RADIOCHROMIC FILM DOSE MEASUREMENTS DURING DIAGNOSTIC CT EXAMINATION ON PATIENTS

Jonathan Boivin, Nada Tomic, Bassam Fadlallah, François Deblois, and Slobodan Devic

Medical Physics Unit, McGill University, Montréal, Québec H3G 1A4, Canada,
Departments of Radiation Oncology and of Biomedical Engineering, Jewish General Hospital, Montréal, Québec H3T 1E2

PURPOSE

Increased availability of computed tomography systems (CT) and high quality imaging technologies helped physicians in making better diagnosis, but it also increased the amount of dose received by patients. Nowadays, delivered dose is not measured during CT examination, but it is rather estimated by an industry established standard technique embedded in commercially available CT scanners. Common approaches of direct dose measurement are the use of thermo-luminescent detectors (TLDs) or metal-oxide-semiconductor field-effect transistor (MOSFET) for skin dose (on patients or phantoms), or ionization chamber (in phantoms) for body dose measurements during CT scans. However, these are point dose measurement methods assuming homogeneous dose distribution within a volume, which may underestimate or overestimate the actual dose, especially when multi-slice scanners are used with pitch different than one during helical scans. We use a 2D reference dosimetry technique for dose measurements from CT scans on GE Lightspeed VCT 64 that employs XR-QA radiochromic film model [1], specifically designed for dose measurements at low energy photons. We report on surface dose measurements during clinical CT procedures carried out on patients and humanoid Rando phantom.

METHODS AND MATERIALS

Selection of patients was performed by a diagnostic radiologist based on eligibility criteria, which included a scheduled CT examination. Four of the most commonly used CT protocols were selected on our CT imaging system, covering three different anatomical sites (head, chest and abdomen). These protocols are named: 1) Routine Head Cooperativ, 2) Routine Abdomen, 3) CTA Aorta Abdomen & Pelvis and 4) Chest Abdomen with H-RES. To have a uniform assessment and to minimize heterogeneity in the evaluation, we accrued 25 patients per protocol. Exclusion criteria were fragile patients and patients receiving more than one procedure.

Pieces of films (1”x 6”) were taped on the skin of patients using paper tape, within the scanning region and along the longitudinal scanning axis. For each patient, four films were taped in the anterior (ANT), posterior (POST), right lateral (RLAT) and left lateral (LLAT) aspects of skin. Smaller films were used (1” x 2”) for Head protocol. For Chest & Abdomen protocol, two films were needed to measure both chest and abdomen skin dose; they were marked as UP (chest) and DOWN (abdomen) position. Films were taped on the patient in the CT room prior to examination, and then removed from the skin immediately after the CT scan. Also, XR-QA film sheets were placed between Rando slices in order to measure the interior dose for one site (Head). Preparation of the film includes cutting, labeling and scanning with the Epson Expression 10000XL document scanner in a reflective mode. Twenty-four hours after irradiation, pieces of film were scanned again on the document scanner with the very same scanning parameters. Spatial dosimetry was performed by adapting the formalism previously developed for the transparent EBT model radiochromic film [2].

Response of the reference film dosimetry system was calibrated in terms of air-Kerma in air, for 120 kVp in combination with either small filter (head) or large filter (body). Air-Kerma in air was measured for the two resulting beam qualities with the calibrated FLUKE TNT-12000 X-ray Test Device and the equations were based on TG-61 protocol [3].

Pieces of films were placed on a custom made phantom, designed for this purpose (two tiny fish strings spread between two plastic holders). Films were then irradiated at selected mAs setups, receiving known amount of air-Kerma. Pieces of film were scanned prior to and 24 hours post-irradiation using the same scanning protocol. To cover the dose measurements within the dose range 0-20 cGy, we found that green channel extracted from the scanned RGB image was the best suited.

The optical reflectance of the non-irradiated film piece was subtracted from the exposed one to obtain change in reflectance after irradiation (ΔR). Then, change in optical reflectance of an unexposed control film piece was also subtracted to take temporal and environmental effects into account, which result in final change in reflectance ($net\Delta R$). The resulting calibration curves (Figure 1) are obtained using the following formula:

$$\boldsymbol{Air\ Kerma} = [(\boldsymbol{a} + \boldsymbol{c} \cdot \boldsymbol{net\Delta R})/(\boldsymbol{1} + \boldsymbol{b} \cdot \boldsymbol{net\Delta R})] - \boldsymbol{a}$$

Their corresponding calculated uncertainties (Figure 2) show that the presented dosimetry method can provide uncertainty of less than 8.0 % for CT doses within the investigate dose range.

RESULTS

Figure 3 shows the post-irradiation anterior film of one patient who had an Abdomen exam, as well as its related dose profile. Measurements show that skin dose variation has a sinusoidal pattern along the scanning axis due to the helical movement of the X-ray tube around the body and axial movement around the head. The period is related to scanning step and film's angle to scanning axis.

In Figure 4, histograms with dose distribution for Head (averaged over 17 patients) and Abdomen (averaged over 24 patients) protocols at four aspects of the patient's skin are presented. Lateral right and left skin dose are higher than anterior and posterior when using Head protocol. However, anterior skin dose is the highest when using Abdomen protocol. Posterior skin doses are the lowest because of the table and head holder attenuation. Measured skin doses are about two times higher for patients receiving the Head

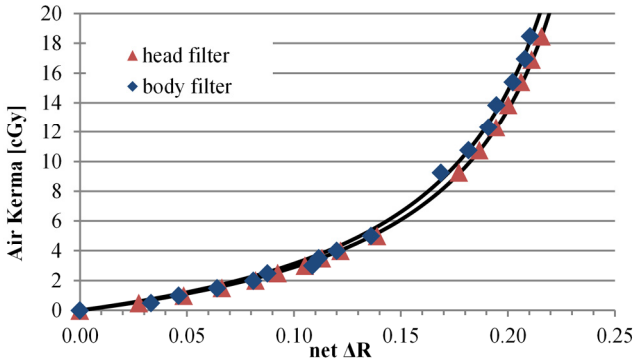

Figure 1: Calibration curves of XR-QA films for two beam qualities used in clinical CT protocols

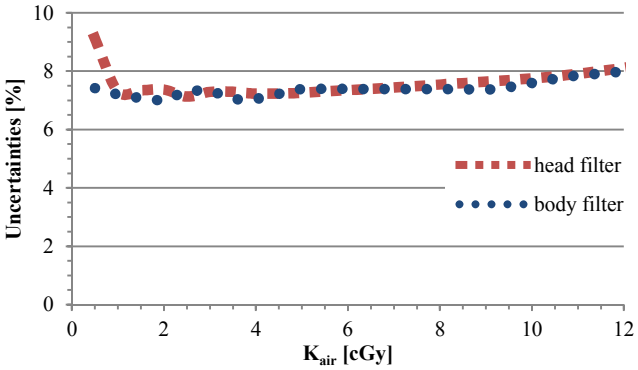

Figure 2: Total uncertainties from experimental error and fitting function error for the 2 different beam qualities used in clinical CT protocols

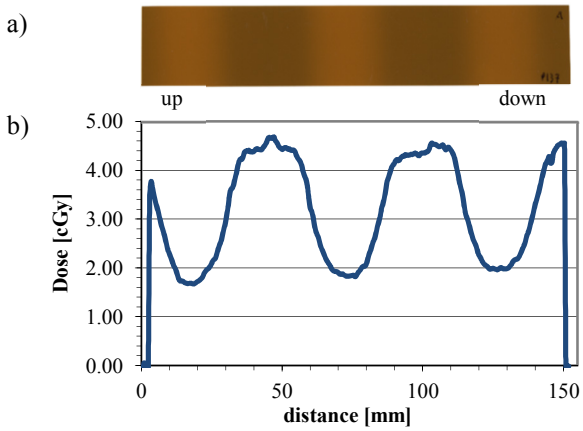

Figure 3: a) Post-irradiated anterior skin dose film and b) anterior skin dose profile for one patient scanned with Abdomen CT

scanning protocol than those receiving the Abdomen one.

The calculated difference between Dose-Length Product (DLP) value provided by CT scanner and an experimental DLP evaluation for Abdomen protocol is summarized in Figure 5.

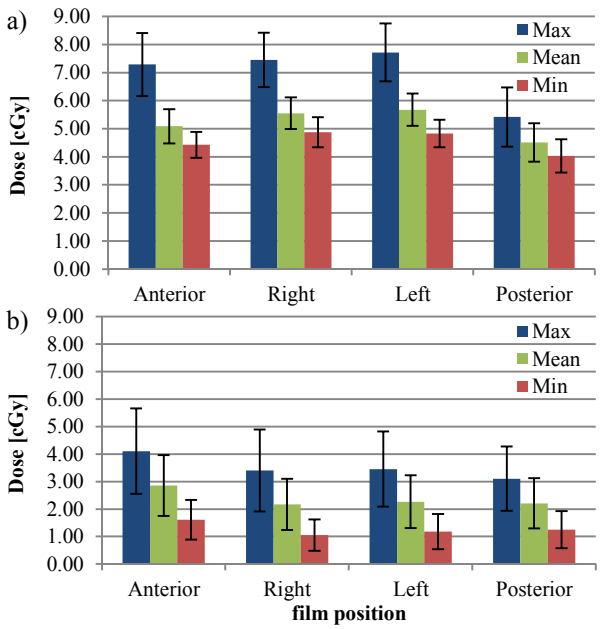

Figure 4: Skin dose distribution for a) Head and b) Abdomen CT protocols

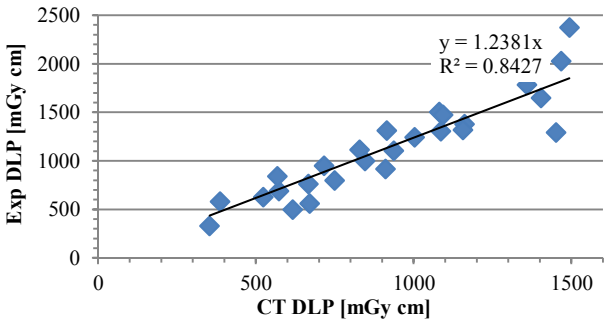

Figure 5: Experimental DLP as a function of DLP provided by CT scanner for patients scanned with Abdomen CT protocol

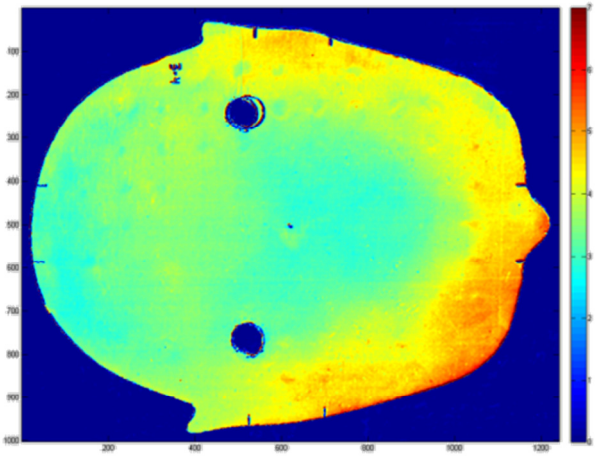

Figure 6: 2D dose distribution with a film sheet placed between two slices of Rando phantom

Since the size of the film do not cover the whole longitudinal range of the CT scan, integrated DLP value from Figure 3b was subsequently scaled by the ratio of the actual longitudinal scanning length and the film integration length. The slope on the graphic shows that experimental DLP values are higher for Abdomen protocol scans.

Figure 6 illustrates the 2D interior dose distribution for head site from film sheet placed between Rando slices (Head protocol). Similar results were obtained by Brady et al. using a CTDI head phantom and a 5 year old anthropomorphic phantom [4].

CONCLUSIONS

We applied the air-Kerma based radiochromic film dosimetry protocol to measure skin dose during CT examinations on patients and Rando phantom. Our results show that the average skin dose can be up to 6.8 cGy for Head and up to 6.0 cGy for Abdomen clinical CT protocol. However, at peaks, skin dose can reach up to 9.6 cGy for Head and up to 8.5 cGy for Abdomen clinical CT protocol. Results for skin doses and corresponding DLPs are higher than expected from the CT scanner, because our effective point of measurement is on the skin of the patients as opposed to the manufacturer's measurements performed with ion chamber inside CTDI phantoms.

REFERENCES

[1] N. Tomic, *et al.*, Reference radiochromic film dosimetry in kilovoltage photon beams during CBCT image acquisition, *Medical Physics,* vol. 37, pp. 1083-1092, Mar 2010.

[2] S. Devic, *et al.*, Precise radiochromic film dosimetry using a flat-bed document scanner, *Medical Physics,* vol. 32, pp. 2245-2253, Jul 2005.

[3] C. M. Ma, *et al.*, AAPM protocol for 40-300 kV x-ray beam dosimetry in radiotherapy and radiobiology, *Medical Physics,* vol. 28, pp. 868-893, Jun 2001.

[4] S. Brady, *et al.*, Implementation of radiochromic film dosimetry protocol for volumetric dose assessments to various organs during diagnostic CT procedures, *Medical Physics,* vol. 37, pp. 4782-4792, Sep 2010.