**CONCLUSION**

This study presents the establishment of appropriate adult diameter-based local and national DRLs, in order to comprehensively represent the size range of the examined population.

**Background**

Diagnostic Reference Levels (DRLs) provide an investigative level to identify unusually high patient doses. CT adult DRLs are currently calculated as the 75th percentile of exam specific CTDIvol and DLP datasets for adult patient samples of weight range 60-80kg and typically based on small samples of 10 or more. While DRLs provide a practical metric for ‘normal’ adult patients, these investigative levels if used for the broad size range of all patients may prove inappropriate. Further, it is well known that body weight is poorly correlated with CT dose metrics, prompting the question as to whether DRLs in their current form are fit for representing the entire adult population. Size-specific reference doses have been suggested for paediatric patients; however, such analyses have not been performed in adults. Accordingly, the object of this work was to propose diameter-based local and national DRLs and to examine the variability of diameter-specific metrics across examinations and hospitals sites.

**Evaluation**

Dose metric data from 19 CT scanners across the Irish National Integrated Medical Imaging System (NIMIS), for all examinations (n=149784), was captured by Radimetrics eXposure™ software over an 18-month period, allowing for the collation of CT scanning parameters including CTDIvol, DLP, Size-Specific Dose Estimate (SSDE) and effective patient diameter. After data cleansing, diameter-specific 25th, 50th and 75th parameter percentiles were calculated to inform on establishing local and national DRLs with high volume, high dose and newly established CT exams investigated.

**Discussion**

For patients of increased diameter, elevated 75th percentiles were evident when compared with normal-sized patient levels, suggesting traditional DRLs to be ineffective at flagging higher dose investigative levels for all patients. The work also allowed for the comparison of examination- and size-based CT dose metrics for systems of similar model and manufacturer, in addition to across a range of manufacturers.

**Effective Dose of Chest X-ray, Tomosynthesis, and Thoracic CT in a Multi-Center Clinical Trial**

**PURPOSE**

Digital tomosynthesis (DTS) imaging is increasingly being used for numerous thoracic indications. In addition to evaluation of the diagnostic capability of this technique, it is important to understand the dose to the patient relative to conventional chest x-ray (CXR) and CT protocols.

**METHOD AND MATERIALS**

An international, multi-center, clinical trial was designed and conducted under IRB approval to compare the performance of DTS to conventional two-view CXR for the detection of lung nodules, using CT as the reference standard.
standard. Subjects in the study had a diagnostic CT exam as part of routine care for a variety of thoracic indications, and then received conventional 2-view CXR and DTS exams (GE Healthcare, XR656 with VolumeRAD). Effective dose for CXR and DTS was calculated using the PCXMC Monte Carlo tool (STUK, Finland). Calculation of absorbed dose was based on estimates of incident air kerma from exposure technique data and the assumption of average habitus subjects. CT effective dose was calculated using the ICRP 103 methodology from the DLP determined from reported CTDI values.

RESULTS

Technique data for dose estimation was available for all 158 subjects in the study for some modalities, and for 91 subjects for all modalities. For the 91 cases with valid data for all modalities, the mean effective dose (and standard deviation) was 0.059 (0.033), 0.088 (0.037), and 4.86 (3.2) mSv for CXR, DTS, and CT respectively. The use of 0.2 mm Cu additional filtration (at 120 kVp) was observed to reduce the effective dose for the DTS subjects. The variation in DTS effective dose was much less than CXR as a result of increased uniformity of delivered mAs per projection in the DTS acquisition.

CONCLUSION

For the patients in this clinical trial, the average effective dose of a DTS acquisition was only 1.5 times greater than that of a conventional two-view chest radiograph, and significantly less than that of the diagnostic thoracic CT exams. DTS provides tomographic image information, enabling significantly increased nodule detection sensitivity, with less than 0.1 mSv effective dose.

CLINICAL RELEVANCE/APPLICATION

Digital tomosynthesis imaging provides volumetric image data enabling increased lung nodule detection compared to conventional chest x-ray at a similar, minimal, radiation level (less than 0.1 mSv).

SSG15-03

Multi-phase CT: Impact of Contrast Medium Propagation on Radiation Dose across a Population of Patient Models

Pooyan Sahbaee (Presenter): Nothing to Disclose, William Paul Segars PhD: Nothing to Disclose, Ehsan Samei PhD: Research Grant, Siemens AG Research Grant, General Electric Company Research Grant, Carestream Health, Inc

PURPOSE

To quantify the radiation dose variation as a function of time due to the contrast medium (CM) administration in multiphase liver CT scan across a library of 5D XCAT models.

METHOD AND MATERIALS

The dose estimation was performed on a library of 58 adult extended cardiac-torso (XCAT) models. To generate the 5D XCAT patient models, a unique method was developed to incorporate the dynamics of CM propagation into our 4D XCAT (as demonstrated in our prior work, the fourth dimension reflects the heart and respiratory motions) anthropomorphic models. The models were created based on patient-specific iodine concentration-time results from our computational CM propagation computer model for different injection protocols, such that each organ in a patient model subjected to a specific injection protocol was assigned to its own unique CM time-concentration curve. The radiation dose to individual organs in the models was estimated from a four-phase (pre-contrast, arterial, portal venous, and delayed phases) liver CT examination modeled via a validated Monte Carlo simulation software package (PENELOPE). For each scan time point after the injection, 80 million photons were initiated and tracked through the phantoms. Finally, the dose to the liver was tallied from the deposited energy.

RESULTS

The liver CT scan simulation results from 5D XCAT models subjected to a commonly used injection protocol (120 mL of 350 mgI/mL CM at 4 mL/s) indicated up to 10%, 32%, and 24% increases in radiation dose delivered to the liver for arterial phase (to 9.45 mGy), portal venous phase (to 11.29 mGy), and delayed phase (to 10.65 mGy), respectively.

CONCLUSION

Administration of contrast medium in enhanced CT scan not only remarkably affects the CT image quality (thus the reason for its use), but also notably increases the radiation dose. Particularly, multiple acquisitions in several enhanced CT protocols accentuate the radiation dose as a critical objective in optimization of the protocols.

CLINICAL RELEVANCE/APPLICATION

The study aimed to provide a methodology to incorporate the contrast medium propagation in XCAT models, thus building toward an opportunity to optimize radiation dose and injection protocol in concert.

SSG15-04

Dose to Organs and Tissues from Scattered Radiation in Breast CT: Impact on Effective Dose

Sabrina Viviane Vollmar PhD: Nothing to Disclose, Daniel Kolditz PhD (Presenter): Employee, CT Imaging GmbH, Martin Hupfer PhD: Employee, CT Imaging GmbH, Willi A. Kalender PhD: Consultant, Siemens AG
PURPOSE
To evaluate potential dose contributions by scattered radiation to organs and tissues not directly exposed and the resulting effective dose in dedicated breast CT.

METHOD AND MATERIALS
Calculation of dose in the directly and not directly exposed parts of the body were performed for dedicated breast CT at tube voltages of 40, 60 and 80 kV with a Monte Carlo (MC) software tool (ImpactMC, CT Imaging GmbH, Erlangen, Germany). Effective dose was calculated according to the ICRP publication 103. We used the standard female ORNL (Oak Ridge National Laboratory) phantom to mimic the patient lying prone on the examination table and added cylindrical phantoms with 10 and 14 cm diameter, and 7.5 and 10.5 cm in length, respectively to mimic the pendant breast. Only the examined breast was directly exposed. The air kerma of the scans was adapted to achieve an average glandular dose (AGD) of 1.6 and 4.6 mGy, respectively, for the two breast sizes, which corresponds to the dose limits in mammography in the European Guidelines for screening mammography.

RESULTS
Effective dose was confirmed at 0.192 mSv and 0.552 mSv for 10 and 14 cm breast sizes, respectively, for all tube voltages without scattered radiation. When taking scattered radiation into account effective dose increased to 0.200 and 0.591 mSv when adding an absorption foil (150 µm Pb) to the examination table. Respective values were 0.196 and 0.570 mGy for 40 kV and 0.202 and 0.608 mGy for 80 kV. For the not directly exposed tissues highest organ dose values were found in the lung amounting to 0.029 and, 0.146 mGy, respectively. Adding the absorption layer to the table reduced these values to 0.026 and 0.128 mGy, respectively.

CONCLUSION
Effective dose in dedicated breast CT for a bilateral examination with typical values of 0.2 to 0.6 mSv is low; scattered radiation only contributes 2-3%, 3-7% and, 5-9% additional dose to these values for 40, 60 and 80 kV, respectively.

CLINICAL RELEVANCE/APPLICATION
Dedicated breast CT potentially offers higher sensitivity and specificity for breast cancer detection without increasing dose levels significantly.

Quantifying the Effects of Patient Size, Scanner Selection and Scan Start Location on Organ Dose Estimates in Contiguous Axial Head CT Examinations

Kyle McMillan (Presenter): Institutional research agreement, Siemens AG Research support, Siemens AG, Maryam Bostani PhD: Research support, Siemens AG, Maria Zankl PhD: Nothing to Disclose, Christopher H. Cagnon PhD: Nothing to Disclose, John J. Demarco PhD: Nothing to Disclose, Michael F. McNitt-Gray PhD: Institutional research agreement, Siemens AG Research support, Siemens AG

PURPOSE
To evaluate the impact of patient size, scanner selection and scan start location on brain and lens of the eye dose for contiguous axial head CT examinations.

METHOD AND MATERIALS
Using Monte Carlo simulations of contiguous axial scanning for 64-slice multi-detector row CT scanners from four major manufacturers, brain and lens of the eye dose were estimated for eight patient models from the GSF family of voxelized phantoms. Simulations were initially performed with a scan from the top of the C1 lamina through the top of calvarium. Additional simulations were performed with start locations 1 cm, 2 cm, 3 cm and 4 cm inferior to the C1 lamina. CTDIvol-to-organ-dose conversion coefficients were calculated for each combination of patient model, scanner and start location by normalizing brain and lens of the eye dose by scanner-specific 16 cm CTDIvol values. These scanner-specific conversion coefficients were averaged across all scanners and start locations to determine scanner-independent CTDIvol-to-organ-dose conversion coefficients for each patient model. Scanner-independent conversion coefficients were then correlated with patient size, and variation between scanner-specific and scanner-independent conversion coefficients was assessed.

RESULTS
An exponential relationship between scanner-independent CTDIvol-to-organ-dose conversion coefficients and patient size was observed with correlation coefficients of 0.92 and 0.85 for the brain and lens of the eye, respectively. For the lens of the eye, scanner-specific and scanner-independent conversion coefficients for each patient model varied up to 26.1%. For the brain, variation upwards of only 8.9% was observed.

CONCLUSION
Patient size, scanner selection and scan start location all influence organ dose in contiguous axial head CT examinations. Scan start location causes surface dose variation in a manner similar to tube start angle for helical scanning. This effect can be enhanced by the scanner-specific dose efficiency of beam collimations. Dose to small, superficial organs like the lens of the eye may have pronounced variation due to these start location effects, while brain dose is relatively constant.
CLINICAL RELEVANCE/APPLICATION
For contiguous axial head CT exams of a given patient size, scanner selection and scan start location may have a noticeable impact on lens of the eye dose, while brain dose is relatively constant.

SSG15-06 Modern CT Pulmonary Angiography or Lung Perfusion Scintigraphy in Pregnant Patients Suspected for Pulmonary Embolism? Comparison of Associated Radiation Risks

Konstantinos Perisinakis PhD (Presenter): Nothing to Disclose, Ioannis Seimenis PhD : Nothing to Disclose, Antonis Tzedakis MS : Nothing to Disclose, John Emmanuel Damilakis MD : Nothing to Disclose

PURPOSE
To provide and compare maternal and fetal radiation dose burden and associated radiation cancer risk estimates from 256-slice CT pulmonary angiography (CTPA) and lung perfusion scintigraphy (LPS).

METHOD AND MATERIALS
The BodyBuilder software package was employed to generate mathematical anthropomorphic phantoms representing the average female individual at early pregnancy and at 1st, 2nd and 3rd trimester of gestation. In each phantom, 1-3 additional 1.5 cm-thick fat tissue layers were added to produce phantoms of different body size. Monte Carlo methods were used to simulate low-dose 256-slice CTPA exposures on each of the 16 generated phantoms. Normalized maternal organ and conceptus dose data were derived for exposures at 80, 100 and 120 kV. Maternal and conceptus doses from 256-slice CTPA were determined and compared to corresponding estimates for low-dose LPS. Total life attributable risks (LARs) of cancer associated with 256-slice CTPA and LPS were determined using previously published radiation cancer risk factors and compared to intrinsic risk of cancer for 20-, 30- and 40-years old female individuals.

RESULTS
For an average-size pregnant patient, the low-dose 256-slice CTPA exposure was found to result in a maternal effective dose of 1 mSv and a conceptus dose of <0.06 mGy. However, maternal effective dose was found to considerably increase with body size, while conceptus dose was increased with both body size and gestational stage. Compared to LPS, low-dose CTPA to an average-sized pregnant patient was found to result in 15% higher maternal effective dose, but 3.4-6 times lower conceptus dose. Nevertheless, LPS was found to be associated with less aggregated radiation risk for an average size pregnant patient with the difference from CTPA to be further increased for larger patients. Low-dose 256-slice CTPA at the age of 20, 30 and 40 years marginally increases the intrinsic risk of cancer by 1.0007, 1.0004 and 1.0003, respectively.

CONCLUSION
LPS remains more dose efficient even compared to low-dose CTPA performed with a modern wide-area CT scanner.

CLINICAL RELEVANCE/APPLICATION
LPS should be maintained as the preferable next step of imaging for pregnant patients suspected for pulmonary embolism who have a normal chest X-ray radiograph and require further investigation.

SSG15-07 Radiation Dose and Image Quality Performance of Organ-based Tube Current Modulation for Head and Chest CT Scans


PURPOSE
The purpose of this study was to quantify dose and noise performance of organ-dose-based tube current modulation (ODM) through experimental studies with an anthropomorphic phantom and simulations with a phantom library.

METHOD AND MATERIALS
ODM reduces tube current for anterior source positions, without increasing current for posterior positions. Axial CT scans at 120 kV were performed on head and chest phantoms (Rando Alderson Research Laboratories, Stanford, CA) on an ODM-equipped scanner (Optima CT660, GE Healthcare, Chalfont St Giles, England). Dosimeters quantified dose to breast, lung, heart, spine, eye lens and brain regions (mobile MOSFET Dosimetry System, Best Medical, Ottawa, Canada) for ODM, automA (z modulation), and smartmA (angular and z modulation) settings. Noise standard deviation was calculated in brain and chest regions of reconstructed images. To study a variety of patient sizes, Monte Carlo simulations, validated with experimental data, were performed on 28 voxelized head phantoms and 10 chest phantoms. Organ dose and reconstructed noise standard deviation were compared for all phantoms. Image quality assessment is currently underway using a task-dependent signal detectability metric.

RESULTS
ODM reduced dose at all dosimeters with respect to smartmA, with dose changes of -31.3% (breast), -20.7% (lung), -24.4% (heart), -5.9% (spine), -18.7% (eye), and -10.5% (brain). Simulations indicated average dose changes of -33.4% (breast), -20.2% (lung), -24.4% (heart), -5.9% (spine), -24.4% (heart), -20.0% (eye) and -7.2% (brain). ODM reduced dose to the brain and lung tissue, however these tissues would experience up to 15.2% and 13.1% dose increase respectively at noise standard deviation equal to smartmA. ODM reduced dose to the eye lens in 22 of 28 phantoms (-1.2% to -12.4%), had no change in dose for two phantoms, and increased dose for three phantoms (0.7% to 2.3%) with respect to smartmA at equal noise standard deviation. All phantoms demonstrated breast dose reduction (-2.1% to -27.6%) at equal noise standard deviation.
CONCLUSION
Experimental and simulation studies over a range of patient sizes indicate that ODM has the potential to reduce dose to sensitive organs by 5 - 38% with a limited increase in image noise.

CLINICAL RELEVANCE/APPLICATION
Organ-based tube current modulation has the potential to reduce the dose to radiosensitive tissues with limited degradation in noise standard deviation.

Monitoring and Controlling Patient Radiation Exposure from Computed Tomography at a Community Hospital Using a Collaborative, Data-driven Approach

Jenifer Willmann Siegelman MD, MPH (Presenter): Consultant, Bayer AG, Marie Kate MacGregor MPH: Consultant, Bayer AG, Mark Patrick Supanich PhD: Research agreement, Siemens AG

PURPOSE
Evaluate the effectiveness an organization-wide stewardship initiative based on a systematic evaluation of radiation dose using automated dose tracking software coupled with targeted interventions that included protocol modification, equipment replacement or software upgrades and operator training

METHOD AND MATERIALS
Design: Retrospective, observational study of consecutive CT exams with a 3-month control, 12 month intervention and 3-month follow-up period in a community health system. Intervention: Periodic analysis of dose by protocol, equipment and operator using automated radiation dose capture software with built-in analytic tools provided the data for the intervention and confirmation of dose optimization. The optimization strategy engaged physicians, physicists, technologists, and hospital administrators and included equipment software upgrades, new equipment, changes in protocol parameters and training/retraining of technologists. Analysis: Pre- and post-intervention radiation dose (surrogate parameters CTDIvol, Dose Length Product (DLP) and Size Specific Dose Estimate (SSDE)) by protocol group was assessed and significance tested using an Analysis of Covariance on log transformed values.

RESULTS
Compared with control period, mean CTDIvol by protocol in the follow up period was reduced by 13% for all head exams and by 22% for all body exams. The difference in mean CTDIvol between the control and follow up period within all protocols was significant. Model R-squared values for analysis of covariance (ANCOVA) ranged from .03 to .68 and demonstrated equipment and gender as significant covariates. Low model R-squared values for the majority of tests indicated changes in protocol parameters and technique were likely contributors to dose reduction. Analysis of the difference in means pre- and post-intervention by equipment found dose reduction was significant for equipment that was not upgraded during the intervention and for equipment that was upgraded.

CONCLUSION
Systematic review of radiation dose by protocol and by patient demographics combined with an iterative process of image review, education, protocol modification and equipment upgrades resulted in a decrease in radiation exposure to a patient population

CLINICAL RELEVANCE/APPLICATION
Tracking radiation dose by protocol and patient demographics provides information for ongoing, targeted quality improvement and quality control

Calculation of Individualized Organ Dose for CT Patients in National Lung Screening Trial

Choonsik Lee PhD (Presenter): Nothing to Disclose, Randell L. Kruger PhD: Nothing to Disclose, Philip F. Judy PhD: Nothing to Disclose, Wesley E. Bolch PhD: Nothing to Disclose, Dianna D. Cody PhD: In-kind support, General Electric Company, Michael James Flynn PhD: Nothing to Disclose

PURPOSE
We calculated doses to major organs associated with CT screening examinations for 23,773 CT scans, a subset of the total cohort of the National Lung Screening Trial (NLST), using a library of computational human phantoms coupled with Monte Carlo radiation transport technique.

METHOD AND MATERIALS
First, we collected scan parameters (patient ID, age, gender, height, weight, scanner manufacturer, model, scan length, kVp, and mAs) from 23,773 CT scans. Second, organ dose conversion coefficients (organ dose normalized to CTDIvol of a reference CT scanner) was calculated using Monte Carlo code, MCNPX2.7, where experimentally-validated CT scanner simulation was coupled with 193 adult hybrid computational phantoms representing the height and weight of the current U.S. population. Finally, dose to selected organs (lung, heart, and thyroid) were calculated by using the organ dose library and the abstracted scan parameters. The other set of organ doses was also calculated for comparison using organ dose conversion coefficients based on a single adult male phantom with reference body size.

RESULTS
We established a comprehensive organ dose library for 193 adult phantoms: six dimensional dose matrix, $D$ (31 organs, 190 slices max, 7 height bins, 19 weight bins, 2 genders, and 6 x-ray spectra). Patient size-specific organ doses were calculated for 23,773 CT scans using the dose library coupled with abstracted technical parameters. Mean doses to lung, heart, and thyroid were 4.5 (SD=1.6), 4.5 (SD=1.6), and 3.7 (SD=2.0) mGy, respectively, while mean CTDIvol was 3.6 mGy (SD=1.2). Organ doses based on the reference size phantom under- or over-estimated the values of thin and obese patients, respectively, up to 60%.

**CONCLUSION**

We calculated individualized doses to major organs for 23,773 CT scans involved in the NLST by using size-dependent computational phantoms coupled with Monte Carlo calculations. The organ dose conversion coefficients and batch calculation technique developed in this study can be also used for other studies including patient dose monitoring, epidemiological studies of cancer risk, and the analysis of CT dose trend.

**CLINICAL RELEVANCE/APPLICATION**

The results from the study provide the individualized organ dose estimations for NLST patient cohort. The dosimetry method used in this study will be useful for calculation patient size-specific organ dose in other studies without performing intensive Monte Carlo simulation.