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Retrospective analysis of 1118 outpatient chest CT scans to determine factors associated with excess scan length

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Abstract

Rationale objectives: Excess z-axis scanning continues as an unnecessary source of radiation. This study seeks to determine patient, technologist and CT factors that affect excess scan length for chest CT.

Materials and methods: Retrospective evaluation of 1118 consecutive noncontrast chest CT scans, over twelve consecutive months, was performed for evaluation of scan length above and below the lung parenchyma. Scan length >2 cm was considered excessive. Bivariate analysis for mean excess scan length and presence of excess scan length analyzed technologist's exam volume during the study period, patient age, patient gender, day of week, and time of day as categorical variables. Technologists performing >100 chest CT scans during the study period were considered high-volume while all others were considered low-volume.

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Data

The author(s) declare(s) that they had full access to all of the data in this study and the author(s) take(s) complete responsibility for the integrity of the data and the accuracy of the data analysis."

IRB statement

This research was performed with IRB approval and waiver of informed consent.

Declaration of competing interest

On behalf of all authors, the corresponding author states that there is no conflict of interest or financial disclosure relevant to this article.

Results: Mean excess scan length was 5 mm, 29 mm, and 33 mm above the lungs, below the lungs, and total. 81% and 95% of studies had excess scanning above the lungs and below the lungs respectively. Multivariable analysis showed that high volume technologists, male patients, and patients younger than 65 had a greater amount of excess scan length and presence of excessive scanning above the lungs; high volume technologists and male patients had a greater amount of excess scan length below the lungs, and high volume technologists and patients older than 65 had greater presence of excessive scanning below the lungs, each $p < 0.001$.

Conclusions: Excess scanning on chest CT is common, varies by patient age and gender and was significantly greater for high volume technologists.

Keywords

Chest CT; Radiation dose; Excess scanning; Technologist

1. Introduction

Medical radiation exposure has greatly increased over the past several years, much of it due to the increased frequency of CT imaging [1]. Given the biological risks associated with radiation from diagnostic imaging [2–5], it is important to keep the radiation exposure as low as reasonably achievable [6–8]. This can be achieved by decreasing the number of examinations utilizing ionizing radiation and by minimizing the radiation dose for those examinations. CT dose reduction strategies have been widely implemented and include optimizing CT technical scan parameters, limiting scanning outside of the limits of the requested scan, and utilizing new dose reduction technological advances such as automatic exposure control and advanced reconstruction algorithms [9–13].

Despite this, scanning beyond the limits of the requested scan continues to be an unnecessary source of radiation. One study demonstrated that up to 98% of chest CT scans exceed the predefined anatomic boundaries of their scan protocols [14]. These extra images do not necessarily add additional diagnostic information and are associated with excess organ specific dosage to the thyroid and liver [14,15]. Liao et al. explored contributory factors to extraneous scan length for CT of several body parts and found excess scan length to vary significantly by patient gender, scan location (emergency department, inpatient, versus outpatient), and exam time but did not account for patient age or technologists factors [16]. The purpose of this study is to document prevalence and extent of excess scanning specifically for outpatient chest CT and to evaluate the influence of patient, technologist, and CT scan factors on excess scanning. This information will help identify factors that can be targeted for personalized radiation dose reduction interventions.

2. Materials and methods

2.1. Study design

This was a retrospective cohort study that evaluated consecutive noncontrast chest CTs over one year at a single outpatient imaging center of an academic radiology practice to determine *Z*-axis scan length outside of the anatomic area of interest. CT scans which required scanning from the lung apex to the lung bases were included. CT scans with concomitant neck or abdominal CT scans, CT performed for lung cancer screening, and CT scans without frontal and lateral topograms were excluded. Study was performed with the approval of the institutional review board with waiver of informed patient consent.

2.2. Data collection

Eligible patients were identified by searching the radiology information system for patients. Patient, CT scan, and technologists variables were collected from the RIS. Categorical variables include technologist performing study, and day of the week (Monday, Tuesday, Wednesday, Thursday, or Friday). Binomial variables include technologist volume (high versus low volume), age (greater than or equal to 65, or <65), gender, and time of day (AM before noon, PM after noon). For the purposes of this study, technologists performing >100 chest CT scans during the one year of the study were considered high-volume while all other technologists were considered low-volume.

The *Z*-axis scan length above and below the lungs for each CT scan was determined by the number of CT slices superior and inferior to the lung parenchyma multiplied by the slice thickness. Evaluation was performed on 2.5 mm-thick axial CT slices. Excess scan length was defined as any imaging performed >20 mm above or below the lungs as has been previously suggested to account for differences in patients' respiration [15,17,18]. Excess scan length above the lungs (scan length above the lungs minus 20 mm), excess scan length below the lungs (scan length below the lungs minus 20 mm), and total excess scan length (scan length above and below the lungs minus 40 mm) was determined per patient and means were calculated above the lungs, below the lungs, and total. For example if four hypothetical scans below the lungs had scan length 40 mm, 30 mm, 20 mm, and 10 mm the excess scan length below the lungs per study is 20 mm, 10 mm, 0 mm, and −10 mm. The hypothetical mean scan length below the lungs is 25 mm (40 mm + 30 mm + 20 mm + 10 mm)/4 and the hypothetical mean excess scan length is 5 mm (20 mm + 10 mm + 0 mm + −10 mm)/4.

The presence of excessive scanning is defined by the percentage of studies with scan length above and below the lungs >20 mm (>0 mm excess scan length), >30 mm (>10 mm excess scan length), and >40 mm (>20 mm excess scan length), was also determined.

2.3. CT technique

All CT examinations were performed on 64-detector row CT scanners (Siemens Somatom [Erlangen, Germany], General Electric VCT and HD750 [Waukesha, WI]). Immediately prior to the localizer and CT acquisition, each patient was coached by the technologist and given the instruction, "Breathe in and hold your breath." For each CT, the technologist was instructed to scan the entire chest during inspiration. The pre-established top anatomic boundary was the upper margin of the first ribs. The pre-established anatomic bottom boundary is the estimated location of the adrenal glands below the costophrenic angle. We did not exclude patients who underwent high resolution CT scans. However, only the inspiratory CT scan was analyzed. The expiratory phase CT data was not analyzed because patients received different breathing instructions, as expected, during the expiratory phase.

2.4. Data analysis

Mean excess scan length was compared across categorical variables with ANOVA and across binomial variables with 2-way unpaired *t*-test. Percent of studies exceeding various excess scan length thresholds was performed with chi-square for binomial and categorical variables. Multivariable linear regression for mean excess scan length above and below the lungs and multivariable logistic regression for presence of excessive scanning (20 mm scan length/0 mm excess scan length), above or below the lungs was performed for all categorical and binomial variables. In all regression models technologist and technologist volume were found to be co-linear and the models were performed with technologist volume but not individual technologist. All analyses were conducted using the programming language R [19]. p-Values <0.05 were considered significant.

3. Results

A total of 1118 total CT scans were analyzed. The median age was 63 years (range 19 to 98 years), 56% of patients were older than 64, and 53% of patients were male. Six technologists were considered high volume and performed between 129 and 174 exams during the study period. Six technologists were considered low volume and performed between 12 and 96 exams during the study period. High volume technologists scanned 66% of CT scans and low volume technologists scanned 34% of CT scans. Most scans were performed on Friday (24%), the least scans performed on Monday (19%) and 56% of scans were performed in the morning (Table 1).

3.1. Mean excess scan length

Mean scan length was 25 mm above the lungs (5 mm excess scan length) and 49 mm below the lungs (29 mm excess scan length), thus totaling 73 mm outside of the lungs (33 mm excess scan length). There were significant differences by technologists for excess scan length above the lungs, below the lungs, and total, each $p < 0.001$.

Scans performed on younger patients had 43% greater mean excess scan length above the lungs compared to scans performed on older patients (5.4 versus 3.7 mm, $p < 0.005$) but no significant differences below the lungs (28.8 versus 28.1 mm, $p = 0.58$) or total (34.1 versus 31.9 mm, $p = 0.08$). Scans performed by high volume technologists had 54% (5.3 versus 3.4 mm), 19% (30.2 versus 25.4 mm), and 22% (35.4 versus 28.8 mm) greater mean excess scan length above the lungs, below the lungs, and total compared to scans performed by low volume technologists (each $p < 0.001$). Scans performed on male patients had 80% (5.8 versus 3.2 mm), 26% (31.5 versus 25.1 mm), and 32% (37.4 versus 28.3 mm mm) greater mean excess scan length above the lungs, below the lungs, and total compared to scans performed on female patients (each $p < 0.001$). No significant differences in mean scan length by day of week or time of day (Table 2).

Multivariable regression showed scans performed by high volume technologists, scans performed on males and patients younger than 65 had greater excess scan length above the lungs and scans performed by high volume technologists and scans performed on males had a greater excess scan length below the lungs (Table 3).

3.2. Presence of excessive scanning

There were 81%, 35%, and 5% of studies that had >20 mm (>0 mm excess), >30 mm (>10 mm excess), and >40 mm (>20 mm excess) scan length above the lungs respectively. 95%, 85%, and 70% of studies had >20 mm (>0 mm excess), >10 mm (>30 mm excess), and >20 mm (>40 mm excess) scan length below the lungs respectively. There were significant differences in percent of studies exceeding all cutoffs of excessive scanning above and below the lungs by technologist, each $p < 0.001$. Presence of excessive scanning above the lungs ranged by technologist from 30 to 100%, 4–69%, and 0–25% for cutoffs of 0 mm, 10 mm, and 20 mm respectively. Presence of excessive scanning below the lungs ranged by technologist from 88 to 100%, 31–100%, and 6–81% for cutoffs of 0 mm, 10 mm, and 20 mm respectively (Table 2).

Scans performed on younger patients had significantly greater presence of excessive scanning above the lungs than older patients (85% versus 76%, $p < 0.001$). Scans performed on male patients had significantly greater presence of excessive scanning exceeding 0 mm, 10 mm, 20 mm above the lungs as well as 10 mm and 20 mm below the lungs, each $p < 0.001$. Scans performed by high volume technologists had significantly greater presence of excessive scanning exceeding 0 mm and 10 mm above the lungs as well as 0 mm, 10 mm and 20 mm below the lungs, each $p < 0.01$. There were significant differences in presence of excessive scanning length above the lungs >10 mm by day of week with 41% on Friday and 26% on Monday ($p < 0.05$). Otherwise there were no significant differences in presence of excessive scanning by day of week or time of day (Table 2).

Multivariable logistic regression showed high volume technologists, patients younger than 65 and males had greater presence of excessive scanning exceeding 0 mm above the lungs, each $p < 0.005$. Multivariable logistic regression showed high volume technologists and patients older than 64 had greater presence of excessive scanning exceeding 0 mm below the lungs, each $p < 0.05$ (Table 3).

4. Discussion

It is well documented that medical radiation exposure continues to increase and its theoretical biological effects are well established [1–5]. The medical community has recognized the need to keep the radiation dose as low as reasonably achievable (ALARA) [6–8]. There has been sufficient concern within the radiology community and dose reduction techniques have been developed [9–13]. While many of these strategies have been adopted, this study of over 1100 patients found mean total excess scan length of 33 mm, which was six times greater below the lungs than above the lungs. Further, this study found 95% of studies had presence of excessive scanning above the lungs and 81% had presence of excessive scanning below the lungs. Interestingly, only 35% and 5% had presence of excessive scanning 10 mm and 20 mm above the lungs while 85% and 70% had presence of excessive scanning 10 mm and 20 mm below the lungs. These numbers are based on a conservative estimate of excess scanning, as previously suggested and published, which incorporates a 2 cm margin above and below the lungs to account for differences in patients' respiration [15,17]. Other studies, however, have suggested that limited information comes from images above or below the lungs and excess scanning in the chest should be defined as any imaging above or below the lung parenchyma [14].

The greater excess scan length below the lungs is likely related to greater difficulty properly acquiring the lower lungs secondary to diaphragm movement between the scout image and the actual CT. Future analysis on the full extent of this motion would be helpful to better appropriately scan chest CTs. Technologists may be faced with added pressure to avoid excluding portions of the lungs without any positive feedback for appropriately minimizing excess scan length. Therefore, technologists may scan excessively due to negative reinforcement.

This study found that excess scanning varies considerably between technologists with statistically significant differences between them. In fact, the amount of excess scanning differed by more than threefold from one technologist to another. These findings are consistent with prior studies that have found operator-dependent causes of excess scanning beyond the requested anatomy and predefined scanning protocols [14–16]. Frequent education, monitoring, and feedback are needed to address this problem. To this end, previous studies have shown that personalized technologist feedback programs can reduce excess scan length and patient radiation dose [18,20]. Further, automated z-axis programs have been analyzed for abdominal CT [21,22]. A similar automated program could serve to be very helpful in the chest. Many CT chest studies for lung cancer are prescribed to the level of the adrenal glands. Unfortunately the adrenal glands are generally invisible on scout CT and this is not an objective landmark. This subjective invisible landmark is used by technologists at many institutions, including those at our institution prior to knowing the results of this study. We believe that landmarks should be based only upon visible structures, in order to reduce operator-dependence and inconsistent/unpredictable results.

This study found that high volume technologists have greater amounts of excess scanning than low volume technologists for all metrics of excess scanning. Technologist volume and degree of excess scanning has not been previously evaluated. It seems counterintuitive that increased technologist experience would result in greater scan excess but the higher burden of work may result in greater false-confidence and less efficiency. While we have previously used experienced and high volume technologists to lead technologists' education, we now must direct education to all technologists regardless of volume or experience level. The technologists should be trained to scan a preset amount below the (costophrenic angle) CPA on lateral view, rather than subjectively and traditionally relying on an invisible anatomic structure such as the adrenal gland [23]. In the future, the scan length can be further personalized according to height and body surface area/body mass index, if those parameters are found to be good predictors of CPA position.

Patient age and gender also were important factors in radiation dose. Males received greater radiation dose than females and there was extra scanning below the lungs for older patients and above the lungs for younger patients. The causes of this are unknown and further evaluation is needed to completely understand this. Regardless, variation in excess scanning should not vary by gender, and excess scanning should be lower for younger patients at greater long term risk of radiation induced malignancy.

Dose reduction is particularly important for lung cancer screening and its associated annual repeat scans [24]. In fact, lung cancer screening scans are supposed to be performed from the lung apices to the costophrenic angles [25]. Using hypothetical models, some investigators have suggested that radiation exposure from cumulative years of lung cancer screening may approach or even exceed those of nuclear power plant workers [26,27]. Despite the theoretical risk from radiation exposure, it is important to recognize that the mortality reduction significantly outweighs the risks from lung cancer screening CT [28]. Even though these scans are done at low dose and the benefits outweigh the radiation risks, decreasing excess z-axis scan length would still be beneficial.

A limitation of this study is that data and reference standards are obtained from only one institution with a limited number of technologists. Furthermore, the estimation of technologist volume was based on the number of scans they performed during the time period, rather than their total lifetime. Total lifetime number of scans is difficult to obtain and the number of years of experience does not necessarily equate with total scanning experience. Height, body surface area, and body max index can directly affect scan length. It is possible that a taller person will require not only a longer scan length but also a greater allowance for costophrenic angle position. It is also possible that a morbidly obese person will require a smaller allowance for costophrenic angle position, due to reduced lung volumes. We do not have this data available in a consistent manner in our electronic medical record for the purposes of this retrospective study. Thus, this interesting question will require a separate dedicated study to adequately answer. Further, this study did not track inclusion of the adrenal glands, a subjective scout landmark used by many institutions.

5. Conclusion

This study demonstrates that excess scanning on chest CT is common, varies by patient age and gender and was significantly greater for high volume technologists. These factors should be targeted with personalized radiation dose reduction interventions to reduce unnecessary ionizing radiation to the patient.

References

[1]. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. N Engl J Med 2007;357(22):2277–84. [PubMed: 18046031]

[2]. Brenner DJ, et al. Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. Proc Natl Acad Sci U S A 2003;100(24):13761–6. [PubMed: 14610281]

[3]. Preston DL, et al. Effect of recent changes in atomic bomb survivor dosimetry on cancer mortality risk estimates. Radiat Res 2004;162(4):377–89. [PubMed: 15447045]

[4]. Cardis E, et al. The 15-Country Collaborative Study of Cancer Risk among Radiation Workers in the Nuclear Industry: estimates of radiation-related cancer risks. Radiat Res 2007;167(4):396–416. [PubMed: 17388693]

[5]. Cardis E, et al. Risk of cancer after low doses of ionising radiation: retrospective cohort study in 15 countries. Bmj 2005;331(7508):77. [PubMed: 15987704]

[6]. Bevelacqua JJ. Practical and effective ALARA. Health Phys 2010;98(Suppl. 2):S39–47. [PubMed: 20386191]

[7]. The ALARA (as low as reasonably achievable) concept in pediatric CT intelligent dose reduction. Multidisciplinary conference organized by the Society of Pediatric Radiology. August 18–19, 2001. Pediatr Radiol 2002;32(4):217–313.

[8]. Strauss KJ, Kaste SC. The ALARA (as low as reasonably achievable) concept in pediatric interventional and fluoroscopic imaging: striving to keep radiation doses as low as possible during fluoroscopy of pediatric patients—a white paper executive summary. Pediatr Radiol 2006;36(Suppl. 2):110–2. [PubMed: 16862422]

[9]. Kalra MK, et al. Strategies for CT radiation dose optimization. Radiology 2004;230(3):619–28. [PubMed: 14739312]

[10]. Kalra MK, et al. Detection and characterization of lesions on low-radiation-dose abdominal CT images postprocessed with noise reduction filters. Radiology 2004;232(3):791–7. [PubMed: 15333797]

[11]. Takahashi M, et al. Low-dose spiral computed tomography of the thorax: comparison with the standard-dose technique. Invest Radiol 1998;33(2):68–73. [PubMed: 9493720]

[12]. Brenner D, et al. Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am J Roentgenol 2001;176(2):289–96. [PubMed: 11159059]

[13]. McNitt-Gray MF. AAPM/RSNA physics tutorial for residents: topics in CT. Radiation dose in CT. Radiographics 2002;22(6):1541–53. [PubMed: 12432127]

[14]. Campbell J, et al. Scanning beyond anatomic limits of the thorax in chest CT: findings, radiation dose, and automatic tube current modulation. AJR Am J Roentgenol 2005;185(6):1525–30. [PubMed: 16304007]

[15]. Zanca F, et al. Excess radiation and organ dose in chest and abdominal CT due to CT acquisition beyond expected anatomical boundaries. Eur Radiol 2012;22(4):779–88. [PubMed: 22105842]

[16]. Liao EA, et al. Extra Z-axis coverage at CT imaging resulting in excess radiation dose: frequency, degree, and contributory factors. J Comput Assist Tomogr 2011;35(1):50–6. [PubMed: 21245690]

[17]. Schwartz F, et al. Over-scanning in chest CT: comparison of practice among six hospitals and its impact on radiation dose. Eur J Radiol 2018;102:49–54. [PubMed: 29685544]

[18]. Cohen SL, Ward TJ, Jacobi AH, Cham M. Institutional impact of a personalized technologist feedback program on scan length and radiation dose. J Am Coll Radiol 2019;16(8):1073–1076. 10.1016/j.jacr.2019.02.001. Epub 2019 Mar 22. https://www.ncbi.nlm.nih.gov/pubmed/30910576/https://www.ncbi.nlm.nih.gov/pubmed/31410602/. [PubMed: 30910576]

[19]. R Development Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2010.

[20]. Miglioretti DL, et al. Personalized technologist dose audit feedback for reducing patient radiation exposure from CT. J Am Coll Radiol 2014;11(3):300–8. [PubMed: 24589406]

[21]. Brassart N, et al. Optimised z-axis coverage at multidetector-row CT in adults suspected of acute appendicitis. Br J Radiol 2013;86(1028):20130115. [PubMed: 23690436]

[22]. Zhang M, et al. Automated detection of z-axis coverage with abdomen-pelvis computed tomography examinations. J Digit Imaging 2015;28(3):362–7. [PubMed: 25413130]

[23]. Cohen SL, Ward TJ, Cham MD. The relationship between CT scout landmarks and lung boundaries on chest CT: guidelines for minimizing excess z-axis scan length. Eur Radiol 2020;30(1):581–587. 10.1007/s00330-019-06394-3. Epub 2019 Aug 13.. [PubMed: 31410602]

[24]. McCunney RJ, Li J. Radiation risks in lung cancer screening programs: a comparison with nuclear industry workers and atomic bomb survivors. Chest 2014;145(3):618–24.

[25]. Fintelmann FJ, et al. The 10 pillars of lung cancer screening: rationale and logistics of a lung cancer screening program. RadioGraphics 2015;35(7):1893–908. [PubMed: 26495797]

[26]. McCunney RJ, Li J. Radiation risks in lung cancer screening programs. Chest 2014;145(3):618–24.

[27]. Mascalchi M, Sali L. Lung cancer screening with low dose CT and radiation harmfrom prediction models to cancer incidence data. Ann Transl Med 2017;5(17):360. [PubMed: 28936454]

[28]. Rampinelli C, et al. Exposure to low dose computed tomography for lung cancer screening and risk of cancer: secondary analysis of trial data and risk-benefit analysis. Bmj 2017;356:j347. [PubMed: 28179230]

Table 1

Patient and CT characteristics (N = 1118).

Scan characteristics	Median (range)	N (%)
Patient age	63 (19–50)	
<65		493 (44%)
≥ 65		625 (56%)
Patient gender		
Male		596 (53%)
Female		522 (47%)
Technologist volume		
Low volume technologists		6 (50%)
High volume technologists		6 (50%)
CT scans by technologist volume		
Low volume technologists		384 (34%)
High volume technologists		734 (66%)
CT scans by day of week		
Monday		208 (19%)
Tuesday		224 (20%)
Wednesday		231 (21%)
Thursday		192 (17%)
Friday		263 (24%)
CT scans by time of day		
AM		627 (56%)
PM		491 (44%)

Table 2

Bivariate analysis of mean excess scan length and presence of excessive scanning by patient and CT characteristics. Excess scan length defined as scan length above or below lungs minus 20 mm to allow for differences in respiration. Presence of excessive scanning is defined by percent of scans with part of the any scan exceeding scan length cutoffs. For example, 95%, 85%, and 70% of studies had excessive scanning below the lungs defined by percent of studies with a scan length below the lungs >20 mm, 30 mm, and 40 mm respectively.

	Mean excess scan length (mm)			Presence of excessive scanning above the lungs by various cutoffs			Presence of excessive scanning below the lungs by various cutoffs		
Scan characteristics	Above the lungs	Below the lungs	Total	0 mm	10 mm	20 mm	0 mm	10 mm	20 mm
All patients	4.6	28.5	33.1	81%	35%	5%	95%	85%	70%
Patient age									
< 65	5.3	28.8	34.1	85%	37%	5%	94%	84%	70%
≥ 65	3.7	28.1	31.9	76%	32%	4%	96%	86%	70%
p-Value	0.002	0.586	0.084	<0.001	0.138	0.596	0.079	0.561	1.000
Patient gender									
Male	5.8	31.5	37.4	85%	40%	7%	96%	89%	76%
Female	3.2	25.1	28.3	77%	29%	3%	94%	81%	64%
p-Value	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.184	<0.001	<0.001
CT scans by technologist volume									
Low volume technologists	3.4	25.4	28.8	74%	28%	6%	92%	79%	65%
High volume technologists	5.3	30.2	35.4	85%	38%	4%	96%	88%	73%
p-Value	<0.001	<0.001	<0.001	<0.001	<0.001	0.496	<0.001	<0.001	0.003
CT scans by day of week									
Monday	4.1	26.8	30.9	79%	26%	4%	94%	82%	68%
Tuesday	4.5	28.4	32.9	86%	32%	4%	94%	84%	67%
Wednesday	4.5	28.9	33.3	79%	34%	5%	95%	87%	75%
Thursday	5.0	29.8	34.8	81%	39%	5%	95%	86%	72%
Friday	5.2	28.6	33.8	82%	41%	6%	95%	84%	68%
p-Value	0.717	0.634	0.446	0.373	0.011	0.826	0.944	0.457	0.299
CT scans by time of day									
AM	4.8	28.6	33.4	81%	37%	5%	95%	85%	70%

	Mean excess scan length (mm)			Presence of excessive scanning above the lungs by various cutoffs			Presence of excessive scanning below the lungs by various cutoffs		
Scan characteristics	**Above the lungs**	**Below the lungs**	**Total**	**0 mm**	**10 mm**	**20 mm**	**0 mm**	**10 mm**	**20 mm**
PM	4.4	28.4	32.9	82%	32%	4%	95%	85%	71%
p-Value	0.470	0.926	0.712	0.790	0.076	0.431	1.000	0.979	0.863

Table 3

Multivariable analysis of mean excess scan length and presence of excess scan length by patient and CT characteristics. For each variable, a positive estimate coefficient indicates increased scan length compared to its reference. Presence of excessive scanning defined by a study with >20 mm scan length beyond the lungs.

Patient characteristics	Excess scan length above the lungs		Excess scan length below the lungs		Presence of excessive scanning above the lungs		Presence of excessive scanning below the lungs	
	Estimate	p-Value	Estimate	p-Value	Estimate	p-Value	Estimate	p-Value
High volume technologists[a]	1.7276	0.002	4.480116	0.000	0.66581	0.000	0.8664	0.002
Patient age ≥ 65[b]	−1.2253	0.021	0.399131	0.747	−0.53084	0.001	0.6315	0.031
Monday[c]	−1.4515	0.083	−2.777917	0.155	−0.33511	0.182	−0.3677	0.402
Thursday[c]	−0.2613	0.753	0.844278	0.663	−0.10587	0.675	−0.1152	0.800
Tuesday[c]	−0.7429	0.391	−0.491557	0.808	0.27518	0.327	−0.3246	0.466
Wednesday[c]	−0.8978	0.264	−0.182374	0.922	−0.22688	0.349	−0.0901	0.836
Study time: AM[d]	−0.4137	0.430	−0.098958	0.936	0.01303	0.935	−0.0177	0.948
Male patients[e]	2.3144	0.000	6.31355	0.000	0.45705	0.004	0.452	0.103

[a] Reference Group: Low volume technologists.

[b] Reference Group: Patient age < 65.

[c] Reference Group: Friday.

[d] Reference Group: Study time: PM.

[e] Reference Group: Female patients.