CLINICAL STUDY

Combined Use of a Patient Dose Monitoring System and a Real-Time Occupational Dose Monitoring System for Fluoroscopically Guided Interventions

Christina Heilmaier, MD, MBA, Levent Kara, MD, EBIR, Niklaus Zuber, RT, CAS, Christian Berthold, MD, and Dominik Weishaupt, MD

ABSTRACT

Purpose: To determine the effect on patient radiation exposure of the combined use of a patient dose monitoring system and real-time occupational dose monitoring during fluoroscopically guided interventions (FGIs).

Materials and Methods: Patient radiation exposure, in terms of the kerma area product (KAP; Gy • cm^2), was measured in period 1 with a patient dose monitoring system, and a real-time occupational dose monitoring system was additionally applied in period 2. Mean/median KAP in 19 different types of FGIs was analyzed in both periods for two experienced interventional radiologists combined as well as individually. Patient dose and occupational dose were correlated, applying Pearson and Spearman correlation coefficients.

Results: Although FGIs were similar in numbers and types over both periods, a substantial decrease was found for period 2 in total mean ± SD/median KAP for both operators together (period 1, 47 Gy • cm^2 ± 67/41 Gy • cm^2; period 2, 37 Gy • cm^2 ± 69/34 Gy • cm^2) as well as for each individual operator (for all, $P < .05$). Overall, KAP declined considerably in 15 of 19 types of FGIs in period 2. Mean accumulated dose per intervention was 4.6 μSv, and mean dose rate was 0.24 mSv/h. There was a strong positive correlation between patient and occupational dose ($r = 0.88$).

Conclusions: Combined use of a patient dose monitoring system and a real-time occupational dose monitoring system in FGIs significantly lessens patient and operator doses.

ABBREVIATIONS

BMI = body mass index, FGI = fluoroscopically guided intervention, KAP = kerma area product, PDM = personal dosimeter, TLD = thermoluminescent dosimeter

Radiation protection of patients and medical professionals during fluoroscopically guided interventions (FGIs) has become an integral part of quality assurance (1,2). The International Commission on Radiological Protection and the new European directive on Basic Safety Standards underlined the importance of this topic by including radiation risk of medical professionals as part of the justification and optimization process of patients undergoing imaging studies with radiation exposure (3–6). To account for this radiation risk, several dedicated computer programs were launched, enabling approximate estimations of patient dose (7,8). These dose monitoring systems allow for collection and reporting of radiation dose data immediately on completion of the examination, providing a patient-specific dose history of the past months to assess potential dose accumulations from FGI sessions.

Until more recently, occupational dose monitoring relied solely on thermoluminescent dosimeter (TLD) badges worn above and beneath the lead apron (9). Usually, TLDs are processed once a month so that timely feedback is impossible (10). To overcome this problem, real-time occupational dose monitoring systems were introduced, providing immediate visual

From the Department of Radiology and Nuclear Medicine, Stadtspital Triemli Zurich, Birmensdorferstreet 497, Zurich CH-8063, Switzerland. Received August 19, 2015; final revision received October 12, 2015; accepted November 9, 2015. Address correspondence to C.H.; E-mail: christina.heilmaier@triemli.zurich.ch

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feedback of the dose rate to which the operator was exposed. As a consequence, a proactive approach is now feasible, and the operator can immediately adapt technical settings or adjust use of protective devices (9). Although patient dose monitoring systems and real-time occupational dose monitoring systems proved to be effective in routine clinical situations (11–17), implications of the combined use of the two systems were not evaluated. The purpose of the present study was to determine the effect on patient radiation exposure of the combined use of a patient dose monitoring system and a real-time occupational dose monitoring system.

MATERIALS AND METHODS

Radiologic Interventional System

The local ethics committee approved this prospective study, and informed consent was waived by all participants. All FGIs were carried out on a Siemens Artis zeego ceiling-mounted angiography system (Siemens Healthcare, Erlangen, Germany), which was located in the angiography suite. The system was composed of an x-ray generator system with a maximum output power of 100 kW. Usually, peak voltages of the x-ray beam of 70 kV were applied, with settings varying between 63 kV and 85 kV based on the individual patient's habitus and on the absorption of the anatomic area imaged. The system included a flat panel detector (30 cm × 38 cm) and was equipped with various low-dose and high-dose protocols, tailored to the different vascular and nonvascular procedures according to the operators' preferences. The standard setting that was usually applied at the beginning of an examination consisted of a pulse rate of four per second in the fluoroscopic mode and a frame rate of one image per second in the radiographic mode. Exceptions were embolization procedures of the visceral arteries or transarterial chemoembolization of the liver, where frame rates of two images per second were used. The spectrum of FGIs consisted of various vascular and nonvascular procedures except for neuroradiologic interventions. To reduce radiation exposure, the Combined Applications to Reduce Exposure technique was routinely applied. This technique included features for pulsed fluoroscopic control, automated copper filter settings, and positioning of collimators. For radiation protection, overhead acrylic and table shields were in place. Both interventional radiologists were normally outside the angiography suite during digital subtraction angiography series.

Patient Dose Monitoring System

A patient dose monitoring software system (DoseWatch; GE Healthcare Systems, Buc, France) was used throughout the entire radiology institute for sustained registration of ionizing radiation doses delivered to the patients. Regarding FGIs, the software provided detailed dose information, such as the kerma area product (KAP; Gy • cm^2), formerly known as dose area product, cumulative air kerma at patient entrance reference point (Gy), fluoroscopic time (decimal of minutes), and number of images. Dose data were transmitted from the fluoroscopic system to the patient dose monitoring system as a separate file, based on the dose protocol of the fluoroscopic system. Moreover, the patient dose monitoring software received information on patient-specific data (eg, sex, age, and body mass index [BMI; kg/m^2]). All data were immediately available on completion of the FGI. Data were displayed on an additional computer located in the angiography control room. The software triggered an alarm if the threshold for deterministic effects was exceeded (KAP $>$ 500 Gy • cm^2 or cumulative air kerma at patient entrance reference point $>$ 5 Gy).

Because there were considerable differences in the complexity levels of FGIs, a grading system was implemented (Table 1). To remind operators to determine the rating on completion of the FGI, a sticker ("Dose Watch") was placed on the monitor of the post processing system. Operators were blinded to dose data when they performed the rating. Data were exported from the patient dose monitoring software as Excel spreadsheets (Microsoft Excel 2010; Microsoft, Redmond, Washington) for further analysis.

Real-Time Occupational Dose Monitoring System

A real-time occupational dose monitoring system (RaySafe i2; Unfors RaySafe, Inc, Billdal, Sweden) was introduced at the radiology institute to improve radiation protection for operators during FGIs. The system consisted of four individual personal dosimeters (PDMs), placed above the lead apron at chest level. The PDMs estimated the user's dose, equivalent to the dose in tissue at a depth of d = 10 mm ($Hp(10)$) (14). Within the scope of the present study, the PDMs of the two main operators were analyzed.

The PDMs wirelessly transmitted dose data to a 10.4-inch touch screen, positioned at the operators' best possible visibility. Dose data were shown for each PDM separately and included current dose rate (mSv/h), accumulated procedure dose (μSv), and accumulated annual dose (mSv). The current dose rate was displayed in color bars, which increased in size and changed color as the radiation dose thresholds altered. Green indicated a dose rate $<$ 0.02 mSv/h, yellow indicated 0.2–2 mSv/h, and red indicated 2–20 mSv/h. To ensure accurate functionality, all PDMs were calibrated before being introduced into clinical routine. Data transfer from the PDMs to dedicated software (RaySafe i2 dose manager) was accomplished via the local network. The software