Organ localization: Toward prospective patient-specific organ dosimetry in computed tomography

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Purpose: With increased focus on radiation dose from medical imaging, prospective radiation dose estimates are becoming increasingly desired. Using available populations of adult and pediatric patient phantoms, radiation dose calculations can be catalogued and prospectively applied to individual patients that best match certain anatomical characteristics. In doing so, the knowledge of organ size and location is a required element. Here, the authors develop a predictive model of organ locations and volumes based on an analysis of adult and pediatric computed tomography (CT) data.

Methods: Fifty eight adult and 69 pediatric CT datasets were segmented and utilized in the study. The maximum and minimum points of the organs were recorded with respect to the axial distance from the tip of the sacrum. The axial width, midpoint, and volume of each organ were calculated. Linear correlations between these three organ parameters and patient age, BMI, weight, and height were determined.

Results: No statistically significant correlations were found in adult patients between the axial width, midpoint, and volume of the organs versus the patient age or BMI. Slight, positive linear trends were found for organ midpoint versus patient weight (max $r^2 = 0.382$, mean $r^2 = 0.236$). Similar trends were found for organ midpoint versus height (max $r^2 = 0.439$, mean $r^2 = 0.200$) and for organ volume versus height (max $r^2 = 0.410$, mean $r^2 = 0.153$). Gaussian fits performed on probability density functions of the adult organs resulted in r^2 -values ranging from 0.96 to 0.996. The pediatric patients showed much stronger correlations overall. Strong correlations were observed between organ axial midpoint versus age, height, and weight (max $r^2 = 0.842$, mean $r^2 = 0.790$; max $r^2 = 0.949$, mean $r^2 = 0.894$; and max $r^2 = 0.870$, mean $r^2 = 0.847$, respectively). Moderate linear correlations were also observed for organ axial width versus height (max $r^2 = 0.772$, mean $r^2 = 0.562$) and for organ volume versus height (max $r^2 = 0.781$, mean $r^2 = 0.601$).

Conclusions: Adult patients exhibited small variations in organ volume and location with respect to height and weight, but no meaningful correlation existed between these parameters and age or BMI. Once adulthood is reached, organ morphology and positioning seem to remain static. However, clear trends are evident between pediatric organ locations versus age, height, and weight. Such information can be incorporated into a matching methodology that may provide the highest probability of representing the anatomy of a patient undergoing a clinical exam to prospectively estimate the radiation dose. © 2014 American Association of Physicists in Medicine. [<http://dx.doi.org/10.1118/1.4901554>]

Key words: CT, organ localization, dosimetry

1. INTRODUCTION

Between 1993 and 2006, the number of computed tomography (CT) examinations performed has increased roughly 10% per yr. The annual radiation dose per person in the United States has subsequently increased over this period as well; 24% of the annual radiation dose per person is attributed to CT.¹ Dose measurement and risk assessment have become vitally important issues to be addressed by the diagnostic imaging community.

CT dosimetry has typically been performed with cylindrical water-equivalent phantoms: one “head” phantom of diameter 16 cm and one “body” phantom of diameter 32 cm, with measurements made along the central axis and along the phantom periphery, to calculate the volume computed tomography dose index (CTDI_{vol}) and dose-length product (DLP). However, CTDI_{vol} and DLP are not dependent on patient size but only on scanner output, and as such cannot be applied to a population of adult and pediatric anatomies. This is especially important in pediatric exams; for smaller pediatric patients,

FIG. 1. Age distributions for adult and pediatric cohorts.

if the $CTDI_{vol}$ and DLP used the “body” phantom for reference, interpreting the $CTDI_{vol}$ or DLP as patient dose can lead to underestimating the patient dose levels by a factor of 2–3. To this end, a new methodology of size specific dose estimation (SSDE) establishes size-dependent coefficients to correct the $CTDI_{vol}$ and DLP for patient size.² Studies have compared the variation of CTDI as measured in anthropomorphic phantoms with the conventional CTDI cylindrical phantom³ or the change in CTDI in cylindrical phantoms of varying diameter.⁴

While SSDE has offered a significant improvement compared to CTDI, it does not deliver the essence of radiation burden to the patient, the organ dose.⁵ Organ dose has been challenging to quantify, particularly due to the emergence of x-ray tube current modulation (TCM) or automatic exposure control (AEC). With the TCM causing the x-ray flux to have nonuniform characteristics, the size and location of the patient’s organs, the body contour, and volumetric tissue distribution are all needed to allow for precise organ dose calculations. This can be done retrospectively, but due to the time required, it is highly impractical.

This study aimed to take a first step toward patient matching and prospective dosimetry, explicitly focusing on the size and location of radiosensitive organs in the torso over a wide spectrum of patient ages and anatomies. A database of organ coordinates and volumes, combined with additional characterization of body contour, enables the dose calculations and risk assessments prior to the CT scan; thus a patient can be given a prospective dosimetry assessment for each organ. The study utilized CT data from anatomically variable patients (adult and pediatric) from our institution. Each set of CT data was segmented and analyzed with respect to organ locations, patient age, BMI, height, and weight. The extracted relationships were used to develop a predictive model for organ location in a given patient that may be incorporated with dosimetry techniques to determine patient-specific organ and effective doses.

2. METHODS

Under IRB approval and in compliance with the Health Insurance Portability and Accountability Act (HIPAA), CT datasets were obtained from the Duke University medical system database. The cohort used in this study included 58 adult (35 male and 23 female) and 69 pediatric (30 male and 39 female) patients. The adult patients ranged in age from 18 to 78 yr with a mean age of 51.5 yr. The pediatric patients ranged from 2 to 17 yr with a mean age of

TABLE I. Linear fit data for adult organ axial midpoint versus patient age, BMI, height, and weight. Slopes are given in mm’s.

Organ	Axial midpoint							
	Age		BMI		Height		Weight	
	Slope	r^2	Slope	r^2	Slope	r^2	Slope	r^2
R lung	−0.065	0.001	0.542	0.009	2.1312	0.4391	0.8276	0.208
L lung	0.0258	0.0002	0.7775	0.0184	2.0221	0.3923	0.864	0.2245
Liver	0.0549	0.0005	2.2803	0.1318	1.38	0.1519	1.1184	0.2867
Stomach	0.1922	0.0053	2.486	0.1202	1.8398	0.2071	1.3294	0.3307
Spleen	0.282	0.0187	2.0746	0.1363	1.1638	0.135	0.9831	0.2961
Gallbladder	0.8248	0.0216	2.4699	0.0259	−0.1482	0.0003	0.7439	0.0229
R kidney	−0.2338	0.0189	0.9211	0.0391	1.0767	0.1682	0.6108	0.1683
L kidney	−0.069	0.0018	0.5733	0.0174	0.6942	0.0803	0.3556	0.0637
Pancreas	0.047	0.0004	2.4687	0.16	1.3651	0.1511	1.2794	0.3722
Heart	0.0142	4.00×10^{-5}	2.2053	0.1334	1.775	0.272	1.2059	0.3823
Max		0.0216		0.16		0.4391		0.3823
Min		4.0×10^{-5}		0.009		0.0003		0.0229
Mean		0.006844		0.07915		0.19973		0.23554

FIG. 2. Axial midpoint versus height (left column) and weight (right column) for right lung, left lung, and heart. Linear fits are shown as dotted lines.

10.4 yr. The uniform age distribution of the CT datasets is shown in Fig. 1. All CT examinations were reviewed by an experienced radiologist to ensure they were representative of normal anatomy, i.e., contained no pathologies that would affect organ size, location, or morphology. The anatomical structures were segmented from the datasets using a graphical application developed in our laboratory. The structures segmented included the individual bones, the lungs, heart, liver, spleen, stomach, kidneys, gallbladder, pancreas (adult

only), and thyroid. Each structure was converted into a 3D polygon surface using the marching cubes algorithm from the Visualization Toolkit (VTK), www.vtk.org.

Each organ was localized by projecting its surface onto the sagittal (X), coronal (Y), and axial (Z) planes; a rectangular volume was formed to enclose the organ. The coordinate system was defined with 0.1 mm precision with the tip of the sacrum designated as the origin. The minimum and maximum values of the extents on all axes were recorded for each organ, and the x , y , and z widths were calculated. The midpoints were defined as the average of the maximum and minimum points. Organ volumes were also measured for both cohorts. The volumes were calculated directly from the polygon surfaces.

For the adults, one-dimensional rect functions were constructed from the minimum and maximum axial (Z) points for each organ, which effectively combine the organ width and location into a single metric. Each rect function was defined as follows:

$$\text{rect}_{\text{organ}}(z) = \begin{cases} 0 & \text{if } z < z_{\min} \text{ or } z > z_{\max} \\ 1/2 & \text{if } z = z_{\min} \text{ or } z = z_{\max} \\ 1 & \text{if } z_{\min} < z < z_{\max} \end{cases}. \quad (1)$$

A probability density function (PDF) was created by normalizing the sum of overlapping rect functions and was fitted with a normalized Gaussian curve given by the following equation:

$$f(x) = \exp \left[-\frac{(x - \mu)^2}{2\sigma^2} \right], \quad (2)$$

where μ is the mean and σ is the standard deviation. The coefficient of determination, r^2 , was calculated for each fit.

For both the adult and pediatric cohorts, organ axial midpoint, axial width, and organ volume were each plotted versus patient age, BMI, height, and weight. Linear fits were established for each dataset, and the goodness of the fits were measured by the r^2 values.

TABLE II. Linear fit data for adult organ axial width versus patient age, BMI, height, and weight. Slopes are given in mm's.

Organ	Axial width							
	Age		BMI		Height		Weight	
	Slope	r^2	Slope	r^2	Slope	r^2	Slope	r^2
R lung	0.1745	0.0064	-2.4524	0.1762	1.8411	0.3125	-0.173	0.0082
L lung	-0.0383	0.0004	-2.7394	0.2611	1.901	0.3958	-0.2383	0.0184
Liver	-0.165	0.0133	0.7158	0.0353	0.3822	0.0317	0.3038	0.0587
Stomach	-0.6808	0.0979	-1.6811	0.0858	-0.496	0.0235	-0.6981	0.1341
Spleen	-0.5733	0.1385	0.2125	0.0026	0.8176	0.12	0.3122	0.0535
Gallbladder	-0.3207	0.1568	-0.0911	0.0016	0.2417	0.0371	0.043	0.0034
R kidney	-0.1338	0.0267	0.4872	0.0486	0.2995	0.0578	0.2195	0.0934
L kidney	-0.0336	0.0021	0.0184	8.00×10^{-5}	0.2692	0.0548	0.0736	0.0129
Pancreas	-0.0934	0.003	0.3541	0.0059	0.1357	0.0027	0.1324	0.0076
Heart	-0.0365	0.0032	-0.4472	0.0675	0.323	0.1109	-0.0112	0.0004
Max		0.1568		0.2611		0.3958		0.1341
Min		0.0004		0.00008		0.0027		0.0004
Mean		0.04483		0.068468		0.11468		0.03906

FIG. 3. Right and left lung axial widths versus patient height display strong linear trends for the adult cohort.

3. RESULTS

3.A. Adult analysis

The adult patients showed no correlation between organ axial midpoint and patient age or patient BMI. The slopes of the linear fits and r^2 -values are listed in Table I. Weak linear trends were seen between the axial midpoint and patient weight: as patient weight increases and axial midpoint increases (as defined from the sacrum). The heart demonstrated the strongest of these positive linear trends with weight, with $r^2 = 0.382$. The lungs showed the strongest correlation with patient height, with $r^2 = 0.439$ (right) and $r^2 = 0.392$ (left). Plots of the axial midpoint versus height and weight are shown in Fig. 2 for the heart and lungs with the superimposed linear fits.

The axial width of the organs exhibited behavior similar to that of the organ midpoints; no correlations were seen between the midpoints and the patient age or BMI. There was also no relationship observed between the axial width and the patient weight, as shown in Table II. Slight linear correlations were seen for axial width versus patient height for the right lung ($r^2 = 0.313$) and the left lung ($r^2 = 0.396$). Figure 3 plots the axial width versus height for the right and left lung with the linear fits.

The organ volumes were found to share similar trends with the axial widths and midpoints in that there were no meaningful linear correlations between organ volume and patient age or BMI. Table III displays the linear fit parameters for the

TABLE IV. Gaussian fit parameters for organ PDFs. Mean and standard deviation are given in mm's.

Organ probability density functions			
Organ	Mean (μ)	SD (σ)	r^2
R lung	442.1664	93.6612	0.9623
L lung	441.663	93.2645	0.96
Liver	294.1617	67.1118	0.9854
Stomach	304.9158	46.7638	0.9907
Spleen	313.2051	40.0721	0.9951
Gallbladder	262.9172	34.8877	0.9695
R kidney	247.3155	40.9452	0.9932
L kidney	255.119	40.8493	0.9869
Pancreas	275.4646	35.7119	0.9804
Heart	407.1313	47.9158	0.9962

organ volumes versus patient height and weight. There was a slight positive correlation between the liver volume and patient weight ($r^2 = 0.309$). There was also a slight correlation between the lung volumes and patient height, with $r^2 = 0.410$ and 0.370 for the right and left lungs, respectively.

The fits between the PDFs and the Gaussian functions were strong: r^2 -values ranged from 0.96 to 0.996, with the mean $r^2 = 0.982$. The r^2 -values, as well as the values for the mean μ and standard deviation σ are given in Table IV. The r^2 -values signify a very high correlation between the fits and the measured distributions. This validates the use of normal distribution statistics to determine a 95% confidence interval within 2σ of the mean. Figures 4 and 5 show the probability density functions and the Gaussian fits for the organs listed in Table IV.

3.B. Pediatric analysis

Contrary to adult patients with virtually static organs, pediatric organs develop rapidly from infancy into adolescence. The results demonstrated that expectation. The axial midpoints showed high correlations to the linear fit for age, height, and weight, as shown in Table V. The mean r^2 values were 0.790,

TABLE III. Linear fit data for adult organ volumes versus patient age, BMI, height, and weight. Slopes are given in mm's.

Organ	Organ volume							
	Age		BMI		Height		Weight	
	Slope	r^2	Slope	r^2	Slope	r^2	Slope	r^2
R lung	6.3051	0.0176	-32.965	0.0655	46.497	0.41	4.344	0.0114
L lung	0.1387	8.00×10^{-6}	-34.874	0.073	44.213	0.3695	2.6952	0.0042
Liver	-0.4979	0.0003	31.433	0.1463	17.89	0.1492	14.248	0.3087
Stomach	-4.0777	0.1434	-3.7133	0.0203	1.6342	0.0124	-0.7203	0.0058
Spleen	-2.5961	0.0965	1.7593	0.0058	5.9677	0.2118	2.4687	0.1137
Gallbladder	-0.1309	0.0133	0.3191	0.01	0.5109	0.083	0.2643	0.0663
R kidney	-0.0861	0.0008	2.039	0.058	1.5531	0.1058	0.9795	0.1284
L kidney	0.0233	5.00×10^{-5}	2.3009	0.0683	1.2314	0.0616	0.9588	0.1141
Pancreas	0.0032	1.00×10^{-6}	0.3397	0.0334	0.4176	0.01	0.4824	0.0404
Heart	2.1668	0.0361	4.7098	0.0225	6.0583	0.1174	3.4247	0.1174
Max		0.1434		0.1463		0.41		0.3087
Min		0.000001		0.0058		0.01		0.0042
Mean		0.030806		0.05031		0.15307		0.09104

FIG. 4. Probability density functions and associated Gaussian fits for right and left lungs, liver, stomach, spleen, and gallbladder.

0.894, and 0.847 for the organ midpoints versus age, height, and weight, respectively. Figure 6 shows the plots of the axial midpoint versus the three parameters as well as the linear fit for the left lung and spleen, which overall had the highest r^2 -values. There was also a slight positive correlation between the organ midpoints and the patient BMI (mean $r^2 = 0.4$).

The r^2 -values for the organ axial widths versus age, BMI, height, and weight only showed weak to moderate correlations for all fits. The strongest correlations were seen for the axial width versus height, as shown in Table VI. The best fits were found for the lungs, liver, kidneys, and heart. The stomach and gallbladder were found to have no notable correlations with any of the fits. Figure 7 shows the plots and fits for the right lung and the gallbladder.

In comparing the same variables for the organ volumes, weak correlations were seen for the volumes versus BMI; moderate correlations were seen for the age, height, and weight, with the patient weight displaying a slightly higher correlation. These

FIG. 5. Probability density functions and associated Gaussian fits for right and left kidneys, pancreas, and heart.

fits are shown in Table VII. The highest correlations were seen for the volumes of the liver and kidneys versus weight.

4. DISCUSSION

We utilized a set of segmented patient CT exams to characterize organ volumes and locations in relation to patient age and size. For the adult population studied, axial midpoints, widths, and volumes were found to have no significant correlation with patient age or BMI. There was a weak, positive linear relationship between these parameters and patient weight and height. The lung parameters most highly correlated with height, while the heart midpoint and liver volume correlated best with patient weight.

Probability density functions were generated for the axial location of each organ, and Gaussian functions were fit, as shown in Figs. 4 and 5, with r^2 -values shown in Table IV. All PDFs showed a high agreement with the Gaussian fits; the lowest r^2 -values were for the right and left lungs, with $r^2 = 0.9623$ and 0.96 , respectively. The other structures showed higher r^2 -values, ranging from 0.9695 for the gallbladder to 0.9962 for the heart.

TABLE V. Linear fit data for pediatric axial midpoint versus age, BMI, height, and weight. Slopes are given in mm's.

Organ	Axial midpoint							
	Age		BMI		Height		Weight	
	Slope	r^2	Slope	r^2	Slope	r^2	Slope	r^2
R lung	15.511	0.8276	10.608	0.3323	2.8394	0.948	3.5403	0.8339
L lung	15.74	0.8418	10.626	0.3295	2.8589	0.9494	3.558	0.8321
Liver	11.314	0.7612	9.4689	0.4578	2.0595	0.8622	2.7456	0.867
Stomach	11.753	0.7433	9.8101	0.4447	2.1507	0.8508	2.8786	0.8625
Spleen	11.948	0.8093	9.3659	0.4271	2.1528	0.8982	2.8171	0.8703
Gallbladder	11.132	0.7284	9.4992	0.4554	2.0345	0.8316	2.7256	0.8445
R kidney	9.6663	0.8008	7.4351	0.4068	1.7428	0.8898	2.2632	0.8491
L kidney	9.7222	0.7909	7.1831	0.3707	1.7684	0.8945	2.2482	0.8181
Heart	14.428	0.8108	10.635	0.3782	2.632	0.9222	3.359	0.8499
Max		0.8418		0.4578		0.9494		0.8703
Min		0.7284		0.3295		0.8316		0.8181
Mean		0.790456		0.400278		0.894078		0.847489

FIG. 6. Axial midpoint versus age (top), height (middle), and weight (bottom) for the left lung and spleen in the pediatric patients.

The normal distribution statistics associated with the Gaussian functions give us a powerful tool for predicting organ location. With a larger number of patients in the cohort, we expect the PDFs to become smoother and to get a higher degree of agreement between the PDFs and their Gaussian fits. This same method can be applied to the sagittal and coronal organ positions and widths.

With the mean volumes calculated and displayed in Table III, an organ characterized by average volume and typical morphology can be placed within the 95% confidence interval for dose calculations. However, it is important to note that in dose calculations, there are more factors than organ volume and location with respect to bony anatomy. For example, the exact geometry of the body habitus and the

FIG. 7. Pediatric axial width versus height for the right lung (best fit) and gallbladder (worst fit).

broader distribution of adipose tissue and skeletal muscle significantly affects organ dose. Such factors should be incorporated if prospective dosimetry should become a reality. In this work, our focus was primarily on organ location, as an essential first step toward that goal.

There are significant variations in organ midpoint, width, and volume within the pediatric population as the organs develop to maturity with age. Because of this dynamic nature of the organs, pediatrics should not be treated as a single cohort with probability density functions as was done with the adult models. Strong correlations were seen for the axial midpoint versus age, height, and weight. The organ axial width showed the weakest correlations overall—only moderate correlations were seen with the patient height. The lungs, liver, heart, and kidneys showed the best agreement; the stomach and spleen showed the worst, as shown in Table VI. This can be accounted for by the large variations in size of the stomach and gallbladder with eating and digestion.

Moderate correlations were seen for organ volumes versus age, height, and weight, with the strongest correlations being seen for weight, as shown in Table VII. The best correlations were seen for the liver, kidneys, and heart, and again, the worst correlations were seen for the stomach and gallbladder. This can again be attributed to the varying size of the stomach and gallbladder with eating and digestion.

The study was limited to a total of 127 patients (adults and pediatrics). In order to more fully characterize organ locations and volumes and examine correlations with patient height and weight, a larger number of individuals needs to be studied. With a large population, height and weight may be more easily

TABLE VI. Linear fit data for pediatric organ axial width versus age, BMI, height, and weight. Slopes are given in mm's.

Organ	Axial width							
	Age		BMI		Height		Weight	
	Slope	r^2	Slope	r^2	Slope	r^2	Slope	r^2
R lung	6.7538	0.7208	2.4466	0.0812	1.1867	0.7607	1.281	0.5015
L lung	6.5068	0.6819	2.2541	0.0703	1.1756	0.7609	1.2633	0.4972
Liver	4.466	0.61	2.8637	0.2154	0.8351	0.729	1.0239	0.6201
Stomach	2.0214	0.1729	0.2655	0.0026	0.3585	0.1858	0.3108	0.079
Spleen	2.3672	0.4134	1.6789	0.1785	0.4628	0.5401	0.5702	0.464
Gallbladder	-0.1727	0.0031	-0.0237	5.0×10^{-5}	0.0095	0.0003	-0.0128	0.0003
R kidney	2.5643	0.6193	38.918	0.2752	64.284	0.7718	23.462	0.7313
L kidney	2.3822	0.4551	1.6156	0.1797	0.483	0.6394	0.5809	0.5235
Heart	2.5149	0.5526	1.5062	0.1702	0.4724	0.6665	0.5644	0.5384
Max		0.7208		0.2752		0.7718		0.7313
Min		0.0031		0.00005		0.0003		0.0003
Mean		0.4699		0.13035		0.561611		0.439478

TABLE VII. Linear fit data for pediatric organ volumes versus age, BMI, height, and weight. Slopes are given in mm's.

Organ	Organ volume							
	Age		BMI		Height		Weight	
	Slope	r^2	Slope	r^2	Slope	r^2	Slope	r^2
R lung	75.203	0.6953	32.512	0.1116	13.398	0.7544	15.191	0.5487
L lung	64.933	0.6489	25.313	0.0847	11.377	0.6809	12.688	0.4792
Liver	70.91	0.6524	66.083	0.4865	12.911	0.7393	18.385	0.8482
Stomach	8.713	0.1814	8.6594	0.1538	1.6997	0.2359	2.3458	0.2543
Spleen	14.787	0.5563	11.321	0.28	2.7087	0.638	3.5657	0.6256
Gallbladder	0.668	0.1315	0.8924	0.2015	0.1281	0.1652	0.2014	0.2313
R kidney	8.0878	0.651	7.3764	0.465	1.5152	0.781	2.1074	0.8549
L kidney	9.0679	0.6247	8.3514	0.455	1.7153	0.7641	2.4003	0.8466
Heart	27.428	0.5328	26.072	0.4134	5.1668	0.6463	7.3849	0.7471
Max		0.6953		0.4865		0.781		0.8549
Min		0.1315		0.0847		0.1652		0.2313
Mean		0.519367		0.294611		0.600567		0.603989

separated out to see their individual contributions to organ location. Due to our limited numbers, we also did not perform separate analyses based on sex and race. As we segment more datasets, we will be able to perform such studies in future work. We will also investigate external anatomical distances as possible predictors of internal organ position. A previous study⁶ has shown that trunk height (distance from the left superior clavicle to the left inferior pubic ramus) coupled with a measurement of midchest circumference or thickness provides a reasonable predictor of patient anatomy.

In order to estimate organ dose, two major pieces of information are needed, the knowledge of patient/organ geometry and the knowledge of the irradiation condition. The former can be further differentiated into the knowledge of organ location and body contour. The latter is also of prime relevance, particularly in CT scans that deploy TCM. This project was concerned with organ location characterization alone, and thus should be considered a first step toward patient specific organ dosimetry. Once the knowledge of patient geometry (organ location and body contour) are properly accounted for, these information should be combined with the knowledge of the TCM profile to assess the local irradiation condition of the organ to enable organ dose estimation.⁹ The body contour, TCM, and the integration of these components are beyond the scope of the current investigation. They will be addressed in subsequent studies.

5. CONCLUSION

We have conducted a first-order analysis of organ size and location with respect to the axial direction, using segmented patient CT. Further analyses should be performed to incorporate sagittal and coronal axes, which will yield a more complete localization of patient organs. This information can be applied to CT organ dosimetry; combined with knowledge of the scan protocol including automatic exposure control, prospective organ dosimetry is achievable. Monte Carlo models of CT examinations have been successfully developed and validated and have been applied for organ dose estimation.^{7,8} We ultimately

plan to create a library of phantoms based on the segmented data used in this study. We plan to use these phantoms to conduct irradiation simulations to calculate organ doses and supraorgan risk constructs for different populations. As most prior Monte Carlo dose methods have been based on a fixed tube current, that expansion needs to further accommodate tube-current modulation. There have been a number of advances in that direction, incorporating the knowledge of organ location and the TCM profile toward organ dosimetry.⁹ However, the knowledge of the organ location is still a major factor in that process.

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