Low-Dose High-Resolution CT of the Chest in Children and Young Adults: Dose, Cooperation, Artifact Incidence, and Image Quality

Javier Lucaya[1,2]
Joaquim Piqueras[1]
Pilar García-Peña[1]
Goya Enríquez[1]
Maribel García-Macías[1]
Jesús Sotil[3]

OBJECTIVE. The radiation dose, artifact incidence, and image quality of high-resolution chest CT examinations performed with standard and low doses and patient cooperation were investigated in children and young adults.

SUBJECTS AND METHODS. Three successive controlled studies were conducted in different groups of children and young adults, totaling 203 patients. Dosimetry of high-resolution CT was performed at 180, 50, and 34 mAs in three groups of 25 patients. Streak artifact incidence using alternating 50- and 34-mAs slices was assessed and correlated with patient compliance with breath-holding commands in 44 children. Image quality was evaluated in scans obtained with 34 versus 180 mAs in cooperative patients ($n = 42$) and in scans obtained with 50 versus 180 mAs in noncooperative patients ($n = 42$). Artifacts and image quality were assessed by controlled repeated interpretations.

RESULTS. Radiation dose was 5.4 ± 1.6 mSv for 180 mAs, 1.5 ± 0.5 mSv for 50 mAs, and 1.1 ± 0.3 mSv for 34 mAs. Cooperation was obtained in 66% of the patients. Artifacts were more frequently seen in scans of noncooperative patients (30%) and in 34-mAs scans (47%); the highest incidence was found using 34 mAs in noncooperative patients (60%, $p = 0.02$). No differences in image quality scores were seen in scans obtained with 50 mAs versus those obtained with 180 mAs in noncooperative patients ($p < 0.05$), and small differences were found in scans obtained with 34 mAs versus those obtained with 180 mAs in cooperative patients for fissures ($p = 0.005$) and peripheral structures ($p = 0.02$).

CONCLUSION. Low-dose high-resolution CT provided a significant reduction in radiation dose (72% for 50 mAs and 80% for 34 mAs) and good-quality images of the lung when performed with 50 mAs in noncooperative and 34 mAs in cooperative pediatric and young adult patients.

Because chest CT provides more information than chest radiography [1–3] and is increasingly used in children, efforts must be made to ensure that CT will be performed with the least radiation possible while maintaining good image quality.

High-resolution CT of the chest, generally performed using milliampere-second settings of between 100 and 200 mAs [1–4], is the examination of choice for detection of many lung disorders in children. Lowering the milliampere-second value will result in a proportional reduction in patient dose; it will also, however, increase image noise and potentially decrease the detectability of low-contrast detail [5–9]. In 1990, Naidich et al. [10] reported that good-quality conventional lung scans could be obtained in adults using low milliamperage. Ambrosino et al. [11], in a retrospective study, showed the feasibility of low-dose high-resolution CT for evaluating the pediatric chest. However, this approach has not been widely adopted and, to date, a controlled comparative study investigating image quality of high-resolution CT scans using different milliamperage settings has not been performed in children.

In 1995, we began to routinely use a low-milliamperage setting for high-resolution CT in our pediatric patients. We noticed that when using the lowest setting available on our unit (34 mAs), some of the examinations, particularly those of young children, showed an elevated incidence of linear artifacts, which we attributed to low milliamperage, lack of cooperation, or both. In this study, we measured radiation dose delivered with standard-dose and with low-dose high-resolution CT and compared the incidence of streak artifacts and its relation with patient cooperation in examinations performed with two low-milliampere settings. Using the results

Received December 30, 1999; accepted after revision March 17, 2000.

[1]Radiology Department, HMI-Vall d'Hebron Hospitals, ps. Vall d'Hebron 119-129, 08035 Barcelona, Spain. Address correspondence to J. Lucaya.

[2]Institute of Diagnostic Imaging, Vall d'Hebron Hospitals, 08035 Barcelona, Spain.

[3]Radiation Protection Department, Vall d'Hebron Hospitals, 08035 Barcelona, Spain.

AJR 2000;175:985–992

0361–803X/00/1754–985

from our artifact study, we designed an image evaluation protocol that was aimed at comparing the quality of high-resolution CT chest images obtained with one standard (180 mAs) and two low-milliampere settings (34 and 50 mAs) in infants, children, and young adults.

Subjects and Methods

Radiation Dose Study

A study was conducted to compare relative radiation doses in three groups of 25 children and young adults of similar ages (age range, 1–19 years; mean age ± standard deviation [SD], 8.23 ± 4.32 years; average weight ± SD, 26.7 ± 11.3 kg) who were examined with high-resolution chest CT at our institution. All studies were performed on the same CT unit (CT Twin II-Plus; Elscint, Haifa, Israel). High-resolution CT in group A was performed using a 1-mm collimation at 10-mm intervals, 120 kVp, 180 mAs, and 1 sec. In group B, we used the same technical factors as in group A, but we changed the milliamperage to 50 mAs (50 mA and 1 sec). In group C, we used 34 mAs (50 mA and 0.67 sec; 223° partial-arc scanning), while keeping the remaining technical factors constant. The 34-mAs setting was selected because 50 mA is the minimum tube current and 0.67 sec is the shortest scan time available on our CT unit.

Reconstruction of the raw data from groups A and B was carried out using a high-resolution acquisition interpolation algorithm, whereas in group C because of technical limitations of partial-arc scanning, a standard acquisition interpolation algorithm was applied. High-spatial-frequency reconstruction algorithms were used for presentation of mediastinal and lung images. In addition, mediastinal images were reconstructed using the standard filter. The sensors for radiation dose measurement were strips of nine contiguous lithium fluoride (LiF:Mg,Ti) thermoluminescent chips (TLD-100; Harshaw-Bicron, Newbury, OH), each measuring 3.2 × 3.2 × 0.9 mm, that were mounted on the underside of a 10-mm-thick acrylic block, which was taped to the patient's skin on the upper third of the chest. Two slices per strip were usually registered. The chips were calibrated for a 10-mm-depth individual dose equivalent and were read using reader chips (Harshaw 3500 TLD; Harshaw-Bicron). The average dose per strip was calculated. For additional dosimetric information, we measured doses from conventional (120 kVp, 100 mAs, 10-mm slices every 10 mm) and helical (120 kVp, 100 mAs, 10-mm slice thickness, pitch of 1.5) chest CT techniques in another two groups of 10 children, examined with the same CT unit and dosimetric method.

Artifacts and Patient Cooperation Study

This comparative controlled repeated-measurements study was designed to determine the influence of radiation dose and patient cooperation on the incidence of linear artifacts in low-dose high-resolution CT. A group of 44 consecutive children (age range, 15 days–16 years; mean age ± SD, 7.61 ± 4.65 years; median age, 7 years) referred for high-resolution CT examination were included in the study. None of our patients received contrast material or had central catheters during high-resolution CT. Once the patient arrived at the CT unit, the technician instructed older children in breath-holding and recorded whether they followed commands during the examination. Sedation was not required. CT scans were obtained alternating 1-mm-collimation slices with two different low-dose techniques at 10-mm intervals as follows. Two consecutive series were obtained with slices at 20-mm intervals: the first, with 50 mAs (in 1 sec); the second, starting 10 mm below the first slice of the previous series, with 34 mAs (in 0.67 sec). The remaining technical parameters (1-mm slices, 120 kVp, 512^2 matrix, and high-spatial-frequency reconstruction bone algorithm) were kept constant. At the end of the CT acquisition, half the slices had been obtained using 34 mAs, and the other half had been obtained using 50 mAs. The field of view was adjusted to match the patient's chest width: 180 mm (11.36% of patients), 250 mm (68.18%), and 430 mm (20.45%). The total number of slices varied from eight to 18 (median, 14.5 slices). Using lung parenchyma window settings (level, –700 H; width, 1500 H), the series of images that had been obtained with 50 and 34 mAs were printed on separate 35 × 43 cm laser-camera films. The images were identical in size, fully anonymous, and had no technical factor overlay.

Artifact Interpretation

Three radiologists, two senior pediatric radiologists and one senior radiology resident, interpreted the images independently. Image sets were assessed in random order on the same standard viewbox. The characteristics of the evaluation were established in consensus before starting the experiment. Only streak artifacts affecting the lung structures were assessed. Artifacts originating from medical devices were not present and were not considered. Each set of images was classified according to the following ordinal scale: 1, no artifacts present; 2, artifacts in one or two slices; 3, artifacts in more than two slices; 4, artifacts in all slices; and 5, artifacts prevent interpretation.

Study of Image Quality

According to the results of the artifacts and patient cooperation study, in which artifacts were found to be more frequent on scans in noncooperative patients when obtained with 34 mAs rather than with 50 mAs, we designed a protocol to conduct two comparative controlled repeated-measurements studies of high-resolution CT image quality. One study was in noncooperative patients examined with 50 versus 180 mAs, and the other study was in cooperative patients examined with 34 versus 180 mAs. To test the null hypothesis that there is no significant difference in image quality between low- and conventional-dose chest CT images, the study was designed to compare in each patient an image obtained with a low milliampere setting with a repeated image obtained with the standard milliampere setting. Blinded random repeated interpretations were performed by multiple observers.

The study of the noncooperative group included 45 consecutive pediatric patients (age range, 1 week–9.6 years; mean age ± SD, 2.45 ± 2.68 years; median age, 1.5 years) referred for high-resolution CT of the lung who were unable to follow breath-holding commands. The chest CT examinations were performed using 50 mAs and 1 sec. Sedation was required in one patient only. Indications for high-resolution CT in this group were cystic fibrosis, bronchopulmonary dysplasia, meconium aspiration, histiocytosis X, pneumonia associated with immunodeficiency, bronchiolitis obliterans, severe asthma, and suspected bronchiectasis. Findings from 19% of the examinations were normal. On completion of low-dose high-resolution CT examinations and after informed parental consent had been obtained, an additional single slice was repeated at the level of the carina using 180 mAs and 1 sec while maintaining the other technical factors constant.

The study in the cooperative group included 45 consecutive pediatric and young adult patients (age range, 7.0–21.9 years; mean age ± SD, 12.8 ± 3.54 years; median age, 13 years) who were referred for high-resolution CT of the lung and able to follow breath-holding commands. The chest CT examinations were performed using 34 mAs and 0.67 sec. Sedation was not required. Indications for high-resolution CT in this group were suspected cystic fibrosis, bronchiectasis, interstitial lung disease, pneumonia associated with immunodeficiency, bronchiolitis obliterans, severe asthma, and histiocytosis X. Findings in 26% of the examinations in this group were normal. As in the noncooperative group, an additional 180-mAs slice was obtained at the level of the carina. All CT examinations were performed between September 1997 and January 1998.

The standard- and low-milliamperage scans obtained at the carina were recorded on 36 × 43 cm laser-camera film after removal of all identifying data and technical details. Six images were printed per patient: two lung images (at the level of the carina), obtained with standard and low milliamperages at settings appropriate for visualization of the pulmonary parenchyma (level, –700 H; width, 1500 H) and four mediastinal images (at the level of the carina), two obtained with standard and two with low milliamperage. Each pair was reconstructed with both standard and high-spatial-frequency reconstruction algorithms (level, 35 H; width, 450 H). Individual images were cut from the multiformat film and given a random number. Three cases from each group were excluded for failing to meet image presentation requirements, leaving a total of 42 patients in each group for analysis. Eighty-four lung images (42 pairs) were obtained for the comparison of 50 versus 180 mAs in noncooperative patients. One hundred sixty-eight mediastinal images were obtained for the comparison of 50 versus 180 mAs with standard (42 pairs) and with high-spatial-frequency (42 pairs) reconstruction algorithms. The same number of paired images was obtained in the 42 cooperative patients examined with 34 versus 180 mAs.

Image Quality Assessment

After the scoring criteria were established in consensus, the images were reviewed by four pediatric radiologists and one radiology senior resident. The radiologists assigned a subjective image quality score to each of the six following parameters using a 5-point ordinal scale from 5 (highest quality) to 1 (lowest quality): number and severity of streak artifacts (0, 1, >1, interpretation difficult, interpretation impossible); bronchi identified within 20 mm of hila (>3 well defined, <3 well defined, >3 poorly defined, <3 poorly defined, 0); identification of vascular structures within 20 mm of hila (>4 well defined, <4 well defined, >4 poorly defined, <4 poorly defined, 0); identification of fissures (complete well defined, incomplete well defined, complete poorly defined, incomplete poorly defined, not seen); peripheral structures within 10 mm from pleura (abundant and well defined, scarce and well defined, abundant and poorly defined, scarce and poorly defined, none) and mediastinum mottle (none, slight, abundant, interpretation difficult, interpretation impossible). When the score for the two lungs differed, the higher score was selected.

Lung images and mediastinal images were assessed three times by each radiologist, randomly and independently, at 1-week intervals on the same standard viewbox. During each session, the images were successively presented in a frame centered on a black background (blackened radiographic film) with no technical overlay and in a random sequence. The series were rerandomized after each session. To reduce duration of and reviewer fatigue from each interpretation session, lung images and mediastinal images were interpreted separately on different days. In two patients, the repeated slice was above the origin of the major fissures; these images were excluded from the statistical analysis for this item. After completion of the 15 interpretation sessions, 30,240 scores (720 per patient) were analyzed.

Measurement of image noise, the random variation of the CT number of a homogeneous density object, was assessed by scanning a homogeneous CT calibration cylindric water phantom (diameter, 200 mm) with the same three techniques described (34, 50, and 180 mAs). The values of the CT number were obtained from the average of five round 1000-mm^2 regions of interest centered at the isocenter and at the 3-, 6-, 9-, and 12-o'clock positions.

Statistical Analysis

Nonparametric methods were applied to analyze image scores. Statistical significance was set at a p value of less than 0.05, and confidence intervals were set at 95%. The interquartile interval, the range of the central 50% of values, was used as the index of dispersion for nonparametric results and is less sensitive to outliers than the mean and standard deviation. Means were enclosed for parameters that behaved as interval data. Spearman's rank correlation analysis was used to test for trends. Chi-square tests were applied for intertechnique comparisons. The Mann-Whitney test and Wilcoxon's signed rank test were used to compare scores between techniques and their significance. Intra- and interobserver agreement were measured using kappa statistics, a method to analyze multivariate categoric data obtained from repeated measurements [12–14]. Kappa values were reported as follows: 0, agreement is a random effect; less than 0.20, poor agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.00, almost perfect agreement [12]. Relative risk analyses were performed between low-dose techniques to assess how dose and cooperation influence the incidence of artifacts. To assess the relevance of the differences between image quality scores, we calculated the effect size index. Effect size statistics are used to determine the magnitude of an effect, expressed as the mean difference in SD units, and calculated for paired observations using the following formula: $(\text{mean}_{A-B} / SD_{A-B}) \times 2.5$. An effect size index value of close to 0.2, 0.5, and 0.8 is considered small, medium, and large, respectively [15].

Results

Radiation Dose Study

Dosimetric readings adjusted to a 10 mm depth provided relative dosimetry of the different techniques, and they were reported as "individual dose equivalent penetrating." The number of high-resolution CT slices per patient varied from seven to 18 (mean, 13.75; SD, 3.95) according to the patient's chest length. High-resolution CT dose results were 5.4 ± 1.6 mSv for 180 mAs, 1.5 ± 0.5 mSv for 50 mAs, and 1.1 ± 0.3 mSv for 34 mAs. Compared with the standard-dose technique (180 mAs), low-dose techniques resulted in dose reductions of 72% for 50 mAs and 80% for 34 mAs. The dose for conventional chest CT (120 kVp, 100 mAs, 10-mm slices every 10 mm) was 13.6 ± 1.4 mSv, and the dose for helical CT (120 kVp, 100 mAs, 10-mm slice thickness, pitch of 1.5) was 8.7 ± 1.0 mSv.

Artifacts and Patient Cooperation Study

Twenty-nine (66%) of our 44 patients cooperated with the breath-holding commands (95% confidence interval [CI], 51–80%; $p = 0.04$). The cooperative patients were older (age range, 5–16 years; mean age ± SD, 10.13 ± 3.34 years; median age, 10 years) than those who failed to cooperate ($n = 15$; age range, 15 days–6 years; mean age ± SD, 2.73 ± 2.31 years; median age, 3 years), with a strong positive correlation with age (Spearman's rank correlation coefficient, rho = 0.816; two-sided, $p < 0.0001$).

A score of 1—no artifacts present—was assigned to four and 26 of 29 cooperative children examined with 34 and 50 mAs, respectively, and to one and nine of 15 noncooperative children examined with 34 and 50 mAs, respectively. A score of 2—artifacts limited to one or two slices—to 13 and three of 29 cooperative children scanned with 34 and 50 mAs, respectively, and to five and five of 15 noncooperative children studied with 34 and 50 mAs, respectively. A score of 3—artifacts in more than two slices—was assigned to 12 and 0 of 29 cooperative children with 34 and 50 mAs, respectively, and to five and one of 15 noncooperative children with 34 and 50 mAs, respectively. A score of 4—artifacts in all slices—was only assigned to four noncooperative children examined with 34 mAs. A score of 5—artifacts prevent interpretation—was not assigned to any patient in our series.

Scans without artifacts were obtained with 50 mAs in 77% of patients and with 34 mAs 11%. Scans in cooperative patients were obtained without artifacts with 50 mAs in 90% of patients and with 34 mAs in 14%. Regardless of patient cooperation, examinations performed with 50 mAs had fewer artifacts (range of scores, 1–3; mean score ± SD, 1.22 ± 0.47; median score, 1; interquartile interval, 1–1) than those with 34 mAs (range of scores, 1–4; mean score ± SD, 2.45 ± 0.81; median score, 2; interquartile interval, 2–3). Regardless of the technique used, artifacts were more frequently seen in noncooperative patients than in cooperative patients ($p < 0.01$). Patient-by-patient analysis showed more artifacts on scans obtained with 34 mAs than on scans obtained with 50 mAs, with a median difference between scores of one (95% CI, 1–1.5; $p < 0.0001$). The highest incidence of artifacts was found in the group of noncooperative patients when examined with 34 mAs: only 7% of the noncooperative patients examined using the 50-mAs technique had more than two artifact-affected slices, whereas this occurred in 60% of the patients examined with 34 mAs ($p = 0.02$). A score of 4 (all slices affected) was applied only to the group of noncooperative patients examined with 34 mAs (27%).

Interobserver agreement in scoring artifacts was substantial in both series (50 mAs, $\kappa = 0.793$; 34 mAs, $\kappa = 0.743$). To detect potential interobserver bias in scoring depending on their ability to identify the technique applied to each image, we subtracted the score for 34 mAs from the score for 50 mAs and performed a kappa analysis of the differences for each patient. We found substantial agreement among the observers ($\kappa = 0.668$), suggesting that no bias was present.

Relative risk analysis was performed after patients were grouped as having examinations with "low" (≤2 slices affected) or "high" (>2 slices affected) artifact incidence. For the total population ($n = 44$), without taking cooperation into account, the relative risk of higher artifact incidence was 1.86 times greater with 34 mAs (95% CI, 1.46–2.58) than with 50 mAs. The highest relative risk, 2.44 times greater (95% CI, 1.51–4.93), was found when noncooperative patients ($n = 15$) were examined with 34 versus 50 mAs. In an attempt to find a balance between artifacts and dose, the scores obtained with 50 mAs in noncooperative patients ($n = 15$) and in the total population ($n = 44$) were compared. The difference in relative risk, 1.04 times greater (95% CI, 0.95–1.39), was not significant. Interestingly, artifact incidence was lower ($p = 0.01$) in CT examinations performed with 50 mAs in noncooperative children ($n = 15$) than in CT examinations performed with 34 mAs in cooperative children ($n = 29$). The relative risk for the latter was lower (1.59 times; 95% CI, 1.11–2.32; risk difference, 34.71%) than the relative risk for 34 versus 50 mAs in the whole population (1.86 times; 95% CI, 1.46–2.58) without taking into account patient cooperation.

According to these results, patients were assigned to cooperative or noncooperative groups in the subsequent image quality studies conducted to compare low and standard milliampere high-resolution CT techniques.

Study of Image Quality

Scores from pairs of CT images acquired at the level of the carina with the standard- and low-amperage technique in the same patient were statistically compared to assess variations in quality parameters. The results obtained with this approach should not be affected by pathology, age, or body size diversity within the groups of patients. Analysis of the image quality parameters in the noncooperative patients showed no statistically significant differences in studies performed with 50 versus 180 mAs (Table 1 and Fig. 1). In the group of cooperative patients examined with 34 and 180 mAs (Table

TABLE 1 Image Quality Scores for Repeated Scans Obtained with Low-Dose (50 mAs) and Standard-Dose (180 mAs) High-Resolution CT in 42 Noncooperative Children

Variable Evaluated	Image Quality Score[a]						p	κ (Range)[b]	
	50 mAs			180 mAs					
	Median	Interquartile Interval	Mean ± SD	Median	Interquartile Interval	Mean ± SD		Interobserver	Intraobserver
Streak artifacts	5	5–5	4.90 ± 0.37	5	5–5	4.91 ± 0.35	0.70	0.36–0.44	0.63–0.75
Bronchi	4	3–4	3.57 ± 1.18	4	3–4	3.61 ± 1.18	0.73	0.36–0.50	0.78–0.88
Vessels	4	3–5	3.62 ± 1.23	4	2–5	3.59 ± 1.28	0.93	0.31–0.52	0.76–0.83
Fissures	2	1–4	2.50 ± 1.57	3	1–5	2.86 ± 1.59	0.28	0.47–0.58	0.77–0.90
Peripheral structures	4	2–5	3.44 ± 1.35	4	3–5	3.67 ± 1.29	0.23	0.35–0.45	0.69–0.88
Mediastinum									
Standard filter	4	3–4	3.54 ± 0.76	5	5–5	4.72 ± 0.53	<0.0001	0.21–0.40	0.63–0.72
High-contrast-resolution filter	2	2–3	2.20 ± 0.79	3	3–3	2.99 ± 0.76	<0.0001	0.19–0.40	0.57–0.73

[a] Each set of images was classified according to the 5-point ordinal scale from 5 (highest quality) to 1 (lowest quality) as detailed in the "Image Quality Assessment" section of "Subjects and Methods."

[b] Kappa values were reported as follows: 0, agreement is a random effect; less than 0.20, poor agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.00, almost perfect agreement [12].

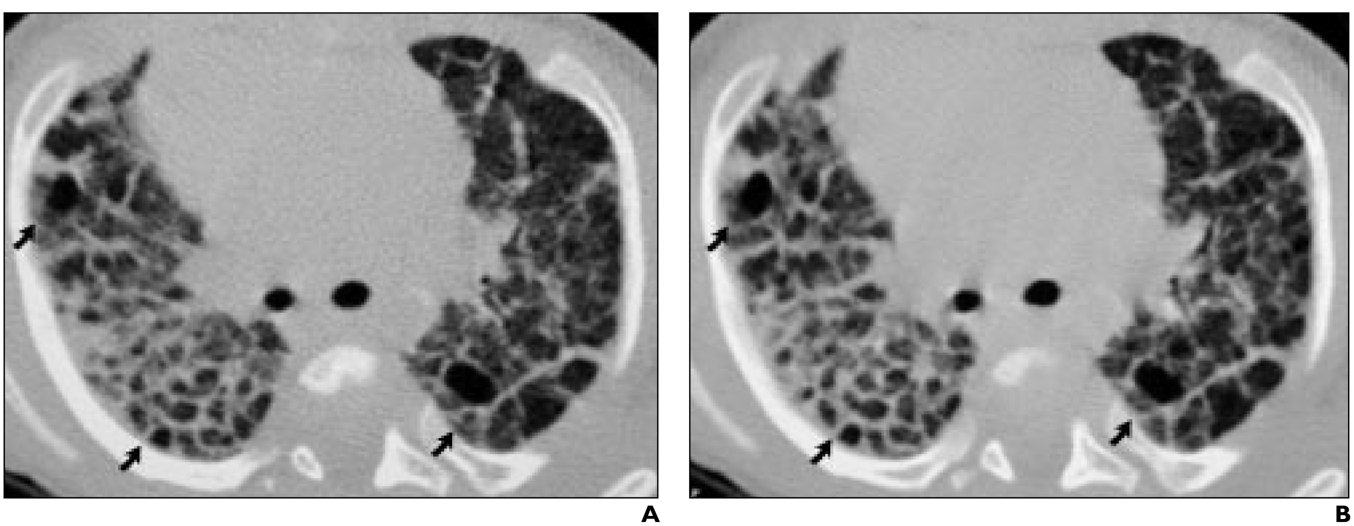

Fig. 1.—3-month-old female infant with bronchopulmonary dysplasia.
A and **B**, High-resolution CT scans of chest obtained with 50 mAs (**A**) (average image quality score, 2.36) and with 180 mAs (**B**) (average image quality score, 2.57) reveal no significant difference in image quality between **A** and **B**. Interstitial thickening and areas of hyperlucent lung (*arrows*) producing pseudocystic appearance are clearly visible on both images.

2), we found statistically significant differences in three scores. Images obtained with the 34-mAs technique received lower scores regarding fissures (–9.4%, $p = 0.002$) (Fig. 2) and peripheral structures (–4.92%, $p = 0.02$) (Figs. 2–4) and had a small but significant advantage over 180 mAs in streak artifacts (+4.26%, $p = 0.04$). Effect size index values were medium for differences in fissures (0.47) and peripheral structures (0.53) and medium to large for streak artifacts (0.75). The scores assigned to the remaining parameters showed no significant differences (Figs. 2–4).

The evaluation of the quality of the images of the mediastinum resulted in poor scores for both low-dose high-resolution CT techniques. Images acquired with either 34 or 50 mAs received significantly lower scores than their 180 mAs counterparts (Tables 1 and 2). All mediastinum images reconstructed using the standard filter received better scores than those obtained with the high-spatial-frequency reconstruction algorithm ($p < 0.0001$). Image noise (SD of the mean CT number of a water phantom) was significantly higher with the low-dose techniques. Mean values were 78.32 ± 9.56 for 34 mAs, 91.88 ± 14.61 for 50 mAs, and 48.48 ± 6.51 for 180 mAs.

After analyzing intraobserver agreement of the image quality parameters, we found a substantial to near-perfect kappa correlation (range, 0.57–0.91; mean, 0.78) for the three repeated interpretations. The kappa coefficient for interobserver correlation was moderate, with a range of between poor and substantial (range, 0.16–0.67; mean, 0.48). The greatest differences were found assessing mediastinal images and in the evaluation of vessels and bronchi in the group examined with 34 mAs. Results for intra- and interobserver agreement were within the range usually reported in controlled blinded interpretation studies and sustain the reproducibility of our results [16].

TABLE 2 Image Quality Scores for Repeated Scans Obtained with Low-Dose (34 mAs) and Standard-Dose (180 mAs) High-Resolution CT in 42 Cooperative Children

Variable Evaluated	Image Quality Score[a]						p	κ (Range)[b]	
	34 mAs			180 mAs					
	Median	Interquartile Interval	Mean ± SD	Median	Interquartile Interval	Mean ± SD		Interobserver	Intraobserver
Streak artifacts	5	5–5	4.86 ± 0.41	5	5–5	4.63 ± 0.68	0.04	0.45–0.55	0.65–0.77
Bronchi	4	4–5	4.11 ± 0.83	4	4–5	4.17± 0.70	0.54	0.20–0.44	0.72–0.87
Vessels	4	4–4	3.97 ± 0.85	4	4–5	4.09 ± 0.77	0.10	0.16–0.26	0.60–0.79
Fissures	5	3–5	3.95 ± 1.33	5	4–5	4.35 ± 1.17	0.005	0.36–0.47	0.71–0.92
Peripheral structures	4	2–5	3.67 ± 1.15	4	3–5	3.85 ± 1.13	0.02	0.36–0.47	0.67–0.91
Mediastinum									
Standard filter	3	3–4	3.29 ± 0.78	5	4–5	4.71 ± 0.52	<0.0001	0.27–0.50	0.57–0.73
High-contrast-resolution filter	2	2–3	2.16 ± 0.78	3	3–4	3.34 ± 0.71	<0.0001	0.20–0.32	0.68–0.81

[a]Each set of images was classified according to the 5-point ordinal scale from 5 (highest quality) to 1 (lowest quality) as detailed in the "Image Quality Assessment" section of "Subjects and Methods."

[b]Kappa values were reported as follows: 0, agreement is a random effect; less than 0.20, poor agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.00, almost perfect agreement [12].

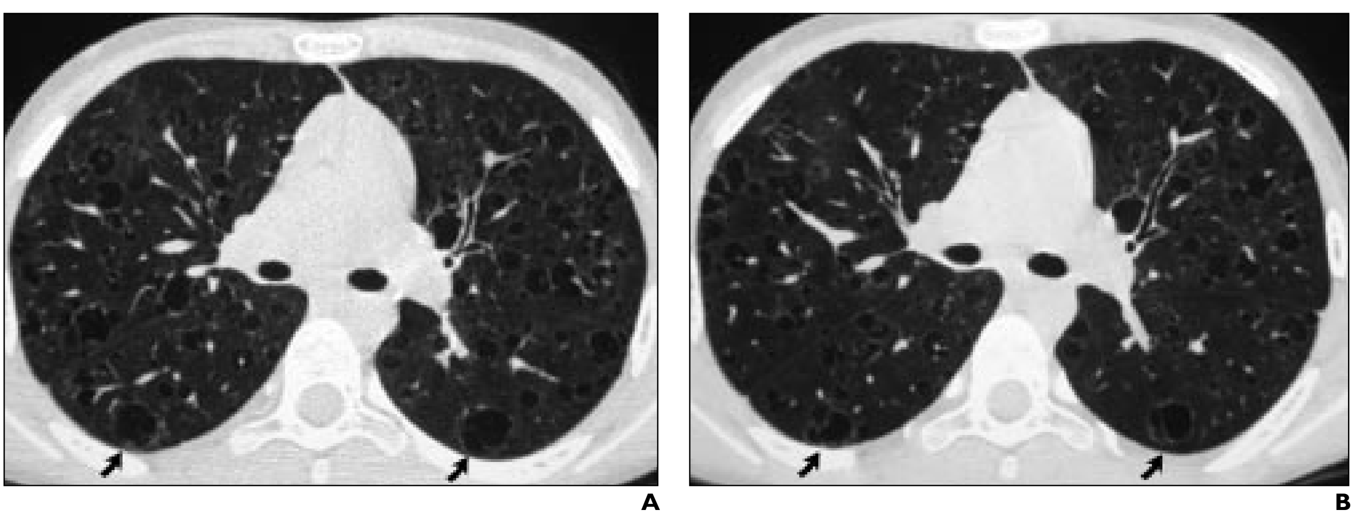

Fig. 2.—11-year-old boy with pulmonary histiocytosis X.
A and **B**, High-resolution CT scans of chest obtained with 34 mAs (**A**) (average image quality score, 4.07) and 180 mAs (**B**) (average image quality score, 4.01) show widespread thin-walled, air-filled cysts (*arrows*). Fissures appear sharper in **B** than in **A**.

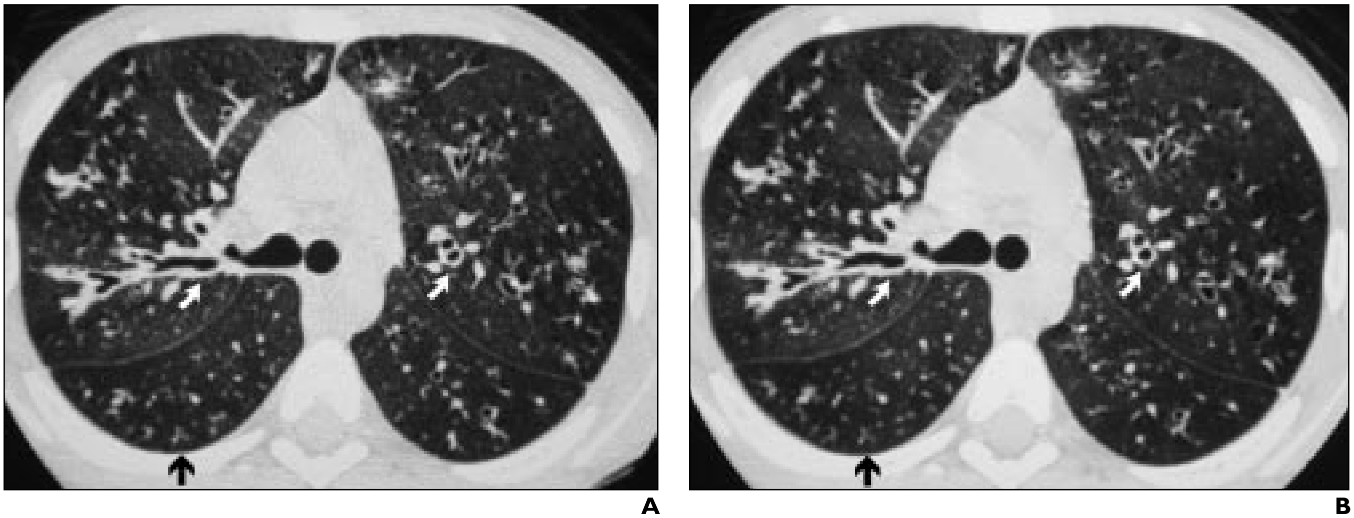

Fig. 3.—12-year-old boy with cystic fibrosis.
A and **B**, High-resolution CT scans of chest obtained with 34 mAs (**A**) (image quality average score, 4.40) and 180 mAs (**B**) (average image quality score, 4.33) show peribronchial thickening (*curved arrows*), bronchiectasis, and tree-in-bud appearance of peripheral bronchi (*straight arrows*).

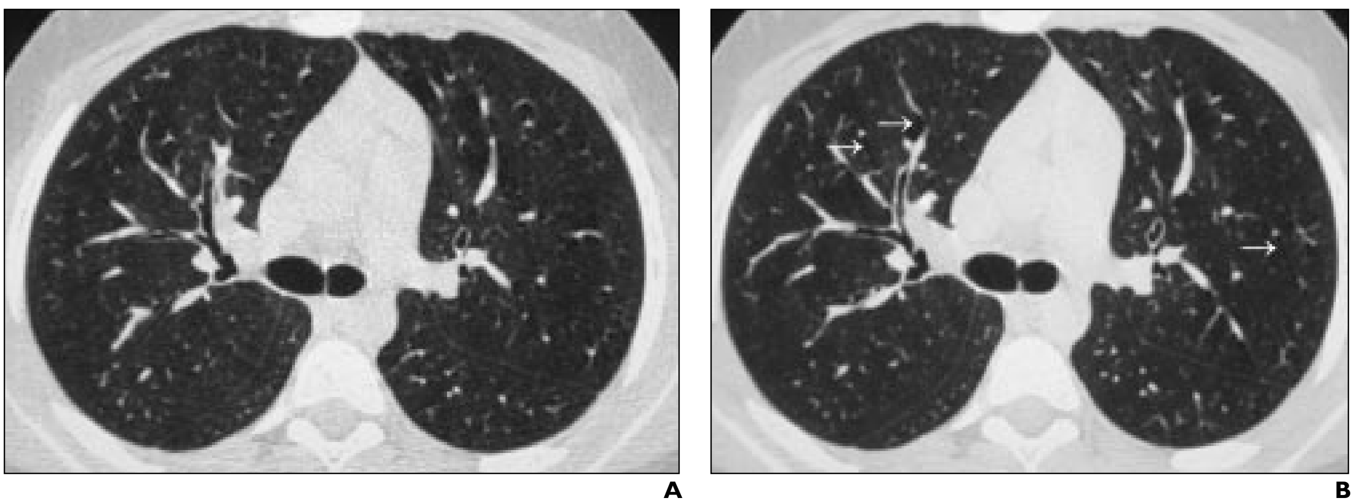

Fig. 4.—13-year-old boy who was examined to rule out bronchiectases. Images show normal findings.
A, High-resolution CT scan of chest obtained with 34 mAs (average image quality score, 4.58) shows that depiction and sharpness of lung structures are good. Noise, best identified in low-contrast structures of mediastinum and chest wall, is more evident in this image than in **B**.
B, High-resolution CT scan of chest obtained with 180 mAs (average image quality score, 4.50) shows several streak artifacts (*arrows*).

Discussion

High-resolution CT plays a major role in lung studies, and its indications for the assessment of pediatric lung disorders are increasing [1, 2, 4, 17–19]. The high-resolution CT dose with a standard-milliampere setting is 6.5 times lower than that of conventional CT, but it is still 12 times higher than that of anteroposterior and lateral chest radiography [20]. Radiation exposure is particularly worrisome in children, in whom absorbed CT dose is more uniform, effective dose is higher, and risk of radiation-induced damage is considered greater than in adults [21, 22]. Because radiation dose is directly proportional to amperage at a fixed kilovoltage, slice width, and table increment, reductions in amperage reduce dose. However, because high-resolution CT increases noise in the CT image, high milliamperage-second settings have been recommended to reduce this effect [6, 17, 23]. Our results confirm that compared with standard-dose high-resolution CT, low-milliamperage techniques decrease radiation dose proportionally to milliamperage reduction: 72% for 50 mAs and 80% for 34 mAs [24]. The concept of reduced tube current for conventional 10-mm-collimation chest CT was introduced by Naidich et al. [10], who obtained diagnostic-quality images of the lung with settings as low as 20 mAs, although noise degraded image quality of mediastinal structures. Rusinek et al. [25] showed low-dose (20 mAs) conventional CT to be suitable for primary screening of lung nodules. Rogalla et al. [26] reported adequate image quality of helical chest CT scans obtained using 25 mAs in children.

Zwirewich et al. [27] showed that, in most of their adult patients, high-resolution CT images acquired with 40 mAs yielded anatomic information equivalent to that obtained with 400 mAs with no significant loss of spatial resolution or image degradation caused by streak artifacts. Use of low-dose high-resolution CT in children was first reported by Ambrosino et al. [11] who showed that high-resolution CT performed using between 40 and 80 mAs provided acceptable images for evaluation of most lung disorders. The results of our study investigating artifacts and patient cooperation using low amperages revealed that streak artifact incidence not only depended mainly on radiation dose, but also depended, to a high degree, on patient cooperation. Overall, the artifact incidence was more significant in 34-mAs studies than in 50-mAs studies. However, in most cooperative children examined with 34 mAs, artifacts were limited to a few slices. In 27% of the noncooperative children, the scans obtained with 34 mAs were found to have artifacts in all slices, whereas this never occurred in cooperative patients. Our experience differs from that of Posniak et al. [28] who when studying adult noncooperative patients with 0.6 and 1 sec found no differences in artifact incidence, although low doses were not used. Regardless of patient cooperation, artifact incidence in 50-mAs scans was very low. Cooperation plays a major role when the lowest milliamperage settings are applied. Although some slices obtained with 34 mAs in cooperative children may contain artifacts, the overall image quality was preserved. With the goal of reducing radiation exposure as much as possible, the use of this setting in cooperative patients can be sustained.

Because high-resolution CT is routinely performed with low-milliamperage settings in our department, we considered it unethical to perform a complete standard-dose high-resolution CT for comparison purposes. This consideration is why only a single additional slice at standard dose was added for our image quality study. Our results show that low-dose high-resolution CT scans effectively depict normal vascular, bronchial, and peripheral structures of the lung. In the comparative study on 50 versus 180 mAs, we found no significant differences in lung image quality scores (Fig. 1). With the exception of lung fissures, all parameters received good scores in the group of noncooperative patients examined with either 50 or 180 mAs. The low scores assigned to fissures with both techniques in the noncooperative group were probably caused by age-related poor visualization of this anatomic landmark. Comparison of scans obtained with 34 versus 180 mAs only showed very small differences for fissures (Fig. 2) and peripheral structures. The median score for these parameters was the same at the two settings, but the scans obtained with 34 mAs received lower scores more frequently than their 180-mAs counterparts. This discrepancy in scoring was caused by blurring of the anatomic landmarks in the 34-mAs scans, which explains the small but significant statistical difference between the 34- and 180-mAs scores. Fissures and peripheral structures were, however, identified with the same incidence using the two settings (Figs. 2–4). In contrast to our findings in the artifacts study, the score for artifacts in the image quality study was slightly better for the 34-mAs scans than for 180-mAs scans ($p = 0.04$). This finding may have come about because the latter study was conducted only in cooperative patients, scan time for the low-milliamperage technique was shorter than that for the standard technique, and, most important, we evaluated a single slice rather than a set of slices. The quality of mediastinal images is poor with all high-resolution CT techniques. This low quality is because low-contrast structures, such as the mediastinum, are affected more by noise than high-contrast structures, such as the lung [8, 22]. However, mediastinal image scores were significantly better for scans obtained with 180 mAs than those obtained with low-milliampere settings ($p < 0.0001$). In addition, regardless of the milliamperage setting used, mediastinal images reconstructed with the standard filter received better scores than those reconstructed with the high-contrast-resolution filter. This finding is because of the smoothing effect of the standard reconstruction filter on noise involving low-contrast mediastinal structures.

The current study has proved that good-quality scans can be obtained using low-milliamperage techniques. However, this study was not designed to assess the diagnostic accuracy of the scans obtained with different techniques, which is work that remains to be done (one we plan to complete).

In conclusion, high-resolution CT of the chest performed with 50 and 34 mAs delivers radiation doses 72% and 80% lower, respectively, than the standard 180-mAs dose. Low-dose high-resolution CT examinations using the 34-mAs technique in children unable to follow breath-holding commands showed a high incidence of linear artifacts and should not be used in these patients. There were no differences in image quality between scans obtained with 50 mAs and those obtained with 180 mAs. Small differences, consisting of slight blurring of fissures and peripheral structures, were apparent when scans obtained with the 34-mAs setting were compared with those obtained with the 180-mAs setting.

High-resolution CT chest images of a quality comparable with that of images acquired the standard technique can be obtained with 50 mAs in all children. In cooperative children, the 34-mAs technique produces good images, which may be affected by some streak artifacts. Nevertheless, to obtain further reductions in radiation exposure, this technique is appropriate for children following breath-holding commands. Our results do not justify the routine use of milliampere settings of more than 50 mAs for high-resolution chest CT in children.

Acknowledgment

We thank Celine L. Cavallo for manuscript editing.

References

1. Kuhn JP. High-resolution computed tomography of pediatric pulmonary parenchymal disorders. *Radiol Clin North Am* **1993**;31:533–551
2. Lynch DA, Hay T, Newell JD Jr, Divgi VD, Fan LL. Pediatric diffuse lung disease: diagnosis and classification using high-resolution CT. *AJR* **1999**;173:713–718
3. Long FR, Castile RG, Brody AS, et al. Lungs in infants and young children: improved thin-section CT with noninvasive controlled-ventilation technique—initial experience. *Radiology* **1999**;212: 588–593
4. Seely JM, Effmann EL, Müller NL. High-resolution CT of pediatric lung disease: imaging findings. *AJR* **1997**;168:1269–1275
5. Curry TS, Dowdey JE, Murry RC. Computed tomography. In: Curry TS, Dowdey JE, Murry RC, eds. *Introduction to the physics of diagnostic radiology*, 3rd ed. Philadelphia: Lea & Febiger, **1984**:320–350
6. Mayo JR, Webb WR, Gould R, et al. High-resolution CT of the lungs: an optimal approach. *Radiology* **1987**;163:507–510
7. Rothenberg LN, Pentlow KS. Radiation dose in CT. *RadioGraphics* **1992**;12:1225–1243
8. Sprawls P. CT image detail and noise. *RadioGraphics* **1992**;12:1041–1046
9. Barnes JE. Characteristics and control of contrast in CT. *RadioGraphics* **1992**;12:825–837
10. Naidich DP, Marshall CH, Gribbin C, Arams RS, McCauley DI. Low-dose CT of the lungs: preliminary observations. *Radiology* **1990**;175:729–731
11. Ambrosino MM, Genieser NB, Roche KJ, Kaul A, Lawrence RM. Feasibility of high-resolution, low-dose chest CT in evaluation the pediatric chest. *Pediatr Radiol* **1994**;24:6–10
12. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*

1977;33:159–174
13. Koch GG, Landis JR, Freeman JL, Freeman DH, Lehnen RG. A general methodology for the analysis of experiments with repeated measurements of categorical data. *Biometrics* **1977**;33:133–158
14. Fleiss JL, Nee JCM, Landis JR. The large sample variance of kappa in the case of different sets of raters. *Psychol Bull* **1979**;86:974–977
15. Cohen J. *Statistical power analysis for the behavioral sciences*, 2nd ed. New York: Academic, **1988**
16. Robinson PJA. Radiology's Achilles' heel: error and variation in the interpretation of the Röntgen image. *Br J Radiol* **1997**;70:1085–1098
17. Webb WR, Müller NL, Naidich DP, eds. *High-resolution CT of the lung*. Philadelphia: Lippincott-Raven, **1996**:1–21
18. Bonelli FS, Hartman TE, Swensen SJ, Sherrick A. Accuracy of high-resolution CT in diagnosing lung diseases. *AJR* **1998**;170:1507–1512
19. Padley S, Gleeson F, Flower CDR. Current indications of high resolution computed tomography scanning of the lungs. *Br J Radiol* **1995**;65:105–109
20. Van der Bruggen-Bogaarts BAHA, Broerse JJ, Lammers JWJ, Van Waes PFGM, Geleijns J. Radiation exposure in standard and high-resolution chest CT scans. *Chest* **1995**;107:113–115
21. Fearon T, Vucich J. Pediatric patient exposures from CT examinations: GE CT/T 9800 scanner. *AJR* **1985**;144:805–809
22. Huda W, Atherton JV, Ware DE, Cumming WA. An approach for the estimation of effective radiation dose at CT in pediatric patients. *Radiology* **1997**;203:417–422
23. Mayo JR, Hartman TE, Lee KS, Primack SL, Vedal S, Müller NL. CT of the chest: minimal tube current required for good image quality with the least radiation dose. *AJR* **1995**;164:603–607
24. Mayo JR, Jackson SA, Müller NL. High-resolution CT of the chest: radiation dose. *AJR* **1993**; 160:479–481
25. Rusineck H, Naidich DP, McGuinness G, et al. Pulmonary nodule detection: low-dose versus conventional CT. *Radiology* **1998**;209:243–249
26. Rogalla P, Stöver B, Scheer I, Juran R, Gaedicke G, Hamm B. Low-dose spiral CT: applicability to paediatric chest imaging. *Pediatr Radiol* **1999**;28:565–569
27. Zwirewich CV, Mayo JR, Müller NL. Low-dose high-resolution CT of lung parenchyma. *Radiology* **1991**;180:413–417
28. Posniak HV, Olson MC, Demos TC, Pierce KL, Kalbhen CL. CT of the chest and abdomen in patients on mechanical pulmonary ventilators: quality of images made at 0.6 vs 1.0 sec. *AJR* **1994**;163:1073–1077