is critical to determine the radiation dose to patients and radiologists and to explore methods to limit the dose. Our purpose was to determine the radiation dose to radiologists during CT fluoroscopic procedures by using a low-milliampere technique and short CT fluoroscopic exposures.

MATERIALS AND METHODS

From May 1, 1999, to September 20, 1999, we prospectively monitored the radiation dose to radiologists performing interventional procedures with CT fluoroscopy. Our institutional review board deemed this project exempt from its review.

During the study period, 220 consecutive CT fluoroscopic–guidance interventional procedures were performed in 189 patients. One hundred sixty patients underwent one procedure, 27 patients underwent two procedures, and two patients underwent three procedures. Interventional procedures included spinal, chest, and abdominal and pelvic procedures as follows: 40 lumbar, 13 sacroiliac, and four cervical injections for neurolysis; 17 fluid aspirations in the abdomen and pelvis; 44 biopsies in the abdomen and pelvis; 20 fluid aspirations in the abdomen or pelvis; and 58 catheter drainages of fluid collections in the abdomen or pelvis; 20 fluid aspirations in the abdomen or pelvis; and 58 catheter drainages of fluid collections in the abdomen or pelvis; and 58 catheter drainages of fluid collections in the abdomen or pelvis; and 58 catheter drainages of fluid collections in the abdomen or pelvis; and 58 catheter drainages of fluid collections in the abdomen or pelvis; and 58 catheter drainages of fluid collections in the abdomen or pelvis. There were 98 women and 91 men. Their mean age was 58 years (age range, 24–80 years).

The procedures were performed or closely supervised by one of 12 attending radiologists (including E.K.P., D.H.S., D.S.E., H.P.M.) who were stationed at the side of the CT table during CT fluoroscopy. These 12 radiologists had a mean of 9 years (range, 3–15 years) of experience as attending staff. For 207 (94%) of 220 procedures, a senior resident or fellow provided assistance, but the individual radiation dose from CT fluoroscopy to these individuals was not specifically monitored. Individual doses were not monitored in residents and fellows because we estimated that they would perform too few procedures to justify monitoring.

CT fluoroscopic images were acquired during continuous scanning with a machine (CT/i equipped with SmartView; GE Medical Systems, Milwaukee, Wis), which was controlled by an integrated foot switch and hand-held controller. Its reconstruction duration was 6 frames per second, which provided real-time guidance to facilitate patient positioning and needle placement. In addition, individual CT fluoroscopic spot images were possible. The radiologist was able to release the table to facilitate patient positioning; the scanning plane was highlighted with a laser marker light. Gantry tilt was possible. The monitor was conveniently suspended from the ceiling. Image reconstruction was performed with a 256 × 256 matrix, with images displayed on a 768 × 768 matrix.

Patients provided routine written informed consent for each interventional procedure. For all procedures, a preliminary scan limited to the region of the target was obtained, with the patient positioned appropriately for the interventional procedure. The target in question was localized on the preliminary scans, and the anticipated path and depth of the target were determined by using electronic calipers on the technologist's console. The anticipated skin entry site was marked, prepared with providone iodine solution (Betadine; Purdue Frederick, Norwalk, Conn), and draped in routine sterile fashion. The soft tissues were anesthetized with lidocaine hydrochloride (Abbott Laboratories, North Chicago, Ill). Many patients received conscious sedation with appropriate monitoring. The milliampere value was set at 10 mA unless the target was small or the lesion was subtle, as in some liver lesions. The decision to increase the milliampere value was made at the discretion of the radiologist.

After the site was prepared and draped, one of the three CT fluoroscopic techniques was used: the quick-check technique, continuous CT fluoroscopy, or a combination of these techniques (5). One of these three techniques was chosen on the basis of radiologist preference. The quick-check technique is analogous to conventional CT and is most frequently used in our practice. This technique used single-section CT fluoroscopic spot images. The biopsy or the aspiration needle was advanced through the skin to confirm needle location. For this technique, continuous CT fluoroscopy was not used. This technique is analogous to guidance with conventional CT, except reconstruction times are faster and the table may be manually positioned by the radiologist.

When the catheter drainage procedures were performed by using the quick-check technique, guide-wire placement, stepwise dilation, and catheter placement were performed by using the CT fluoroscopic spot technique. For these procedures, multiple CT fluoroscopic spot images were often obtained to place, confirm, and document the appropriate location of the needle, guide wire, and catheter.

Continuous CT fluoroscopy denotes the use of a continuous CT fluoroscopic exposure during needle advancement or needle manipulation. For this technique, patients were moved into the CT gantry so that the lesion or needle was in the plane of imaging. For these procedures, a 24-cm metallic sponge forceps was used as a needle holder to prevent direct hand exposure to the primary beam. Needles were advanced by using real-time CT fluoroscopic monitoring.

The combination technique was used in cases in which the quick-check technique failed to depict the needle tip. In these cases, patients were either manually or mechanically moved through the plane of imaging until the needle or target became visible. With this technique, there was no real-time needle manipulation. The video playback function was used to move through the acquisition to confirm needle placement.

A lead shield was not used during manipulation of the needles during CT fluoroscopy. In no case was there direct exposure of the radiologist's hand to the primary beam during needle manipulation.

For each CT fluoroscopic procedure, a data sheet was prospectively completed by the radiologist; the sheet included queries in regard to the procedure site, target depth, type of procedure, target diameter, CT fluoroscopic section thick-
wearing his or her radiation detectors during real-time CT fluoroscopy, or a combination of both techniques was used. For whole-body–dose monitoring, a dosimeter (Luxel; Landauer) was placed on the collar outside a lead apron. This dosimeter allows estimation of the doses to the whole body, skin, and lens of the eye. For hand-dose monitoring, a thermoluminescence ring dosimeter was used.

Minimal detectable radiation doses were 1 mrem (0.01 mSv) for dosimeters and 30 mrem (0.3 mSv) for the thermoluminescence ring monitors, respectively. The cumulative dose from these dedicated detectors represented the dose from CT fluoroscopy alone and did not reflect the dose received from other exposures in the radiology department. The mean dose per procedure was determined by dividing the cumulative dose by the number of procedures. Specific case-by-case procedure doses were not measured; only the dose accumulated during the study was measured.

The whole-body dose refers to the external whole-body exposure and was defined as the dose equivalent at a tissue depth of 1 cm (1,000 mg/cm²). The skin dose referred to the external exposure of the skin and was defined as the dose equivalent at a tissue depth of 0.007 cm, averaged over an area of 1 cm².

To estimate direct radiation doses to patients, a body phantom (Rando; Phantom Laboratory, Salem, NY) was used to measure the surface dose rate and the scatter dose rate. The body phantom was chosen because it was equivalent to the tissue. Dose rates were determined by using our typical clinical technique with 140 kV and 10 mA. The value of 140 kV was chosen on the basis of the manufacturer recommendations. Surface dose rates were measured at the surface by using thermoluminescence dosimeter chips. The chips were 3 × 3 × 1 mm and were arranged in a linear pattern with no gaps between them. Two consecutive measurements were obtained. A commercial vendor (Landauer) was used for dosimeter chip analysis.

Exposures were estimated from scattered radiation from the phantom. An ion chamber (model 450P; Victoreen, Solon, Ohio) was used to measure scattered radiation levels at 25 and 60 cm from the section plane at the edge of the patient table (Fig 1). These distances were chosen to simulate the position of the radiologist’s hands and body. Dose rates were calculated by dividing the total cumulative exposure by the exposure time (10 seconds).

RESULTS

The mean target depth (measured from the skin to the leading edge of the lesion), target diameter, and technical aspects are detailed in Table 1.

One hundred ninety-one (87%) of 220 procedures were performed by using the quick-check technique alone. Twenty-five (11%) procedures were performed by using a combination of the quick-check method and continuous CT fluoroscopy. Only four (2%) of the procedures were performed with needle manipulation by using continuous CT fluoroscopy.

Of the 12 radiologists who performed CT fluoroscopy, six used the quick-check technique exclusively, four used either the quick-check technique or the quick-check technique or the quick-check technique exclusively. We also sought to determine the number of procedures that were not measured; case procedure doses were not measured; only the dose accumulated during the study was measured. The whole-body dose refers to the external whole-body exposure and was defined as the dose equivalent at a tissue depth of 1 cm (1,000 mg/cm²). The skin dose referred to the external exposure of the skin and was defined as the dose equivalent at a tissue depth of 0.007 cm, averaged over an area of 1 cm².

To estimate direct radiation doses to patients, a body phantom (Rando; Phantom Laboratory, Salem, NY) was used to measure the surface dose rate and the scatter dose rate. The body phantom was chosen because it was equivalent to the tissue. Dose rates were determined by using our typical clinical technique with 140 kV and 10 mA. The value of 140 kV was chosen on the basis of the manufacturer recommendations. Surface dose rates were measured at the surface by using thermoluminescence dosimeter chips. The chips were 3 × 3 × 1 mm and were arranged in a linear pattern with no gaps between them. Two consecutive measurements were obtained. A commercial vendor (Landauer) was used for dosimeter chip analysis.

Exposures were estimated from scattered radiation from the phantom. An ion chamber (model 450P; Victoreen, Solon, Ohio) was used to measure scattered radiation levels at 25 and 60 cm from the section plane at the edge of the patient table (Fig 1). These distances were chosen to simulate the position of the radiologist’s hands and body. Dose rates were calculated by dividing the total cumulative exposure by the exposure time (10 seconds).
check technique with continuous CT fluoroscopy, and two used all three techniques at least once.

Not surprisingly, the frequent use of the quick-check method resulted in short CT fluoroscopic times (Fig 2). Overall, the mean CT fluoroscopic time was 17.9 seconds per procedure (range, 1.2–101.5 seconds). Eighty-six (39%) of 220 procedures had a CT fluoroscopic time of shorter than 10 seconds. Seventy-two (33%) of the procedures had a CT fluoroscopic time of 10–20 seconds. The remaining 62 (28%) procedures had a CT fluoroscopic time longer than 20 seconds. Mean CT fluoroscopic times for individual radiologists ranged from 4.8 to 37.6 seconds per procedure. The longest CT fluoroscopic time was 101.5 seconds, which occurred during a difficult biopsy of a 2-cm lesion in the dome of a liver.

Overall, the mean milliampere value was 13.2 mA (range, 10–50 mA) (Fig 3). The low mean milliampere value resulted in adequate image quality for the efficient performance of most procedures. One hundred seventy-two (78%) of 220 procedures were performed with 10 mA, 38 (17%) were performed with 20 mA, and 10 (5%) were performed with more than 20 mA. While in this study we did not measure lesion conspicuity as a function of the technique, the cases in which the milliampere value increased more than 10 mA were in targets that were subtle or small, requiring a higher-exposure technique to achieve adequate image quality. For example, the mean milliampere value of spinal interventional procedures was 16.5 mA, considerably higher than the mean milliampere value of catheter drainages, which was 11.2 mA. This likely reflects the differences in target size; spinal facets are a considerably smaller target than fluid collections, which had a mean diameter of 5.9 cm. Obese patients also required a higher milliampere value for adequate image quality.

Overall, the mean radiation dose per procedure (by radiologist) were as follows: 0.66–4.75 mrem (0.007–0.048 mSv), whole body; 0.7–4.75 mrem (0.007–0.048 mSv), lens of the eye; and 0.79–5.38 mrem (0.008–0.054 mSv), skin (Table 2). The overall mean dose per procedure averaged for all radiologists was 1.03 mrem (0.010 mSv), 1.03 mrem (0.010 mSv), and 1.19 mrem (0.012 mSv) for the whole body, lens of the eye, and skin, respectively. There was no radiologist in whom the cumulative radiation dose to the hand was greater than the minimal detectable value of 30 mrem (0.3 mSv) or less for the ring monitor.

The maximum dose rate on the surface of the phantom determined from the thermoluminescence detector profiles was 0.18 cGy/sec ± .003 and 0.177 cGy/sec ± .003. Figure 4 shows the dose-rate profile as a function of the thermoluminescence detector position on the basis of one measurement of dose rate.

The scattered radiation exposure rate (peak value) at 25 and 60 cm from the center of the section was 23 mR/h (5.9 × 10⁻⁶ C/kg/h) and 12 mR/h (3.0 × 10⁻⁶ C/kg/h), respectively. These dose rates were obtained from the phantom.

**DISCUSSION**

Conventional CT has been widely used and has been proven to be safe and effective in the performance of percutaneous interventional procedures (10–13). In contrast with US or fluoroscopy, conventional CT-guided procedures were limited by the lack of real-time capability. The imaging steps required to monitor and document needle placement are often time-consuming. In many cases, several passes are required to satisfactorily position needles to the lesion. CT-guided procedures are particularly challenging in the uncooperative patient or in organs that are prone to respiratory motion, such as the lung and liver.

Katada et al (1) described CT fluoroscopy for clinical use in 1994. This technology combines the advantages of CT with needle depiction with the speed, accuracy, and elegance of real-time US or
conventional fluoroscopic guidance. One of the concerns of performing CT fluoroscopy is the radiation to patients and operators (4,5,8,9). While radiologists are knowledgeable regarding the radiation doses encountered during conventional fluoroscopy, the doses from CT or CT fluoroscopy are considerably higher due to the higher-exposure techniques required to achieve acceptable image quality. In the worst-case scenario of selecting the highest-milliampere technique (90 mA, 120 kVp, 10-mm section thickness) permissible by one manufacturer, Nawfel et al (8) have shown that patients received 830 mGy during an 80-second CT fluoroscopic exposure. Such a dose is comparable with the patient dose received during 20–30 minutes of conventional fluoroscopy during cardiac catheterization (8). While the 830 mGy dose is less than the often-quoted 2,000 mGy threshold for inducing radiation dermatitis, it approaches 1,000 mGy, which is a level at which radiation-induced skin changes have been reported (14–16).

Recently Silverman et al (5) have shown that CT fluoroscopy is at least as effective as conventional CT in the performance of abdominal and pelvic biopsies and catheter drainages. Compared with conventional CT, CT fluoroscopy was shown to be an efficient technique, with reductions in needle placement time (29 vs 36 minutes, P < .005). In the work of Silverman et al, the most commonly used CT technical parameters were 120 kVp and 50 mA, but in selected cases, a milliampere value as high as 90 mA was used. The mean CT fluoroscopic time was 79 seconds per procedure and ranged from 8 to 546 seconds. Silverman et al provided an estimate of radiation exposure to operators by multiplying the mean CT fluoroscopic times by the exposure rates of scattered radiation on the basis of phantom measurements. These estimates suggest mean hand exposures of 305 mR (7.9 × 10⁻³ C/kg) per procedure and mean neck exposures of 10 mR (2.5 × 10⁻⁶ C/kg) per procedure. A limitation of the Silverman et al study is that...
scattered radiation to personnel was not measured directly.

In a similar study, Daly et al (6) examined 97 patients who underwent 119 abdominal or pelvic procedures by using either continuous real-time or intermittent CT fluoroscopy during needle insertion. Technical parameters were 120–135 kV and 30–80 mA. The mean CT fluoroscopic time for biopsy was 136 seconds (range, 33–336 seconds). Each operator wore standard dosimeters on the neck, waist, and finger, and cumulative doses were measured monthly. The monthly doses were 10–30 mrem (0.1–0.3 mSv) in the neck, 0–10 mrem (0–0.1 mSv) for the detectors worn beneath a 0.5-mm lead apron, 10–970 mrem (0.1–9.7 mSv) (mean, 176 mrem [1.76 mSv]) for the hands during the 1st month of operation, and 10–130 mrem (0.1–1.3 mSv) for the hands thereafter. A limitation of the Daly et al study is that individual procedure doses per physician were not measured.

Our work is distinct from others’ in that the milliamperage value (mean, 13.2 mA) was intentionally set as low as possible for each procedure. In contrast, others report (4–6) using higher milliamperage values, ranging from 30 to 90 mA, with 50 mA being the most frequently used value. Our use of a milliamperage value higher than 10 mA was restricted to those procedures in which the target was small or the lesion was subtle, as in some liver lesions. We suggest that to minimize radiation exposure, the operators select the lowest milliamperage value possible and increase it only when it proves inadequate. In theory, one could use a low milliamperage value for gross needle positioning and increase the milliamperage value for final needle placement. This compromise technique was not used in this study but could potentially decrease the radiation dose. It should be noted that many factors underlie the creation of a high-quality CT fluoroscopic image. It can be anticipated that there will be differences among vendors in the radiation technique required to produce adequate image quality.

Our results differ from those of others (3–6) in that our CT technique consisted primarily of the quick-check method. In the minority of cases, the quick-check method was combined with short exposures of continuous CT fluoroscopy to confirm needle placement. In contrast, others (3–6) report using primarily continuous CT fluoroscopy during needle manipulation, which allows real-time visualization but also necessarily increases the CT fluoroscopic time. The quick-check technique is analogous to a conventional CT technique in which the needle is advanced in the absence of real-time visualization. Single-section CT fluoroscopic spot images (1.2-second exposure) are used simply to check needle placement.

The use of the quick-check method results in short CT fluoroscopic times per procedure. Our mean CT fluoroscopic time of 17.9 seconds is considerably shorter than the 80–143 seconds reported by others (4–6). One could argue that the quick-check technique is simplistic and fails to exploit the full benefits of continuous CT fluoroscopy. However, even this method has considerable advantages than the conventional CT technique, including use of the floating table to precisely position the patient at the level of the needle tip, use of hand and foot controls, and direct communication with patients.

When the quick-check technique is used, scenarios in which the needle tip is difficult to localize, such as when the needle is oblique to the transverse plane or when the patient cannot suspend respiration are possible. In these scenarios, we identify the needle tip by acquiring continuous CT fluoroscopic images in the region of the needle. Such acquisitions are usually only 5–10 seconds. In general, with careful attention to placing the needle in the transverse plane, such a combined technique is used relatively infrequently. In scenarios in which the needles must be angled, tilting the CT gantry facilitates efficient visualization.

Our project included the estimation of the patient dose with a standard anthropomorphic phantom by using the technical parameters most frequently used in our practice (140 kV, 10 mA). The maximum dose rate on the surface of the phantom reported here (0.18 cGy/sec) is considerably lower than the 0.52 cGy/sec reported by Nawfel et al (8) using 120 kVp, 50 mA, and a 10-mm thick image. Given our mean CT fluoroscopic time of 18 seconds per procedure, it can be estimated that patients receive approximately 3.2 cGy per procedure.

The scattered radiation dose, as measured from the phantom by using our routine clinical parameters, was extremely low: 23 mmrem (0.23 mSv/h) at 25 cm from the section and 12 mmrem (0.12 mSv/h) at 60 cm from the section. With this dose rate, it would be unnecessary to perform CT fluoroscopy for hundreds of hours to exceed the occupational whole-body limit of 5,000 mrem (50 mSv) per year (17).

The physician dose per procedure was also low, with whole-body doses ranging from 0.66 to 4.75 mrem (0.007–0.048 mSv) per procedure. With this dose rate, to exceed the 5,000 mrem (50 mSv) body dose per year, a radiologist would have to perform more than 2,000 CT fluoroscopic procedures (on the basis of the mean dose of 2.5 mrem [0.025 mSv] per procedure).

The explanation of our low radiation dose rests in the following equation: dose = kV2 × mA × sec, where kV2 is the kilovolt value squared, mA is the milliamperage value, and sec is seconds (17). Our CT fluoroscopic times were one-fourth to one-seventh those reported by others (4–6). Additionally, our milliamperage value of close to 10 mA was considerably less than the 30–90 mA reported by others (4–6). Any decrease in the milliamperage value or fluoroscopic time will decrease the dose.

It should be emphasized that the scattered radiation dose to the operators reported in this study represents the dose outside the protective lead gown. With the use of an appropriate lead apron, thyroid shield, and protective eyewear, actual doses should be negligible. Further measures to reduce the dose include stepping away from the gantry when possible, preventing direct eye contact with the gantry during exposure, and standing at the head side of the table. Recent work (8) indicates that placing a lead drape over the patient further reduces the scattered dose.

In summary, we have shown that the patient and physician radiation doses at CT fluoroscopy can be reduced to an acceptably low level. To minimize the dose, we suggest limiting CT fluoroscopic time by using the quick-check method and by decreasing the milliamperage value as much as possible.

References


