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CHEST IMAGING
ORIGINAL ARTICLE

Radiation dose management in thoracic CT: an international survey

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PURPOSE
We aimed to examine current practice patterns of international thoracic radiologists regarding radiation dose management in adult thoracic computed tomography (CT) examinations.

MATERIALS AND METHODS
An electronic questionnaire was sent to 800 members of five thoracic radiology societies in North America, Europe, Asia, and Latin America addressing radiation dose training and education, standard kVp and mAs settings for thoracic CT, dose reduction practices, clinical scenarios, and demographics.

RESULTS
Of the 800 radiologists, 146 responded to our survey. Nearly half (66/146, 45% [95% confidence interval, 37%–53%]) had no formal training in dose reduction, with "self-study of the literature" being the most common form of training (54/146, 37% [29%–45%]). One hundred and seventeen (80% [74%–87%]) had automatic exposure control, and 76 (65% [56%–74%]) used it in all patients. Notably, most respondents (89% [84%–94%]) used a 120 to 125 kVp standard setting, whereas none used 140 kVp. The most common average dose-length-product (DLP) value was 150 to 249 mGy.cm (75/146, 51% [43%–59%]), and 59% (51%–67%) delivered less than 250 mGy.cm in a 70 kg patient. There was a tendency towards higher DLP values with multidetector-row CT. Age, gender, and pregnancy were associated more with dose reduction than weight and clinical indication.

CONCLUSION
Efforts for reducing patient radiation dose are highly prevalent among thoracic radiologists. Areas for improvement include reduction of default tube current settings, reduction of anatomical scan coverage, greater use of automatic exposure control, and eventually, reduction of current reference dose values. Our study emphasizes the need for international guidelines to foster greater conformity in dose reduction by thoracic radiologists.

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The overall increase in patient irradiation caused by the growing use of spiral- and multidetector-row computed tomography (MDCT) is of particular relevance for thoracic imaging. The number of clinical indications for thoracic computed tomography (CT) has steadily increased, and CT has become a first line imaging tool for diseases previously imaged with chest radiography, ventilation/perfusion scintigraphy, and pulmonary angiography (1). Moreover, the use of CT for screening purposes has raised the number of examinations performed in clinically asymptomatic patients (2). Finally, the relatively higher number of CT examinations performed in younger patients increases cumulative radiation in a population vulnerable to its potential long-term effects (3). Therefore, the main current challenge of thoracic MDCT is to achieve diagnostic performance at reduced levels of radiation exposure.

Although recent publications have addressed radiation-related topics in CT imaging of specific thoracic diseases (4–10), the approach of thoracic radiologists to patient radiation and their specific strategies for dose reduction are not known. Knowledge of these practice patterns could potentially focus and guide ongoing efforts towards dose reduction (9, 11, 12). The aim of our study, therefore, was to analyze the current practice patterns of international thoracic radiologists regarding dose reduction in adult thoracic CT examinations.

Materials and methods

Survey methods

In June 2008, a survey was sent to all members of five major thoracic radiology societies (the European Society of Thoracic Radiology, the Fleischner Society, the Japanese Society of Thoracic Radiology, the Korean Society of Thoracic Radiology, and the Society of Thoracic Radiology) with approval from the society presidents. Each society member received an email containing an invitation to complete the web-based survey, as well as survey instructions. Only radiologist members were asked to complete the survey. A second request to complete the survey was sent in mid-July 2008.

An institutional review board exemption was granted for this study. All societal members contacted by email were informed of the purpose of our study before participation. All survey responses were completed online and electronically returned for collection and tabulation. Anonymity of individual responses was preserved.

To avoid duplications from individual respondents who are members of more than one society, the instructions specifically stated that the survey be completed only once. To prevent duplicate survey submissions, typically caused when a user hits the "submit" button of a web-based survey more than once, the responsible data collector monitored any instances of more than one survey coming from the same computer address at nearly the same time. Any such occurrences were considered to be duplicates and only the final submission was retained.

Questionnaire

The questionnaire is shown in the Appendix. Part 1 was related to radiation protection in thoracic CT and constituted the main part of the questionnaire. In this part, respondents were asked about their educational background in dose management. The questions also addressed general technical settings for CT, motives for dose reduction, and practical scenarios in which dose reduction could be applied. Part 2 addressed the professional background of the respondents, and the questions collected data on individual demographics, clinical practice, society membership, and types of CT scanners used. Finally, Part 3 gave the respondents the option of providing additional comments related to the topic but not directly covered by the questionnaire.

Statistical analysis

All statistical analyses were performed using a commercially available software (Statistical Package for Social Sciences, version 16.0, SPSS Inc., Chicago, Illinois, USA). Normally distributed data were expressed as mean±standard deviation, and data that were skewed were expressed as medians with the upper and lower quartiles. Sample estimate prevalences were reported with 95% confidence intervals (CI). Comparisons between groups were performed using a Pearson's chi-square test. To facilitate comparisons, individual smaller subgroups were regrouped into larger groups, as indicated in the Results section. For example, individual European countries were regrouped as "Europe", and the United States and Canada were regrouped as "North America". Type 1 error was set at 0.05.

Results

Of the estimated 800 radiologists who received the survey, 146 (18%) completed and returned the survey. Detailed results of our survey questions 1 to 16 are described below.

Question 1: Education and training with respect to radiation protection and dose reduction

Results from Question 1 are presented in Fig. 1. Most survey respondents (68/146, 47% [95% CI, 38%–55%] combined the attendance of dedicated courses, learning from on-the-job training and self-study of the literature to stay up to date regarding radiation reduction and dose protection. Self-study of the literature (n=54, 37% [29%–45%]) was more common than combined attendance of dedicated courses, learning from on-the-job training, or none of the proposed choices (n=21, 14% [9%–20%]).

Question 2: Implementation of automated exposure control

Most survey respondents (117/146, 80% [74%–87%]) had automatic exposure control (AEC) implemented in their CT units.

Question 3: Use of automated exposure control

The proportion of survey respondents who had AEC switched on for all patients was 65% (56%–74%, n=76); the remaining proportion (35%) did not have it switched on (26%–44%, n=41).

Question 4: Use of protection devices for female breast

More survey respondents did not use protection devices for the female breast (n=112, 77% [70%–84%]) than those who did use such devices (n=34, 23% [16%–30%]), either alone (n=8, 5% [2–9%]) or in combination with AEC (n=26, 18% [12%–24%]).

Question 5: Routine standard kVp settings

More survey respondents used standard kVp settings of 120 to 125 kVp (130/146, 89% [84%–94%]) than those who used 100 to 110 kVp (n=14, 10% [5%–14%]), 80 to 90 kVp (n=2, 1% [0%–3%]), or 130 to 140 kVp (n=0, 0%).

Question 6: Patient characteristics leading to kVp and mAs changes

Results from Question 6 are presented in Fig. 2. Pregnancy was the most frequent patient characteristic (n=67, 27% [21%–32%]) for modifying the standard kVp and mAs settings provided by the CT manufacturer. This characteristic was closely followed by "patient younger than 45 years" (n=55, 22% [17%–27%]) and "patients who

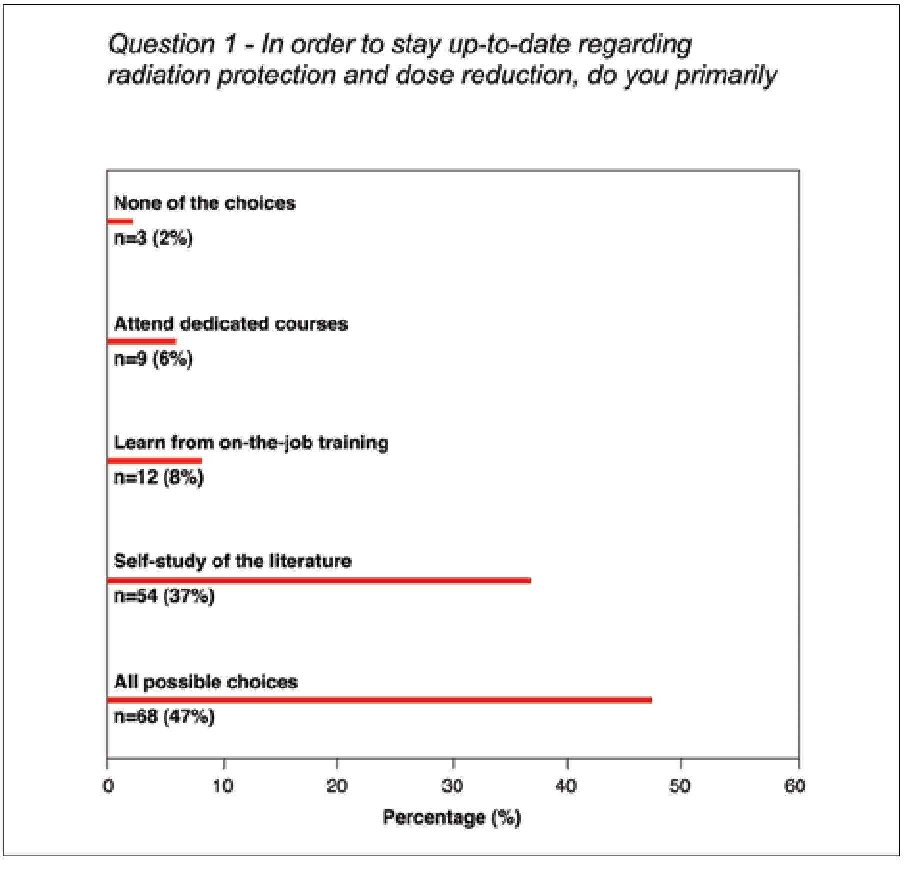

Figure 1. The graph shows the number and percentages of the answers given to survey Question 1. asking primary sources in order to stay up-to-date regarding radiation protection and dose reduction.

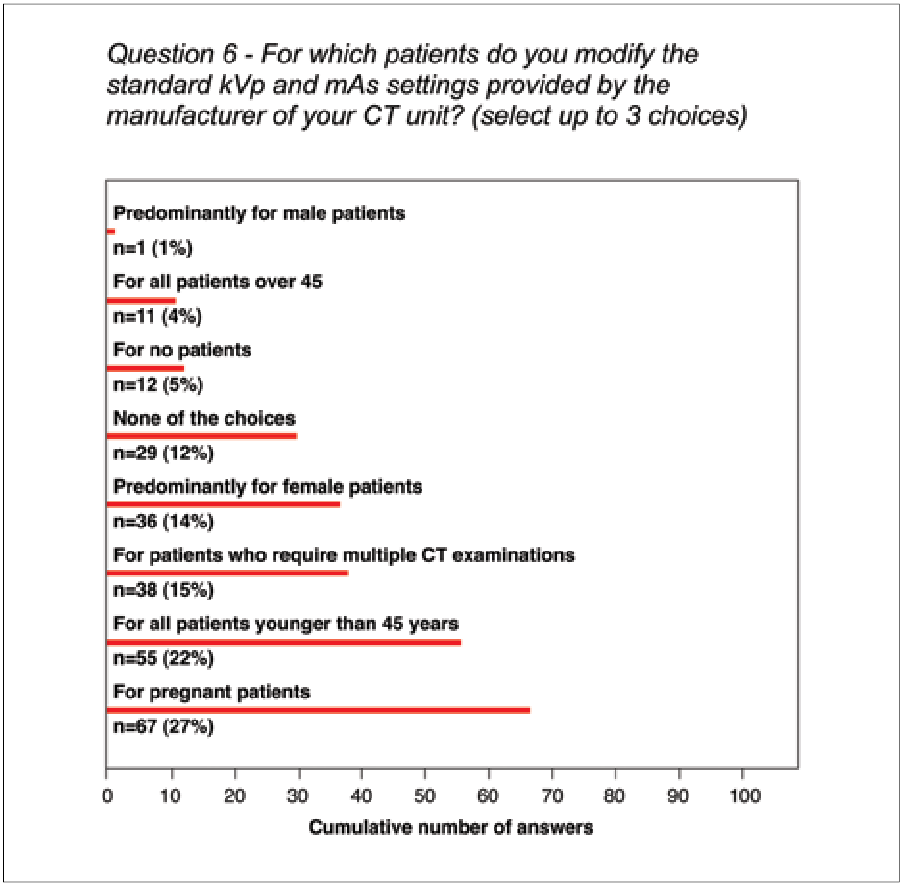

Figure 2. The graph shows the number and percentages of the answers given to survey Question 6. Because multiple answers were possible, the figures are cumulative.

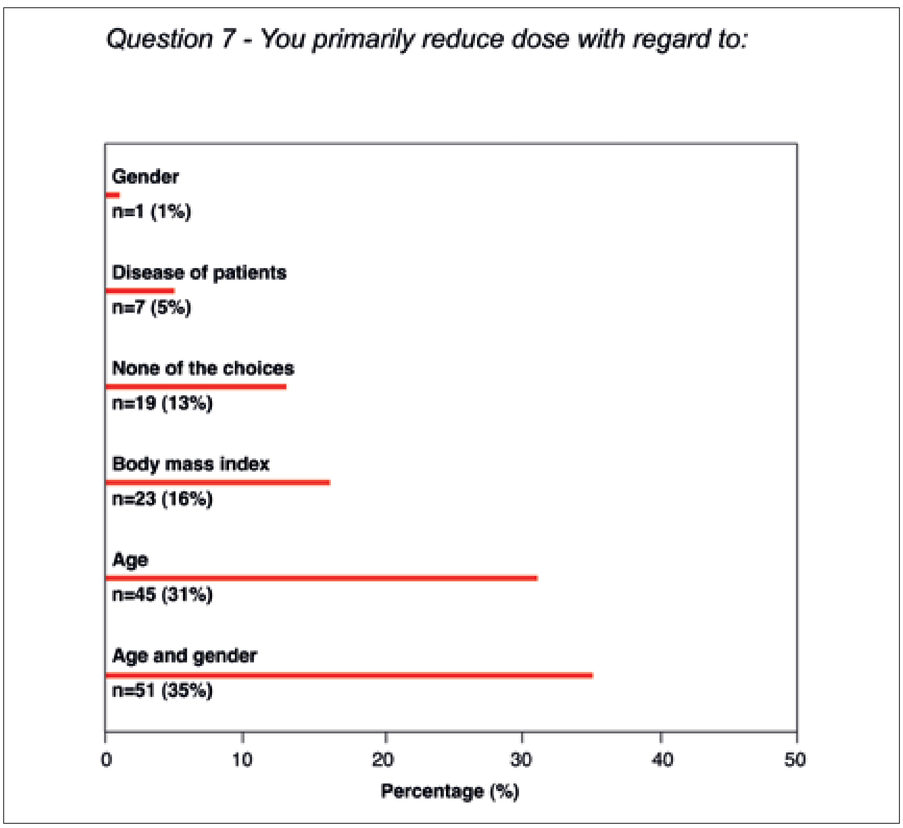

Figure 3. The graph shows the number and percentages of the answers given to survey Question 7.

require multiple CT examinations" (n=38, 15% [11%–20%]). These three motives combined (n=160, 64% [58%–70%]) were more frequent than all other motives (n=89, 36% [30%–42%]).

Question 7: Reasons for dose reduction

Results from Question 7 are presented in Fig. 3. The most common motive for dose reduction (51/146, 35% [27%–43%]) was "age and gender of the patient", followed by "patient age" (n=45, 31% [23%–38%]) and "body mass index" (n=23, 16% [10%–22%]). These three motives combined (n=119, 82% [75%–88%]) were more frequent than all other motives (n=27, 18% [12%–25%]).

Question 8: Adjustment of kVp with respect to patient weight

More survey respondents adjusted the kVp settings according to the patient's weight and/or the indication for CT (n=92, 63% [55%–71%]) than those who did not (n=54, 37% [29%–45%]).

Question 9: Average dose-length-product (DLP)

Results from Question 9 are presented in Fig. 4. The most commonly reported average DLP for a thoracic CT examination of a patient of 70 kg weight and 170 cm height was 150 to 249 mGy.cm (75/146, 51% [43%–59%]). The proportion of respondents who chose DLP settings lower than 250 was not different in North America (44/82, 54% [43%–64%]) compared to Europe (25/36, 69% [54%–84%]).

Question 10: Dose reduction with respect to manufacturer default settings

Results from Question 10 are presented in Fig. 5. When asked about the patient category in which a 40% reduction in mAs could be reasonably achieved without adversely affecting image quality, the most frequent responses were "slim patients" (n=75, 41% [33%–48%]), "normal body weight patients" (n=60, 31% [26%–39%]), and "almost every patient" (n=44, 24% [18%–30%]). No difference was found between "slim patients" and "normal body weight patients", or between "normal body weight patients" and "almost every patient".

Question 11: Additional supine and expiratory CT sections

More survey respondents acquired additional expiratory and/or prone CT sections in less than 20% of their CT

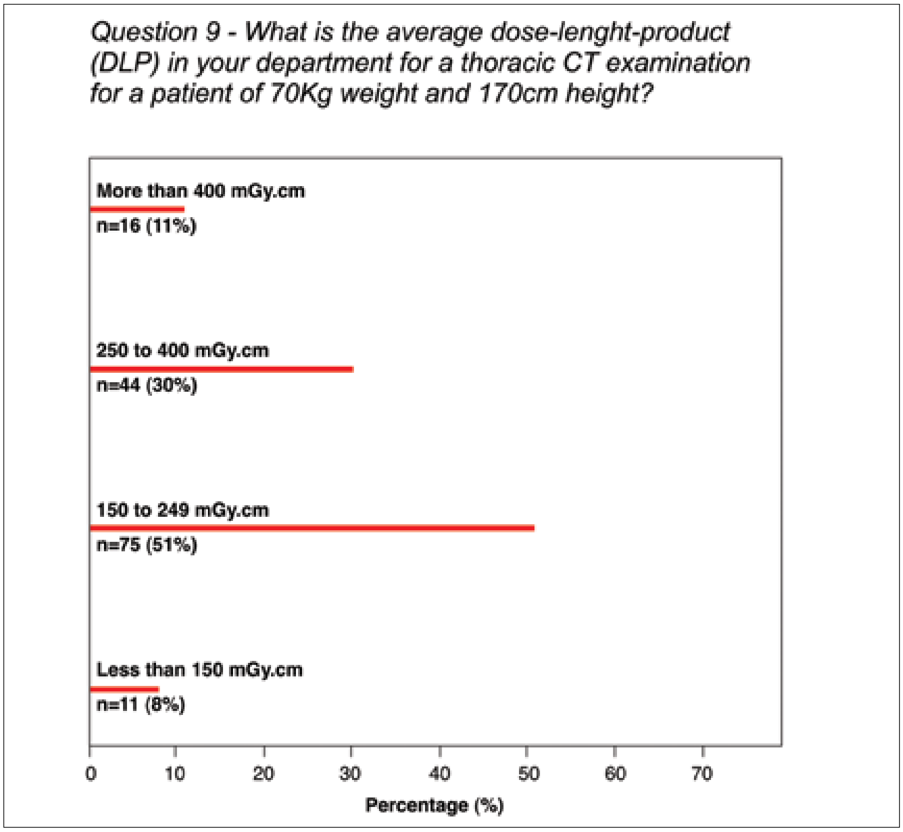

Figure 4. The graph shows the number and percentages of the answers given to survey Question 9.

examinations (122/146, 84% [78%–90%]) than those acquiring additional expiratory and/or prone CT sections in more than 20% of their CT examinations (n=24, 16% [10%–22%]).

Question 12: Years of radiology practice

Fourty-six survey respondents (32% [24%–39%]) had practiced radiology for 11 to 20 years. No difference in number was found in the respondents practicing 10 years or less (n=47, 33% [25%–40%]), practicing between 11 and 20 years (n=46, 32% [24%–39%]), and practicing more than 20 years (n=53, 36% [29%–44%]).

Question 13: Practice setting

Most survey respondents practiced in a primarily academic or teaching hospital setting (115/146, 79% [72%–85%]). These respondents were more numerous than those practicing primarily in private practice (n=11, 8% [3%–12%]) or in a combination of academic and private practice setting (n=20, 14% [8%–9%]).

Question 14: Scanner type

Most survey respondents (125/146, 86% [80%–91%]) used a 16-, 32-, 64-row or greater multidetector row helical CT. These respondents were more numerous than those using a 4- to 8-row multidetector row helical CT (n=11, 8% [3%–12%]), single detector helical CT (n=5, 3% [0%–6%]), or dual-source CT (n=5, 3% [0%–6%]).

Question 15: Society affiliations

Results from Question 15 are presented in Fig. 6. Most survey respondents with memberships in only one thoracic imaging society were members of the Society of Thoracic Radiology (77/146, 53% [45%–61%]), followed by members of the European Society of Thoracic Imaging (n=26, 18% [12%–24%]), and members of the Japanese Society of Thoracic Radiology (n=17, 12% [6%–17%]). Survey response according to this criterion likely reflects the size of the individual societies and does not account for membership in multiple societies.

Question 16: Geographical location of practice

Most survey respondents practiced in North America (82/146, 56% [48%–64%]). These respondents were more numerous than respondents from Europe (n=36, 25% [18%–32%]) or the combined respondents from South America (n=6, 4% [1%–7%]), Asia (n=19, 13% [8%–18%]), and the Middle East (n=28, 19% [13%–26%]).

Eighteen respondents (12% [7%–21%]) provided additional comments. The most common comments included potential additional approaches for reducing dose and for specific patient subsets, such as pediatric patients or patients undergoing thin-section CT follow-up only, that were not explicitly addressed by our survey.

Discussion

Our study analyzed the current practice patterns of international thoracic radiologists regarding dose reduction in adult thoracic CT examinations and has provided the following main findings. First, our survey suggests that the previously common tube setting of 140 kVp for thoracic CT has been widely abandoned. None of the respondents reported using this previously common setting. Instead, 89% of survey respondents use a default tube setting of 120 kVp. Their practice is in accordance with a recent recommendation to use tube settings of 120 kVp or lower in body CT (13). Indeed, 11% of survey respondents already use default tube settings below 120 kVp. Overall, the survey indicates a trend towards lower default kVp settings and, as a consequence, towards lower patient irradiation in thoracic CT.

Second, a majority of survey respondents agreed that default tube current settings of CT scanner manufacturers could be reduced by 40% without adversely affecting image quality. Default tube settings are not necessarily consistent with the as-low-as-reasonably-achievable (ALARA) principle. Indeed, manufacturers' protocols are often aimed to generate images with minimal noise levels and typically result in a DLP of 350 to 400 mGy.cm for a standard patient (13). A 40% dose reduction would result in a DLP averaging less than 250 mGy.cm.

Third, 59% of survey respondents apply a DLP of less than 250 mGy.cm for a standard patient of 70 kg weight and 170 cm height without compromising the quality of the chest CT examination. Remarkably, 250 mGy.cm represents less than half of the current reference level for thoracic CT (14). Reg-

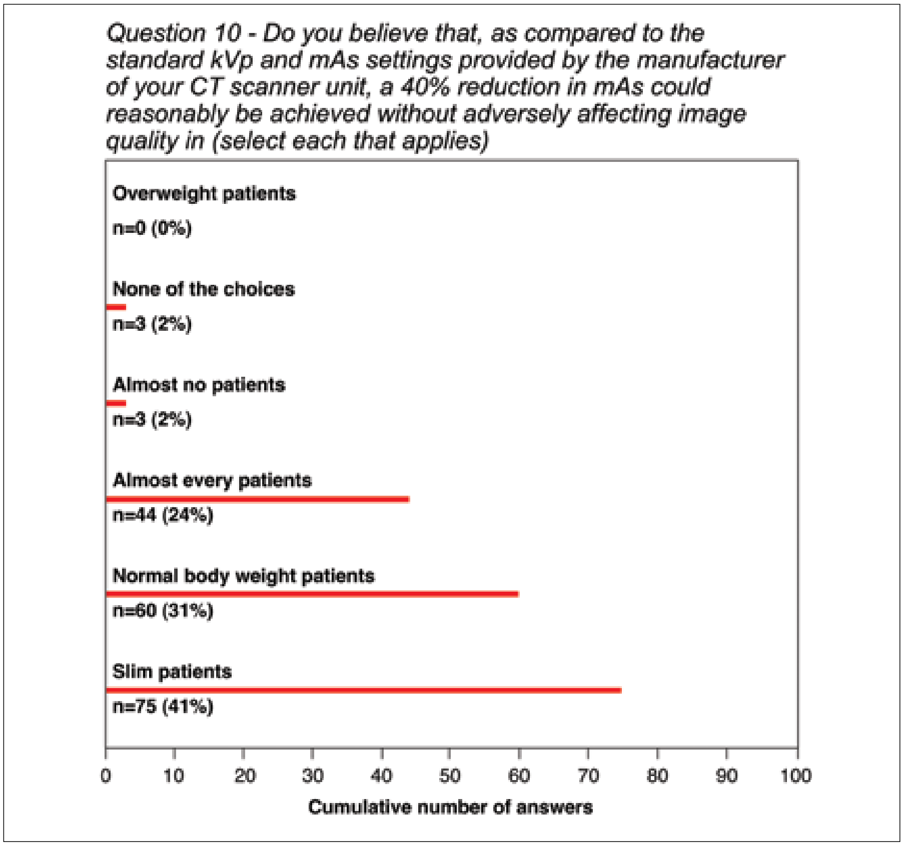

Figure 5. The graph shows the number and percentages of the answers given to survey Question 10. Because multiple answers were possible, the figures are cumulative.

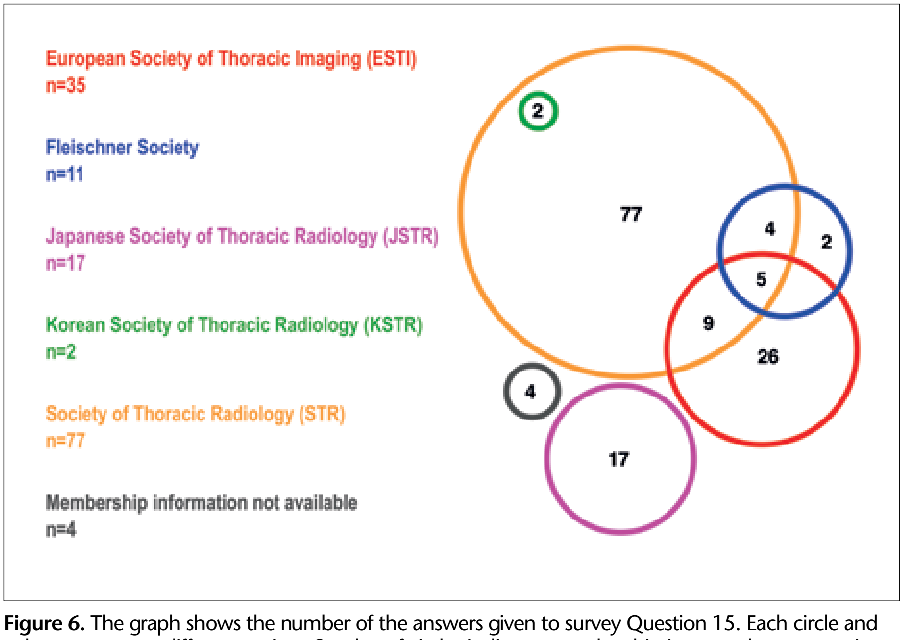

Figure 6. The graph shows the number of the answers given to survey Question 15. Each circle and color represents a different society. Overlap of circles indicates membership in more than one society.

ulatory authorities could consider this survey result as a suggestion for readapting theoretical dose limits to lowered dose practices for standard chest CT.

Fourth, 92% of respondents were equipped with MDCT units. Simultaneously, 92% of respondents confirmed applying DLPs of more than 150 mGy.cm. The two responses can be explained by considering that volume scans performed using MDCT have become popular among chest radiologists. Such volumetric CT coverage can indeed substantially increase the DLP as compared to sequential (non-contiguous) thin-section CT, whereas the restriction to sequential sections has the contrary effect (1).

Fifth, at least 80% of survey respondents have their CT scanner equipped with AEC, but only 65% use it. Although we did not survey the motives for the non-use of AEC, it is possible that the numerous challenges related to the use of AEC might limit its acceptability among some thoracic radiologists (15). For example, in order to provide satisfactory results, AEC requires multiple inputs, such as the definition of desired image quality for different clinical indications and patient age, and the definition of upper and lower tolerance tube settings tailored to the patient's body habitus (15–17). However, little directive information that could help radiologists in generating these multiple inputs currently exists.

The answers to several key questions of our survey reflect a large variability in dose-related practice patterns and methods of training among our respondents. Answers to Question 9, for example, showed a relatively balanced distribution of proposed DLP-values for the standard patient. Questions 6 and 10 showed comparable amounts of patient characteristics that were judged to allow for individual dose reduction. Finally, answers to Question 1 emphasized the variability in radiologists' approaches to education regarding radiation protection. As this variability also associated with the low response rate to the survey, it is possible that dose radiation in chest CT is not considered as a priority for continuous education and clinical practice. Although the etiology for this variability is uncertain, it could reflect the absence of generally accepted guidelines for radiation protection in thoracic radiology and the resulting need of thoracic radiologists to rely upon internally developed approaches to dose reduction. Previous publications have addressed the issue of radiation protection in thoracic radiology (1). However, at the time our survey was performed, there was no detailed, practical manual to guide radiologists in dose reduction in practical clinical situations. Moreover, no internationally accepted curriculum currently standardizes education in radiation dose reduction.

Overall, our findings have the following practical implications. Because of the potential to lower patient irradiation, the trend towards lower kVp settings in thoracic CT should be sustained. The non-use of AEC by a substantial minority of thoracic radiologists calls for further promoting the dose reduction potential of this technique and developing practical guidelines to assist radiologists in implementing this method. In the interest of dose reduction, radiologists might also consider sequential examination protocols whenever appropriate (e.g. thin section CT follow-up of a patient with known interstitial lung disease) and to reserve volumetric CT for indications in which this approach is diagnostically indispensable. A DLP of 250 mGy.cm appears to be a reasonable target for the maximum radiation delivered by thoracic CT. As this falls well below the current reference value, the regulating agencies should, eventually, consider reducing their reference values for thoracic CT. Finally, to reduce variability in practice patterns and methods of training, internationally accepted curricula and practical guidelines for radiation protection in thoracic radiology should be developed.

Our study has several limitations. First, the overall 18% response rate was relatively low, but falls within the range of published physician surveys (18, 19). The recent literature confirms that low survey response rates alone do not necessarily result in response bias and vice-versa (20). Our response rate, however, increases the likelihood that thoracic radiologists who are aware of radiation related issues and are already implementing dose reduction in their current practice could be over-represented in our sample. The potential lack of information about thoracic radiologists with less awareness of dose reduction should, therefore, not encourage an overly optimistic interpretation of our findings. Moreover, any interpretation of our findings should recognize that a vast majority of our respondents worked in academic centers. Second, the small size of individual subgroups resulting from the relatively high number of individual questions precluded the use of multivariate statistical analysis. Overall interdependence of multiple factors, therefore, could not be assessed. To nevertheless allow for more robust statistical comparisons, we merged certain subcategories of surveyed parameter into new categories. For example, individual European countries were regrouped as “Europe”, and the United States and Canada were regrouped as “North America”. It is conceivable that this merging might have diluted differences between some of the originally surveyed parameters. Accordingly, training schemes in individual parts of the world could not be evaluated in detail and will require further investigation. Moreover, the small size of individual subgroups might also have impacted the statistical power of our analyses. Therefore, the lack of statistical significance for some of our comparisons does not necessarily imply that such differences do not exist. Third, although our survey was internationally targeted, our questionnaire was only in English, which might have precluded responses from international radiologists who may not have been comfortable enough with this language to complete the survey. Fourth, although all included societies update their membership lists regularly, it is possible that some of the email addresses might have been outdated and that, as a consequence, prospective recipients did not receive the survey. Fifth, the clinical scenarios described in the questionnaire were basic and did not account for the many nuances encountered in daily practice. For example, the questionnaire did not explore the differences in radiation dose related to the use of specific protocols and settings (unenhanced vs. contrast-enhanced scans, protocols adapted to specific clinical indications, pitch value, etc.). The CT dose index, which is an increasingly used index of radiation exposure but initially not available on individual CT protocols, was not evaluated. The approach of thoracic radiologists to the new iterative reconstruction techniques that allow up to 50% of dose reduction was also not investigated (21, 22). Potential conclusions from these scenarios, therefore, cannot indicate more than a general trend. Sixth, this observational study was performed in 2008. New scanner generations have been introduced since 2008 by all vendors. With modern equipment, the new reference for DLP in chest CT could be much lower than 150 mGy.cm (23).

In conclusion, our study documents the widely prevalent efforts of international thoracic radiologists for reducing patient radiation dose in thoracic CT. Simultaneously, our study highlights potential areas for further improvement, notably as to the reduction of default tube current settings, the reduction of anatomical scan coverage, the greater use of AEC, and eventually, the reduction of current reference dose values. Together with the wide variability in practice patterns highlighted by our results, our study emphasizes the need for international guidelines to foster greater conformity in dose reduction by thoracic radiologists.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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Part 1 The following questions relate to radiation protection in thoracic CT imaging.	
1. In order to stay up-to-date regarding radiation protection and dose reduction, do you primarily:	○ Attend dedicated courses ○ Self-study of the literature ○ Learn from "on-the-job" training ○ All of the above ○ None of the above
2. Is Automated Exposure Control (AEC) software implemented in your CT scanner unit?	○ Yes ○ No. Skip to #4 ○ I don't know. Skip to #4
3. If you answered "Yes" to the previous question, is the Automated Exposure Control (AEC) software switched on for all of your patients?	○ Yes ○ No Clear Answers
4. Do you use protection devices for the female breast?	○ No ○ Yes, protection devices alone ○ Yes, combined with Automated Exposure Control (AEC)
5. For routine CT examinations of the thorax, excluding CT-angiography, your standard kVp-settings are:	○ 130–140 kVp ○ 120–125 kVp ○ 100–110 kVp ○ 80–90 kVp
6. For which patients do you modify the standard kVp and mAs settings provided by the manufacturer of your CT unit? [*Select up to 3 choices*]	☐ For all patients younger than 45 years ☐ Predominantly for female patients ☐ For none of the patients ☐ Predominantly for male patients ☐ For all patients over 45 ☐ For patients who require multiple CT scans ☐ For pregnant patients ☐ None of the above
7. You primarily reduce dose with regard to:	○ Disease of the patient ○ Body mass index of the patient ○ Age of the patient ○ Gender of the patient ○ Age and gender of the patient ○ None of the above
8. Do you adjust the kVp-settings according to the patient's weight, and/or according to the indication for CT (e.g., CT-angiography for suspected pulmonary embolism, screening for lung nodules, follow-up of interstitial lung disease)?	○ Yes ○ No
9. What is the average dose-length-product (DLP) in your department for a thoracic CT examination for a patient of 70 kg weight and 170 cm height?	○ Less than 150 mGy.cm ○ 150–249 mGy.cm ○ 250–400 mGy.cm ○ More than 400 mGy.cm
10. Do you believe that, as compared to the standard kVp and mAs settings provided by the manufacturer of your CT scanner unit, a 40% reduction in mAs could reasonably be achieved without adversely affecting image quality in [*select each that applies*]	☐ Almost no patients ☐ Slim patients ☐ Normal body weight patients ☐ Almost every patients ☐ Overweight patients ☐ None of the above
11. In which percentage of your inspiratory supine CT examinations do you acquire additional expiratory and/or prone CT sections?	○ In less than 20% ○ In 21% to 40% ○ In 41% to 60% ○ In over 60%

Part 2 The following questions relate to background and your practice.	
12. How many years have you been practicing radiology?	○ less than 5 years ○ 5 to 10 years ○ 11 to 20 years ○ 21 to 30 years ○ more than 30 years
13. What is your type of practice?	○ Primarily academic or teaching hospital setting ○ Primarily private practice ○ Combination of academic and private practice settings
14. Which of following CT scanner types is most commonly used for CT examinations of the thorax in your practice?	○ Non-helical CT ○ Single-detector helical CT ○ 4- to 8- multi-detector row (multidetector row) helical CT ○ 16-, 32-, 64- or greater multi-detector row (multidetector row) helical CT ○ Dual-source CT scanner
15. Of which of the following societies are you a member [*select all that apply*]?	☐ European Society of Thoracic Imaging (ESTI) ☐ Fleischner Society ☐ Japanese Society of Thoracic Radiology (JSTR) ☐ Korean Society of Thoracic Radiology (KSR) ☐ Society of Thoracic Radiology (STR) ☐ None of the above
16. Please name the country in which you practice radiology:	

Part 3 (optional) Please feel free to share any comments below:
17.
Submit Survey