A Phantom Study and a Retrospective Clinical Analysis to Investigate the Impact of a New Image Processing Technology on Radiation Dose and Image Quality during Hepatic Embolization

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ABSTRACT

Purpose: To investigate changes in radiation dose and image quality using phantoms and hepatic embolization procedures performed with a new image processing technology (ClarityIQ) for a single-plane flat-detector–based interventional fluoroscopy system.

Materials and Methods: Phantom study was performed using acrylic sheets simulating different patient sizes. Air kerma rates (AKRs) were compared for different fluoroscopy modes and magnification modes without and with ClarityIQ. Repeat hepatic embolization procedures performed on the same lobe of the liver in the same patient by the same interventional radiologist between January 2013 and July 2014 without and with ClarityIQ were evaluated retrospectively. This included treatment of 33 hepatic lobes in 26 patients. Cumulative air kerma (CAK), kerma–area product (KAP), and factors affecting radiation dose were extracted from study metadata and compared. Blinded randomized image quality review was performed on arteriograms using a five-point scale.

Results: The phantom study revealed a significantly lower AKR ($P < .005$) with ClarityIQ. Repeated-measures analysis revealed a significant effect of ClarityIQ ($P \leq .001$) on CAK and KAP, with reductions ranging between 9% and 85% (median, 67%) and between 5% and 89% (median, 75%), respectively, on a case-by-case basis. Mean reductions in CAK and KAP were 279 mGy and 134,030 mGy·cm^2, respectively. Image quality review scores were significantly lower ($P \leq .001$) with ClarityIQ, effecting visualization of tumor vasculature and appearance of noise texture.

Conclusions: ClarityIQ resulted in radiation dose reduction in the phantom study and in the hepatic embolization procedures, but with a decrease in subjective perceptions of image quality.

ABBREVIATIONS

AERLC = automatic exposure rate control logic, AKR = air kerma rate, CAK = cumulative air kerma, CI = confidence interval, KAP = kerma–area product

The number of fluoroscopically guided interventional procedures has increased substantially during the past two decades, with approximately 9 million such procedures performed annually in the United States (1). There have been a number of reports documenting deterministic radiation bioeffects when increased levels of radiation are used during fluoroscopically guided interventions (1–4). Occupational radiation exposure to the performing physician and to other staff members is also of concern, especially for fluoroscopically guided interventions that use relatively high radiation doses (5–7). Therefore, to reduce potential deterministic bioeffects

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caused by elevated levels of radiation during fluoroscopically guided interventions and occupational radiation exposure to the performing physician and staff members, limiting radiation dose during fluoroscopically guided interventions is important. Consequently, there have been a number of published guidelines suggesting methods to optimize and monitor radiation dose during fluoroscopically guided interventions, with a specific focus on potentially high radiation dose procedures (1,8–17). Fluoroscopy systems sold in the United States after 2006 must provide radiation dose indicators, including air kerma rate (AKR), cumulative air kerma (CAK), and kerma–area product (KAP). These dose indicators quantify the total cumulative radiation used during a procedure and provide an indirect estimate of incident skin dose to the patient.

Along with the published guidelines for patient and personnel dose reduction, technologic advancements such as flat-panel x-ray detectors for use in fluoroscopy systems further contribute toward dose savings (18–20). The goal to reduce radiation dose while maintaining diagnostic image quality has led to dedicated signal and image processing applications specifically developed for interventional fluoroscopy systems. Analyses of radiation dose and image quality trade-offs need to be performed in a clinical setting before such applications are adopted in an imaging practice. Therefore, the aim of the present study was to investigate the radiation dose and image quality trade-off for hepatic embolization procedures for one such new image processing technology (ClarityIQ; Philips, Best, The Netherlands) for a single-plane flat-detector–based interventional fluoroscopy system. For this, we initially sought to quantify the changes in radiation dose with ClarityIQ in a controlled setting by using acrylic sheet phantoms to simulate different patient thicknesses. We then further investigated the changes in radiation dose and image quality for hepatic embolization procedures with the use of ClarityIQ.

MATERIALS AND METHODS

All data were acquired from two single-plane flat-detector interventional fluoroscopy systems (Allura Xper FD20; Philips), labeled in the present paper as system 1 and system 2. System 2 was upgraded with ClarityIQ image processing technology in December 2013. System 1, installed in December 2009, and system 2, installed in April 2011, operated on similar software versions before the ClarityIQ upgrade of system 2 (version 8.1.3) during the course of the study period. Both systems had identical detectors.

ClarityIQ Software

ClarityIQ is an image processing feature on Philips Allura Clarity systems and is available as a field upgrade for Philips Allura XPer systems. This software employs algorithms to reduce noise and maintain image quality at relatively low dose rates (21). These algorithms include real-time pixel shifting with automatic motion control, motion compensation, noise reduction in the temporal and spatial domains, and image enhancement with a multiresolution image decomposition approach. Further details about ClarityIQ are provided elsewhere (21).

Phantom Study

For the phantom study, a routinely used abdominal system preset (Abdomen, 3 frames per second) was selected for data acquisition. The system-reported AKR at the interventional reference point (22)—66 cm from the tube focal spot for Philips systems—was verified for accuracy and reproducibility (N = 5) by using a calibrated solid-state radiation detector (MPD; RTI, Mölndal, Sweden) for both systems initially and for system 2 after the ClarityIQ upgrade. The percent error between the system-reported AKR and the measured AKR values were computed to evaluate accuracy and regulatory compliance (22). Acrylic sheets (polymethylmethacrylate; 30 cm × 30 cm × 0.5 cm) were used to simulate three patient thicknesses of 9, 18, and 27 cm, to represent a typical range of patient thicknesses encountered in clinical studies. The system-reported AKR values (for system 1 and system 2 without and with ClarityIQ) were compared for different phantom thicknesses, three fluoroscopy modes, and three magnification modes (19 inches or 48 cm, 13 inches or 31 cm, and 6 inches or 15 cm) representing a full range of available field-of-view options. The default numbers of frames per second without ClarityIQ for both systems were 15, 15, and 7.5; with ClarityIQ for system 2, they were 15, 15, and 15 for fluoroscopy modes 1, 2, and 3, respectively (the default frame rates were configured by the manufacturer and were not changed during clinical use). The default value of 3 frames per second for digital subtraction angiography was same after the ClarityIQ upgrade. The three fluoroscopy modes differ from one another based on system-added filtration in the beam (combination of copper and aluminum) and the maximum radiation output determined by the systems' automatic exposure rate control logic (AERLC). The default filtration of the fluoroscopy systems did not change for fluoroscopy modes 1 (0.4 mm Cu + 0.1 mm Al) and 3 (0.1 mm Cu + 0.1 mm Al) without and with ClarityIQ (for both systems), but, for fluoroscopy mode 2, it changed from a combination of 0.1 mm Cu and 1.0 mm Al without ClarityIQ to a combination of 0.4 mm Cu and 1.0 mm Al with ClarityIQ (for system 2 after the ClarityIQ upgrade). The maximum radiation output rates determined by the systems' AERLC without ClarityIQ were 40 mGy/min, 80 mGy/min, and 80 mGy/min (for system 1 and system 2 without ClarityIQ);