Estimating Radiation Doses to the Skin from Interventional Radiology Procedures for a Patient Population with Cancer

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PURPOSE: To estimate the peak radiation skin doses for interventional radiology cases performed at a cancer center, identify procedure types likely to result in skin doses exceeding the American College of Radiology's 3 Gy follow-up level, and determine a kerma area product (P_{KA}) for use in monitoring.

MATERIALS AND METHODS: A single-center retrospective study was performed to estimate doses from consecutive procedures performed during 2006. Of 6,598 procedures, 3,925 (60%) had P_{KA} recorded and were included. Forty-three procedure types are represented.

RESULTS: The median estimated peak skin dose was 39 mGy (third quartile, 205 mGy). In 2.6% of the cases, the estimated skin dose exceeded 3 Gy. No procedures resulted in skin doses greater than 15 Gy, and 94% of the cases resulted in skin doses less than 1 Gy. Procedure types with instances of skin doses greater than 1 Gy included hepatic, portal, and other arterial embolizations; diagnostic arteriography; biliary drainages; stent placements and catheter exchanges; nephrostomy/nephroureterostomy; urinary catheter exchanges; inferior vena cava filters; foreign body retrieval; abscess drainage; catheter exchange; and fistulography. Hepatic embolizations, nonhepatic arterial embolizations, and biliary drain/stent procedures were most likely to result in skin doses greater than 1 Gy. Significant variations in skin dose were noted within the same procedure type. No patients were noted to have developed any sequelae from radiation.

CONCLUSIONS: It is unlikely that typical cases in an oncologic interventional radiology practice would exceed the Joint Commission's "reviewable sentinel event" skin dose level of 15 Gy. A P_{KA} trigger of 300 Gycm^2 could be used in the authors' clinic to identify follow-up requirements.

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Abbreviations: ACR = American College of Radiology, FDA = Food and Drug Administration, P_{KA} = kerma area product, PSD = peak skin dose

A wide variety of medical specialists employ fluoroscopy to perform image-guided medical interventions. Patient radiation dose carries risks of stochastic or deterministic injury, and the highest dose is to the skin at the entrance site of the radiation beam (1). As public awareness of medical radiation exposure has increased, there has been heightened awareness among physicians and regulatory agencies regarding the monitoring of administered radiation dosages. Instances of skin injury reported in the literature or to the United States Food and Drug Administration (FDA) have primarily resulted from prolonged interventional cardiology procedures such as cardiac radiofrequency ablations or coronary angioplasty (1–4). Other reported injuries include those resulting from interventional radiology procedures such as transjugular intrahepatic portosystemic shunt creation, renal angioplasty, hepatic/biliary procedures, or embolizations (1,2,5–8).

Deterministic radiation-induced skin injuries range from transient erythema at low doses to dermal necrosis or chronic ulceration at very high doses (5,9–11). Threshold doses in sensitive patients for various effects are approximately 3 Gy (300 rad) for temporary epilation, approximately 6 Gy (600 rad) for main erythema, and 15–20 Gy (1,500–2,000 rad) for moist desquamation, dermal necrosis, and secondary ulceration (12). The manifestation of radiation injury to the skin is not immediate, but usually appears days to weeks after irradiation (13). At high doses, such injuries may have permanent sequelae.

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A number of studies have been performed to determine skin dose ranges for various interventional radiology procedures (14–18). In practice, most fluoroscopic equipment provides only surrogate measures of skin dose. Our purpose was to estimate peak radiation skin doses for the entire range of interventional radiology procedures performed at a high-volume cancer center. We sought to identify the procedures most likely to result in skin doses that could exceed the American College of Radiology (ACR) trigger level of 3 Gy for follow-up (19), and to determine an associated kerma area product (P_{KA}) for use in monitoring such a skin dose.

MATERIALS AND METHODS

Case and Subject Selection

A retrospective study was carried out on all consecutive interventional radiology procedures performed on oncology patients at our institution, a National Cancer Institute–designated Comprehensive Cancer Center, during 2006. For each of these procedures, radiologic technologists recorded surrogate measures of skin dose that included fluoroscopy time or P_{KA}, as measured by a dose–area product (DAP) meter. P_{KA} is defined as the integral of air kerma for a cross section of the x-ray beam (20). This study included all cases in which P_{KA} was recorded.

Of the 6,598 consecutive cases, 3,925 (60%) had P_{KA} recorded and formed the study group. The first column of **Table 1** lists each of the 43 types of interventional radiology procedures included in the study. Subjects ranged in age from 5 to 92 years (median, 62 y). Of the 3,925 cases, 2,045 (52%) were performed on male patients and 1,880 (48%) were performed on female patients. Subjects' weight ranged from 18.5 to 177 kg (median, 73 kg).

There was no attempt to influence or control how any instance of any procedure was conducted with regard to fluoroscopic technique, image acquisition, criteria for success, choice of subject, choice of operator, choice of fluoroscopic unit, or any other factor. An institutional review board waiver for retrospective review of data was obtained.

Fluoroscopic Equipment

Procedures were performed on three different angiographic equipment models, including Advantx/LCA (GE Healthcare, Milwaukee, Wisconsin), Integris Allura (Philips Medical Systems, Best, The Netherlands), and Innova 4100 (GE Healthcare) models. These machines incorporate typical state-of-the-art dose reduction features, including modern image intensifier video systems or flat panels, pulsed fluoroscopy, lose-dose continuous fluoroscopy, recursive filtration, digital subtraction angiography, variable-frame-rate digital subtraction angiography, visualization of collimator without radiation, and availability of filters to modify beam quality. Recorded dosimetry information included fluoroscopy time and/or P_{KA}. This study used procedures with recorded P_{KA} values.

Each fluoroscopic unit in this study is capable of operation in various modes of operation. The fluoroscopic mode for each instance of each procedure was chosen by the operator to best suit the intervention and operator preferences. No attempt was made to standardize the use of any fluoroscopic mode. Therefore, the results of this study represent the current typical methodologies for oncologic interventional radiology procedures at the authors' institution. Fluoroscopic beams were automatically filtered with built-in aluminium and/or copper depending on fluoroscopic modes and automatic dose controls to preferentially remove lower-energy x-rays and hence reduce the absorbed dose from these softer radiation beams.

The units are routinely tested for exposure, time, and kVp reproducibility. Fluoroscopic output rates are measured for different patient thicknesses such as those of pediatric patients and small, average, large, and heavyset adults. Imaging tests such as high-contrast and low-contrast resolution are performed as per local Department of Health guidelines. Beam quality tests are also performed for various kVp settings. The estimated average equivalent half-value layer under clinical operation was typically approximately 9 mm of aluminum. The P_{KA} meter outputs were verified accurate to within approximately 10%.

Dose Measurement

A wide variety of dose surrogates have been used to evaluate patient "doses," and a set of useful dose metrics has emerged in the last twenty years (21). Key definitions and elements of their use are found in International Commission on Radiation Units and Measurements Report 74 (22), International Electrotechnical Commission standard 6601-2-43 (23), and current FDA regulations (24). This publication conforms to the notation of International Commission on Radiation Units and Measurements Report 74 as far as possible based on these conventions.

Air kerma is a measure of the energy delivered to air by an x-ray beam. The typical unit of measurement is the gray (Gy). The fluoroscopes used in this study have "dose" meters that actually measure air kerma or calculate P_{KA} from machine settings. Kerma area product is the air kerma measured at a given distance from the x-ray tube multiplied by the area of the x-ray beam, or F_s at that distance. P_{KA} may be used in radiation management programs, provided the beam sizes used for typical clinical procedures can be estimated (13).

Clinical Data Collection

We retrospectively collected demographic and radiation dose data for all instances of interventional radiology procedures during the period from January 2006 through December 2006. Data were collected for each fluoroscopic unit. For each instance, an electronic data form was completed that included fluoroscopic equipment designation, patient data (weight and age), operator, procedure type, and fluoroscopy time and/or P_{KA}. Procedures were divided into subgroup types defined by the institutional radiology data protocols. Any procedures that had only fluoroscopy time recorded or for which data were incomplete after review were discarded. In addition, data were discarded if only one case was recorded for a given procedure type. All data were collected in a computerized database (Excel 2000; Microsoft, Redmond, Washington).