Published in final edited form as:

AJR Am J Roentgenol. 2010 June ; 194(6): 1539–1546. doi:10.2214/AJR.09.3268.

Normalized CT Dose Index of the CT Scanners Used in the National Lung Screening Trial

Dianna D. Cody, Hyun-Jung Kim, Christopher H. Cagnon, Frederick J. Larke, Michael M. McNitt-Gray, Randell L. Kruger, Michael J. Flynn, J. Anthony Seibert, Philip F. Judy, and Xizeng Wu

Abstract

The National Lung Screening Trial (NLST) includes 33 participating institutions, which performed 75,133 lung cancer screening CT exams from 26,724 subjects during 2002–2007. For trial quality assurance reasons, CT radiation dose measurement data were collected from all multidetector-row CT scanners used in the NLST. A total of 247 measurements on 96 multi-row detector scanners were collected using a standard CT dose index (CTDI) measurement protocol. The scan parameters employed in the measurements (tube voltage, mAs and detector-channel configuration) were set according to trial-protocol for average size subjects. The normalized CTDI_w (computed as CTDI_w/mAs) obtained from each trial-participating scanner was tabulated.

This study demonstrated a statistically significant difference in normalized CT dose index among CT scanner manufacturers, likely due to design differences such as filtration, bow-tie design and geometry. Our findings also indicated a statistically significant difference in normalized CT dose index among CT scanner models within GE, Siemens, and Philips. We also demonstrated a statistically significant difference in normalized CT dose index among all models and all manufacturers. And, we demonstrated a statistically significant difference in normalized CT dose index from CT scanners among manufacturers when grouped by 4 or 8 data channels vs 16, 32, or 64 channels, suggesting improved dose efficiency in more complex scanners. Average normalized CT dose index values varied by almost a factor of two across all scanners from all manufacturers. This study was focused on machine specific normalized CT dose index; patient dose and image quality were not addressed.

Introduction

Computed Tomography (CT) imaging is currently experiencing a dramatic increase in popularity and utilization (1). This has included the suggested use of CT in screening for early stages of disease such as lung cancer, heart disease, and colon cancer. Several studies have been initiated to investigate the efficacy of CT in the early detection of lung cancer. One such large study is the National Lung Screening Trial (NLST), sponsored by the National Cancer Institute. The NLST is a randomized, controlled study comparing two ways of detecting asymptomatic lung cancer (using projection chest x-rays and multi-detector row CT scans) conducted by two organizations; the American College of Radiology Imaging Network (ACRIN) and the LSS (Lung Screening Study).

The main objective of the NLST is to determine whether lung cancer screening using “low-dose” helical multi-detector row CT reduces lung cancer specific mortality relative to screening with chest radiographs in a high-risk cohort (7). A total of 53,457 volunteer subjects were enrolled in the NLST; entrance criteria included thirty or more pack-years of cigarette smoking (packs per day multiplied by the number of years smoked) and being between 55 and 74 years old at the date of entry to the study. (Former smokers must have quit within the previous 15 years.) Each participant was randomized to either the CT or

chest radiograph arm of the study and agreed to have a baseline imaging exam and two more annual follow-up exams. Thus, about 26,000 subjects underwent as many as three lung cancer screening CT exams as part of this study (total of about 75,000 CT exams).

These lung cancer screening CT exams were offered nationwide at 33 separate institutions (Table 1, Figure 1). Because of the large subject enrollment in this trial, increased surveillance of the equipment was desired. Therefore, as part of the trial quality assurance procedures, CT dose index (CTDI) measurements were performed on the multi-detector row CT scanners used for this imaging trial on a routine basis throughout the trial.

The NLST was designed so that all resulting data obtained by the two collaborative groups could be combined for analysis. While there are some sources of CTDI data for CT scanners that are available (both online and in scanner technical manuals) these reports tend to be widely scattered and often difficult to obtain. In addition, they either are specific to one scanner (such as the manufacturer's specifications or dosimetry report) or contain general data about several scanners. What these reports do not easily provide are all of the expected values for all of the scanners used in this trial and under the specific scanning conditions (specifically kVp, x-ray beam width and bowtie filter) used in the NLST. Therefore, the trial quality assurance activities provided an opportunity to record and compare CTDI performance for a relatively large sample of scanners (over 100 distinct units) representing a range of manufacturers and models, where all measurements were made using specific parameter settings. In addition, collection of this data provided an opportunity to address some questions in a statistical manner relating to scanner CTDI variability by manufacturer, by CT scanner model, and by CT scanner complexity (number of data channels). Therefore, the purpose of this report is two-fold; first, to provide the normalized multi-detector row CTDI measurement results to the medical technical field, and second, to provide multi-detector row CTDI measurement data required for later calculations of participant radiation dose that will be used later to estimate risk of participants for this and perhaps future CT based screening trials.

Materials and Methods

Image quality assurance programs were implemented over time across the NLST and were very similar between ACRIN and LSS sites. For ACRIN sites, initial CT scanner certification that included a CTDI measurement for tomographic image acquisition was required for all scanners that would be used to acquire images on NLST participants. This CT scanner certification process was repeated for each active scanner used in the trial on an annual basis thereafter until participant screening exams were completed. A similar certification process was implemented at LSS sites. Compliance with the annual certification process was variable across sites, but was reinforced with a reminder notification process sent under cover of the NLST Physics Working Group. Ultimately, dose measurements were available for at least one time point on all NLST scanners trial-wide.

Exposure measurements and dose calculations were conducted at each trial site by a diagnostic medical physicist. This required the cooperation of a large number of medical physicists and adherence to the instructions provided by the administrating organization (ACRIN or LSS). The dose data that have resulted are due in large part to the cooperation of many professional medical physicists from across the nation (Figure 1, Table 1).

Radiation exposure measurements and dose calculations for CT followed the standard CT dose index (CTDI) process (8,9). Instructions were provided to each site to facilitate the measurement procedure. Briefly, the 32-cm diameter PMMA CTDI phantom was placed on the CT scanner patient table top and centered in the gantry. A 100 mm long CT pencil

ionization chamber was placed in the central hole, and a single transverse (axial) exposure was performed at the center of that phantom using the NLST protocol parameter settings (for an average size patient). The measurement was performed three times and each resulting exposure value was recorded on a specific form. The ion chamber was then repositioned in the top (12:00 position) chamber position, and the exposure and recording procedure was repeated, again three times. Using the average exposure values, $CTDI_{100c}$ and $CTDI_{100p}$, $CTDI_w$ and $CTDI_{vol}$ values were calculated (8). In addition to the exposure measurements, the physicist at each site collected specific information regarding the MDCT scanner; e.g., scanner manufacturer, scanner model, test date, and the actual technique factors used for the dose measurement.

Sites were instructed to perform the dose measurement at the technique that would be used for an average size NLST participant. The techniques for the ACRIN sites were developed for each scanner model and can be found elsewhere (7). The technique parameters used for the LSS sites were based on a range of values agreed on by both groups (NLST Medical Physics Working Group Meeting, June 2003). For example, the kVp could range from 120 to 140 but 120 was statistically significant difference in normalized CT dose index among all models and all manufacturers. And, we demonstrated a statistically significant difference in normalized CT dose index from CT scanners among manufacturers when grouped by 4 or 8 data channels vs 16, 32, or 64 channels, suggesting improved dose efficiency in more complex scanners. Average normalized CT dose index values varied by almost a factor of two across all scanners from all manufacturers. This study was focused on machine specific normalized CT dose index; this is one of many factors that influence image quality and patient dose. The end result was that all NLST sites used technique parameters within these specifications. It should be noted that only a small number of scanners used in the trial were operated at a kVp other than 120 ($n=10$). Some were operated at 140 kVp as mentioned above, two were operated at 135 kVp, and one was operated at 110 kVp. Because of these small numbers, these scanners were excluded from this analysis.

If the mAs used for the dose measurement was outside of the acceptable range established for the subjects scanned during the trial, the dose results provided were scaled linearly until they reflected the average patient size dose using an acceptable mAs value. (If repeat dose measurements were required, CT physics reviewers contacted the NLST site physicist directly to discuss the relevant issues.)

Prior to data analysis, all individual dose measurements and calculations were reviewed by the entire NLST Medical Physics Working Group in order to identify spurious data points. Outlier data points were excluded from further analysis on a case by case basis based on consensus of the entire group. Exclusions were limited to unreasonable results or acquisition parameter combinations that were impossible for the scanner platform, and typically involved the reporting of detector configuration. In total, 16 of 237 individual dose measurements were excluded from analysis, such that 93% of collected data were statistically analyzed. All dose values for an individual scanner, which ranged from one to five individual values depending on submitted reports, were averaged prior to analysis of the data. The primary endpoint of the measurement and analysis presented here is the machine-specific parameter of normalized weighted CT dose index, or $CTDI_w$ on a per mAs basis for each MDCT model used in the trial. By definition, normalized $CTDI_w$ excludes mAs and pitch, and therefore reflects the characteristics of a particular scanner model independent of user technique preferences.

Four questions were addressed by statistical analysis of the CT dose measurement data. Were there statistically significant differences in normalized dose index by manufacturer? Were there statistically significant differences in normalized dose index by CT scanner

model within a single manufacturer? Were there statistically significant differences in normalized dose index among all models and all manufacturers? Were there statistically significant differences in normalized dose index by increasing level of technology as described by the number of data channels on the scanners? [Scanners were divided into two groups to examine this question; early designs and more advanced designs. The early design group included scanners with 4 or 8 data channels; the more advanced design group included scanners with 16 or more data channels.] Due to extreme outliers, even after log-transforming the CTDIw/mAs values, Huber's robust regressions were applied for all four addressed questions (10). A hierarchical modeling approach (Stata version 9.0 SE [College Station, TX]) was used to address the first three questions (11). The hierarchical structure of a manufacturer and scanner models within a manufacturer was embedded in the statistical hierarchical modeling approach in that the covariates for CT models were nested in the covariates for the corresponding CT manufacturers. The covariates for CT manufacturer were used to address the first question and the covariates for CT models nested in CT manufacturer were used to address the second question in a single analysis. To test the differences in the dose among all models and all manufacturers, multiple comparisons with Bonferroni adjusted p-values were performed where the previous hierarchical modeling demonstrated a significant difference. For the last question to test the difference in the dose by the number of data channels on the scanner, the robust regression was used. More details regarding the statistical modeling can be found in the Appendix.

Results

A total of 221 CT dose measurements obtained on 96 multi-detector row CT scanners were included for analysis. The CT scanner technology present at the trial initiation was limited to scanners with four data channels, but by the end of the study, a wide variety of scanner models and technology had been included (Tables 2 & 3 and Figure 2). Note that these results were compiled prior to any measurement exclusion in order to more completely describe the scanners used during the NLST image collection phase.

The mean CTDIw/mAs values obtained at 120 kVp was 0.096 mGy/mAs. Overall results by scanner manufacturer and model are shown in Table 4. The four questions addressed by the analysis are shown below.

Were there statistically significant differences in normalized dose index by manufacturer?

A statistically significant difference was found among manufacturers for normalized CTDIw. The normalized CTDIw was significantly different for GE vs Philips ($p < 0.001$). The normalized CTDIw was not significantly different for GE vs Siemens ($p = 0.131$). The normalized CTDIw was significantly different for GE vs Toshiba ($p < 0.001$). The normalized CTDIw was significantly different for Philips vs Siemens ($p < 0.0022$). The normalized CTDIw was significantly different for Philips vs Toshiba ($p < 0.0001$). The normalized CTDIw was significantly different for Siemens vs Toshiba ($p < 0.0001$). The normalized CTDIw mean values and standard deviations are plotted in Figure 3.

Were there statistically significant differences in normalized dose index by CT scanner models within a single manufacturer?

There were statistically significant differences in CTDIw/mAs among different scanner models manufactured by GE. The Lightspeed Qxi and Lightspeed 16 were different from the other three models (p value = 0.011). The Lightspeed Ultra was different from Lightspeed 16 or Lightspeed plus (p value = 0.022). There were statistically significant differences in CTDIw/mAs by Siemens models. The Sensation/Volume Zoom 4 was different from Sensation 16 and 64 models (p value = 0.002, p value = 0.023, respectively). There was a

statistically significant difference in CTDIw/mAs between Philips models. The MX8000 [4-channel] was different from MX8000-IDT [16-channel] (p value = 0.001). No significant difference was observed among Toshiba models, probably due to the small number of observations available. (Table 3).

Were there statistically significant differences in normalized dose index among all models and all manufacturers?

There were statistically significant differences in CTDIw/mAs among models: Sensation 16 was different from LS Qx/i (p = 0.0318) and MX8000IDT (p < 0.0001). LS Ultra was different from MX8000IDT (p =0.0020). These results are shown in Figure 4.

Were there statistically significant differences in normalized dose index by increasing level of technology as described by the number of data channels on the scanners?

Robust regression analysis demonstrated that CTDIw/mAs measured on scanners with 4 or 8 channels was significantly different than CTDIw/mAs from 16, 32 or 64 channel scanners, even after controlling for manufacturer (p <0.001). These results are shown in Figure 5

Discussion

Examination of these figures reveals varying levels of consistency for normalized dose (CTDIw/mAs) reported by sites with the same model of CT scanner. This value would be expected to very consistent. Two independent factors could influence the disparate values. First, some scanners could be behaving differently from others of the same model. Second, there could have been some error or inconsistency in the measurement process or reporting procedures. Thus, the variation among scanners of the same model could be real, or could be due to measurement variability, or (more likely), due to a combination of these two factors. (The large standard deviations observed for Philips and Toshiba scanner models may be due to a combination of a small number of scanners and the relative unfamiliarity of physicists testing those scanners, and cannot be interpreted with great confidence.)

The values reported in this manuscript are reasonably consistent with those available from the ImPACT CT Patient Dosimetry Calculator (www.impactscan.org) which reports CTDI values for many different CT scanners. The mean values reported in Table 4 agree with the values reported by ImPACT to within 10% for 7 of the 13 models listed; with 4 additional scanners having differences between 10 and 15% and only one scanner (Philips MX8000 IDT) reporting larger differences; this last scanner also had one of the larger standard deviations in our study. In addition, data from one of the more recently introduced scanners, the Philips Brilliance 64 (of which there was only 1 in the NLST trial), was not available from ImPACT. The data presented here does represent measured values from a number of different sites and from several different scanners of the same make and model and thus may represent the range of measurement variation due to both measurement variation and scanner variation.

From Figures 4 & 5 we can readily appreciate that the evolving technology with more data channels did not result in noticeably higher dose per mAs. In fact, it appears that the more advanced technology was associated with a consistently lower normalized dose measurement, indicative of greater dose efficiency. This could be due to fewer overlap regions between successive dose profiles that results from wider total x-ray beam collimations available in some newer scanner models, as well as to improvements in the scanner software.

It is important to appreciate the incorporation of more advanced technology as the NLST progressed (Tables 2 & 3, Figure 2). From trial initiation through completion, the increased

speed of the scanners required shorter and shorter breath-holds. The increased complexity of the scanner acquisition parameters required additional physics oversight as the trial progressed.

Normalized dose varied among all scanners by almost a factor of two (minimum of 0.070 mGy/mAs, maximum of 0.127 mGy/mAs). Please note however that the minimum value of 0.07 mGy/mAs was recorded from a single measurement session on a single scanner.

CTDI_{vol} (which is defined as CTDI_w divided by pitch to account for a pitch greater or less than unity) was not analyzed for this manuscript. The authors elected to examine CTDI_w instead of CTDI_{vol} in order to present data describing machine specific dose, independent of pitch, which is a user selected parameter. (For future estimations of population dose, the effect of pitch will have to be explicitly included.)

It should be noted that at the time of this study, there was no DICOM standard widely available for several key values to determine radiation dose performance such as: pitch, total beam collimation, rotation time, and table feed. These have since been incorporated into the DICOM standard (Enhanced CT DICOM object module) and are starting to be implemented by the CT manufacturers. The widespread implementation of these fields will make estimation of radiation dose performance easier and more accurate in the future.

This study of scanner performance represents exclusively dose values that were measured and reported. Although the LSS and ACRIN investigators performed independent visual image quality assessments, such image quality metrics were not factored into these data. It is unknown whether the scanners that delivered relatively higher dose using the technique charts developed for this trial obtained relatively better image quality.

What can be said from these data is that mAs alone cannot be used as a universal indicator of image quality such as noise, or even machine output, since radiation output per mAs varies between scanner manufacturers and models. As radiation dose becomes an increasingly important factor in radiology, the need to collapse many technical factors down to one or two to gain a clearer understanding of the long term effects also increases. Unfortunately, this study indicates that simplifying image quality or noise based on an mAs type parameter is not likely to ultimately be useful due to the output variability among CT scanners.

Summary

A large collection of dose measurements was obtained on current vintage multi-detector row CT scanners during a multi-site lung screening research trial. These dose measurements (CTDI_w) were normalized and reported on per mAs basis, by CT scanner model. This study demonstrated a statistically significant difference in normalized CT dose index among CT scanner manufacturers, likely due to design differences such as filtration, bow-tie design and geometry. Our findings also indicated a statistically significant difference in normalized CT dose index among CT scanner models within GE, Siemens, and Philips. We also demonstrated a statistically significant difference in normalized CT dose index among all models and all manufacturers. And, we demonstrated a statistically significant difference in normalized CT dose index from CT scanners among manufacturers when grouped by 4 or 8 data channels vs 16, 32, or 64 channels, suggesting improved dose efficiency in more complex scanners. Average normalized CT dose index values varied by almost a factor of two across all scanners from all manufacturers. This study was focused on machine specific normalized CT dose index; this is one of many factors that influence image quality and patient dose.

Acknowledgments

The authors would like to formally express their gratitude to all of the medical physicists, research assistants, and technologists who made all the measurements. Without their contribution, this study would not have been possible. The NLST is funded by NIH-NCI ACRIN Grant # CA80098, and by contracts with the Division of Cancer Prevention at NCI, NIH.

Appendix

A hierarchical modeling with robust regression was used to simultaneously address the first three questions: 1) difference among manufacturers in normalized CTDI_w, 2) difference among scanner model within a manufacturer in normalized CTDI_w, and 3) difference among all models and all manufacturers in normalized CTDI_w. The hierarchical structure of a manufacturer (level 1) and scanner models within a manufacturer (level 2) was embedded within the statistical hierarchical modeling. In the first hierarchical structure, four manufacturers were coded as three dichotomized covariates to compare normalized CTDI_w across manufacturers. In the second hierarchical structure, CT scanner models are nested within the CT manufacturers. They were coded as dichotomized variables to compare normalized CTDI_w within the manufacturer. The regression equation is listed below.

$$\text{Log(normalized CTDI}_w) = \Sigma \text{ Manufacturer} + \Sigma \text{ CT scanner model} | \text{ manufacturers} + \text{error term}$$

The third hypothesis of difference among all models and all manufacturers in normalized CTDI_w was tested using Bonferroni's multiple comparisons from postestimation of the regression. The Bonferroni method was implemented conservatively, preventing us from finding false positive differences in normalized CTDI_w. By combining two levels of hierarchical structure into one regression, the three hypotheses were able to be addressed.

The regression model for the last hypothesis, which is to test the difference in normalized CTDI_w by the number of data channels on the scanner with covariates of manufacturers, is listed below:

$$\text{Log(normalized CTDI}_w) = \Sigma \text{ Manufacturer} + \Sigma \text{ Channels} + \text{error term}.$$

References

1. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Report, Annex D Medical Radiation Exposures. 2000.
2. Brant-Zawadzki MN. The role of computed tomography in screening for cancer. *Eur Rad* 2005;15 Suppl 4:D52–D54.
3. Brenner DJ. Radiation risks potentially associated with low-dose CT screening of adult smokers for lung cancer. *Radiology* 2004;231:440–445. [PubMed: 15128988]
4. Brenner DJ, Georgsson MA. Mass screening with CT colonography: should the radiation exposure be of concern? *Gastroenterology* 2005;129(1):328–337. [PubMed: 16012958]
5. Brenner DJ, Elliston CD. Estimated radiation risks potentially associated with full-body CT screening. *Radiology* 2004;232(3):735–738. [PubMed: 15273333]
6. Académie des Sciences [Academy of Sciences] - Académie nationale de Médecine [National Academy of Medicine] Dose-effect relationships and estimation of the carcinogenic effects of low doses of ionizing radiation March 30, 2005.
7. Cagnon CH, Cody DD, McNitt-Gray MF, Seibert JA, Judy PF, Aberle DR. Description and implementation of a quality control program in an imaging based clinical trial. *Academic. Radiology* 2006;13(11):1431–1441.
8. McNitt-Gray MF. AAPM/RSNA Physics tutorial for residents: Topics in CT. Radiation dose in CT. *Radiographics* 2002;22:1541–1553. [PubMed: 12432127]

9. Shope TB, Gagne RM, Johnson GC. A method for describing the doses delivered by transmission x-ray computed tomography. *Med Phys* 1991;8(4):488–495. [PubMed: 7322067]
10. Huber PJ. Robust regression: asymptotics, conjectures, and Monte Carlo. *Ann Statist* 1973;1:799–821.
11. Gelman, A.; Hill, J. *Data Analysis Using Regression and Multilevel/Hierarchical Models*. New York, NY: Cambridge University Press; 2007.

Figure 1.
Geographic spread of the 33 sites of the NLST.

Figure 2.

Bar graph showing number of scanners in trial by the number of data channels during the course of the NLST. Note that the 32 channel Siemens Sensation 64 scanners were included in the 64 channel scanner group for simplicity.

(a)
(b)

Figure 3.

(a) Legend for all succeeding plots. (b) Normalized dose results by manufacturer; these results were significantly different ($p < 0.0001$) by manufacturer.

Figure 4. There were statistically significant differences in normalized dose across manufacturers and models (see text for details).

Figure 5.

Normalized dose measured on scanners with 4 or 8 channels was significantly different than 16, 32 or 64 channel scanners, even after controlling for manufacturer ($p < 0.001$). Note that the 32 channel Siemens Sensation 64 scanners were included in the “16 or 64” channel scanner group for simplicity.

Table 1

CT Lung screening sites and locations

Number	Site Name	Site Location
1	Beth Israel Deaconess Medical Center	Boston, MA
2	Brigham and Women's Hospital	Boston, MA
3	Brown University	Providence, RI
4	Cancer Institute of New Jersey	New Brunswick, NJ
5	Dartmouth-Hitchcock Medical Center	Lebanon, NH
6	The Emory Clinic	Atlanta, GA
7	Georgetown University Medical Center, Lombardi Cancer Research Center	Washington, DC
8	Henry Ford Health System	Detroit, MI
9	Jewish Heart and Lung Institute	Louisville, KY
10	Johns Hopkins University	Baltimore, MD
11	Marshfield Clinic Research Foundation	Marshfield, WI
12	Mayo Clinic Jacksonville	Jacksonville, FL
13	Mayo Clinic Rochester	Rochester, MN
14	Moffitt Cancer Center at the University of South Florida	Tampa, FL
15	Medical University of South Carolina	Charleston, SC
16	Northwestern University Medical Center	Chicago, IL
17	Ochsner Clinic Foundation	New Orleans, LA
18	St. Elizabeth's Health Center	Youngstown, OH
19	Pacific Health Research Institute	Honolulu, HI
20	University of Alabama at Birmingham	Birmingham, AL
21	University of California Los Angeles	Los Angeles, CA
22	University of California San Diego	San Diego, CA
23	University of Colorado Denver	Aurora, CO
24	University of Iowa	Iowa City, IA
25	University of Minnesota School of Public Health/Virginia Piper Cancer Institute	Minneapolis, MN
26	University of Pennsylvania	Philadelphia, PA
27	University of Pittsburgh Medical Center	Pittsburgh, PA
28	University of Michigan Medical Center	Ann Arbor, MI
29	University of Texas M. D. Anderson Cancer Center	Houston, TX
30	University of Utah Health Science Center	Salt Lake City, UT
31	Vanderbilt University	Nashville, TN
32	Wake Forest University School of Medicine	Winston-Salem, NC
33	Washington University School of Medicine	St. Louis, MO

Fleet of CT scanners initially certified for NLIST (as of December 31, 2002). Only the ACRIN component of CT scanners was included in the table (dose measurement data were unavailable for LSS component until 2004).

Table 2

Manufacturer	Model	Max. images per rotation	Beam width (mm)	Table speed used for trial mm/rot	Number of scanners
General Electric	Qx/i	4	10	15	6
	LS+	4	10	15	3
	Ultra	8	10	13.5	5
Philips	LS-16	16	20	27.5	1
	MX8000	4	4 or 10	8 or 15	2
	MX8000-IDT	16	12	18	3
Siemens	Sensation 4	4	4 or 10	8 or 15	2

For a few CT scanner models, a choice of detector configuration (4×1 mm or 4×2.5 mm) and table speed (8 or 15 mm/rotation) was provided for the trial sites.

Table 3

Fleet of CT scanners near termination date of lung screening phase of the NLST (as of Dec. 31, 2006). Table includes scanners in both ACRIN and LSS components of the screening study, but does not include scanners used at voltages other than 120 kVp exclusively for the NLST.

Scanner manufacturer	Scanner model	Number of data channels	Beam Width Used (mm)	Number of scanners in NLST
General Electric	Qx/i	4	10	11
	LS+	4	10	9
	Ultra	8	10	7
	LS-16	16	20	23
	VCT	64	40	1
Philips	MX8000	4	4 or 10	6
	MX8000-IDT	16	12	2
	Brilliance 64	64	40	1
Siemens	Sensation 4 Volume Zoom	4	4 or 10	14
	Sensation 16	16	12	13
	Sensation 64	32	19.2	2
Toshiba	Aquilion 4	4	8	4
	Aquilion 16	16	32	3

Normalized dose values averaged by CT scanner make & model. Overall average normalized dose (CTDI_w per mAs) for all scanners operated at 120 kVp was 0.096 mGy/mAs. (Data collected from scanners operated at other than 120 kVp for NLST were not included in these values.)

Table 4

Scanner manufacturer	Scanner model	Number of scanners	Number of CTDI measurements	Average Normalized CTDI _w (mGy/mAs)	Std. Dev. Normalized CTDI _w (mGy/mAs)
General Electric	Qx/i	11	26	0.10	0.015
	LS+	9	22	0.09	0.025
	Ultra	7	23	0.10	0.011
	LS-16	23	51	0.09	0.011
Philips	VCT	1	2	0.09	..
	MX8000	6	13	0.08	0.010
	MX8000-IDT	2	7	0.12	0.053
	Brilliance 64	1	1	0.07	..
Siemens	Sensation 4 Volume Zoom	14	35	0.10	0.025
	Sensation 16	13	25	0.08	0.008
	Sensation 64	2	4	0.08	0.002
Toshiba	Aquilion 4	4	6	0.12	0.045
	Aquilion 16	3	6	0.13	0.013