Wide Variation in Radiation Exposure During Computerized Tomography

Andrew Cohen, Katie Hughes, Natalie Fahey, Brandon Caldwell, Chi Hsiung Wang, and Sangtae Park

OBJECTIVE To determine the variance in computeed tomography (CT) radiation measured via dose-length product (DLP) and effective dose (ED) during stone protocol CT scans.

METHODS We retrospectively examined consecutive records of patients receiving stone protocol diagnostic CT scans (n = 1793) in 2010 and 2014 in our health system. Patient age, body mass index (BMI), and gender were recorded, along with the hospital, machine model, year, DLP, and ED of each scan. Multivariate regression was performed to identify predictive factors for increased DLP. We also collected data on head (n = 837) CT scans to serve as a comparison.

RESULTS For stone CT scans, mean patient age was 55.1 ± 18.4 years with no significant difference in age ($P = .2557$) or BMI ($P = .1794$) between 2010 and 2014. Gender, BMI, and machine model were independent predictors of radiation dosage ($P < .0001$). Within each BMI class, there was an inexplicable 6-fold variation in the ED for the same imaging test when comparing the lowest and highest CT dose patients. There was no significant change in DLP over time for stone CT scans, but head scan patients in 2014 received lower radiation doses than those in 2010 ($P < .0001$). Low-dose scans for renal colic (defined as <4 mSv) were underutilized. Substantial variation exists for head scan radiation doses.

CONCLUSION Our data demonstrate large variations in diagnostic CT radiation dosage. Such differences within a single institution suggest similar trends elsewhere, warranting more stringent dosage guidelines and regulations for diagnostic CT scans within institutions. UROLOGY 95: 47–53, 2016. © 2016 Elsevier Inc.

Use of computed tomography (CT) for diagnostic imaging has drastically increased in recent decades.[1-3] Indeed, about 14 % of all emergency room visits result in a CT scan, an increase of 330% from 1996 to 2007.[4] Compared to traditional radiography, CT administers significantly higher doses of ionizing radiation, predisposing patients to increased risk for serious health conditions including cancer.[3,5] Others warn that overzealous fears of radiation may hinder appropriate diagnosis and treatment because the low doses of radiation from CT do not pose significant problems for human health.[6,7] In reality, there is no known safety threshold for ionizing radiation exposure, and the "as low as reasonably achievable" principles is agreed among the medical community.[5]

As such, institutions including the American College of Radiology have released guidelines for CT radiation doses. Ultimately, administered doses are at the discretion of certified radiation technicians and CT scanner model they are working with.[8] In a retrospective review of doses administered for common CT scans, Smith-Bindman et al found large variations in radiation dosage.[3] A later investigation of CT scans for suspected urolithiasis confirmed drastic differences in radiation by patient and by hospital, and demonstrated that few patients are receiving recommended low-dose scans despite meeting indications.[9] Although specific explanations for these dose differences have not been identified, Sera et al demonstrated that type of equipment, department of scans, and machine calibration impact dosage levels in a wide variety of radiologic settings.[10] Thus far, published population-based studies investigating this question are limited due to a lack of information on patient body mass index (BMI) and their grouping of different types of CT scanners in a single analysis.[9]

In light of the above-mentioned limitations, we performed a novel study on the variations in ionizing radiation exposure for diagnostic noncontrast-enhanced CT scans. Specifically, we analyzed the radiation dose associated with noncontrast CTs of the head for various indications, and for abdominopelvic (A-P) stone protocol scans. We aimed to assess whether there are radiation exposure variations within a single medical institution with multiple scanner locations, make, and models. We hypothesized that within a single radiology department, little

Financial Disclosure: *The authors declare that they have no relevant financial interests.*

From the Section of Urology, University of Chicago, Chicago, IL; and the Division of Urology, NorthShore University HealthSystem, Evanston, IL

Address correspondence to: Sangtae Park, M.D., M.P.H., Division of Urology, NorthShore University HealthSystem, 1000 Central St., Suite 720, Evanston, IL 60201. E-mail: spark@northshore.org

Submitted: April 17, 2016, accepted (with revisions): May 18, 2016

http://dx.doi.org/10.1016/j.urology.2016.05.036
0090-4295

variation in radiation exposure would exist, given the same set of clinical circumstances and shared staff.

We collected data on head CTs in addition to A-P CTs, because head CT radiation dose should not be significantly impacted by BMI. We also compared scans in 2010 with those in 2014, hypothesizing that advances in technology and increased awareness of the merits of "low-dose" CT scans would have changed behavior, to decrease radiation exposure to the patient by 56% to 77%.[11,12]

METHODS

We retrospectively reviewed all consecutive (n = 1793) noncontrast-enhanced A-P stone CT scans performed for suspected urolithiasis in April, May, and June 2010, and April, May, and June 2014. CT scans were ordered at the discretion of the treating physician and were included in the analysis no matter the final diagnosis. Because head density exhibits less variation than abdominal girth, we reviewed all consecutive noncontrast-enhanced head (n = 837) CT scans administered in June 2010 and June 2014 to serve as an indirect comparison.

The studies we specifically queried were "CT stone protocol" and "non-contrast CT head." Estimated exposure levels for individual scan protocols were retrievable. Hence, if a patient underwent a noncontrast head CT and a noncontrast neck CT, only the radiation associated with the head CT would be included in this study. No further clinical or diagnostic information prior to, or that resulted from the scans was recorded, as this study was approved under a quality improvement exemption with our local Institutional Review Board.

Patient demographics including age and gender were recorded. BMI was available for all patients undergoing noncontrast A-P stone CT scans and a random selection of 10% of those undergoing head CT. The hospital location and model of machine used, and the dose-length product (DLP), as reported by the scanner software itself, were recorded for each scan performed. In our health system, there are four outpatient CT scanner facilities in addition to scanners within the four hospitals. Many physicians travel between multiple office settings and hospitals as convenient for the patient. A single diagnostic radiologist or treating physician may interpret CT scans from any of the outpatient or inpatient scanners. Our health system includes over 900 physicians seeing patients in over 100 office locations. There were 1.6 million office and emergency room visits in fiscal year 2014.

Using the SAS (Cary, NC) statistical program, we analyzed variations and distributions of CT DLP between A-P CT and head CT scans, stratified by machine type and patient demographics. Multivariate regression was performed to identifying independent predictive factors for increased DLP. Kruskal-Wallis, Chi-square, correlation and T-tests were used as appropriate to analyze other results. All tests were 2 tailed, and a threshold of $P < .05$ was considered significant for statistical analyses.

In terms of radiation dose and absorption measures, the CT Dose Index (CTDI) is a proxy for the absorbed dose in a phantom in a single plane. The Dose Length Product (DLP) is related to the total energy imparted based on phantom references and incorporates length of the scan. Simply put, CTDI multiplied by length of scan gives the estimated DLP. Overall, this serves as a marker for radiation exposure in a particular patient and is the value reported by the CT scan output.[13] There is a linear relationship between effective dose and DLP. Using appropriate *k* coefficients for organ and patient age effective dose (ED) estimates were annotated in the text for ease of comparison to other literature.[14,15]

Effective dose allows comparison across the different types of CT studies and between CT and other imaging tests, providing an understandable value. We emphasize it was not developed to measure patient exposure, but are a means to compare doses between scanners. Despite varied limitations, this exact methodology has been utilized elsewhere to describe variation in radiation dose.[3,9,13-18] Because of some of the limitations regarding ED, we also reported raw DLP values.

RESULTS

A-P Stone Protocol Scans

Baseline characteristics for patients undergoing stone protocol CT scans are summarized in Table 1. The cohort demonstrated no significant difference in patient age or BMI between 2010 and 2014. There was a significant ($P = .0204$) increase in number of scans performed at Hospital D over time, whereas Hospitals A, B, and C performed fewer A-P scans in 2014 than in 2010. Scanner model usage also differed significantly over time ($P < .0001$); whereas GE scanners were predominantly employed in 2010, newer Siemens models largely replaced these GE models by 2014.

Mean effective dose was 11.8 ± 4.8 and 11.4 ± 5.8 mSv for 2010 and 2014, respectively. Mean DLPs stratified by varied patient characteristics are summarized in Table 2. On univariate analyses, adult patients received higher radiation doses than children under age 18 ($P < .0001$), and male patients received higher radiation doses than females ($P < .0001$). Additionally, obese and overweight patients ($P < .0001$) and patients treated at Hospital D ($P < .0001$) received significantly higher levels of radiation. GE scanners delivered significantly higher radiation doses than their newer Siemens counterparts ($P < .0001$). There was increased DLP dosage in 2014 compared to 2010. Overall, only 0.95% of CT stone protocol scans was designated "low-dose" or <4 mSv.

Controlling for patient age, gender, BMI, hospital, year of scan, and machine model, multivariate analysis demonstrated higher BMI ($P < .0001$), male gender ($P < .0001$), and year of scan ($P < .02$), and certain scanner models ($P < .03$) predict higher DLP dosage (Table 3). A visual depiction of variability in radiation exposure can be seen in Figure 1, stratified for abdominal CT by BMI, year of scan, and particular scanner. We also collected data on the