

Pediatricians' awareness of diagnostic medical radiation effects and doses: are the latest efforts paying off?

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PURPOSE

The number of radiological exams performed on children increases each year. We assessed the current understanding of radiation doses and risks among a sample group of pediatricians and evaluated whether the latest efforts to improve radiation awareness affected the results.

MATERIALS AND METHODS

A multiple-choice survey comprising 16 questions was answered by 237 pediatricians in 10 hospitals.

RESULTS

Although the overall knowledge was poor, underestimation of radiation doses of common radiological procedures was significantly lower (75.2%) than that reported in previous surveys (87%–97%). In contrast to previous reports, the percentage of underestimates did not increase for computed tomography (74.8%), and residents scored (7.5±5.1) better than specialists (11.0±6.3) in estimating the radiation doses ($P < 0.001$). Only 3.1% of the pediatricians had received formal education on medical radiation, and 89% were not aware of the ALARA (*As Low As Reasonably Achievable*) principle.

CONCLUSION

Pediatricians' radiation dose awareness is better than it was a few years ago, and the latest educational efforts in the form of campaigns, reports, publications, and news media seem to have had a beneficial effect. The younger generation had better knowledge, possibly because they were exposed to discussions of radiation dosage at an earlier stage in their training.

Key words: • radiation dosage • radiation effects • children
• survey methodology • continuing education

Radiographic imaging is extremely valuable as a diagnostic tool in medicine, but ionizing radiation also carries well-known potential risks. The United States Food and Drug Administration classified X-ray as a human carcinogen in their 11th report on carcinogens in 2004 (1).

Due to the rapid advances in imaging technology, such as the introduction of multidetector arrays and positron emission tomography-computed tomography (PET-CT), both the number and variety of radiological applications are dramatically increasing (2, 3). In particular, CT, which accounts for approximately 4% of the medical radiologic examinations but contributes to 40% of the total collective dose, is responsible for the majority of the radiation received by patients (4). Importantly, there has been an eight-fold increase in the number of yearly CT exams performed in the pediatric population since the 1980s (3).

Children are more sensitive to radiation than middle-aged adults by a factor of 10 and are the ultimate risk group (5, 6). They face an increased organ dose per mAs and an increased lifetime risk per organ dose. In addition, children have more decades of life ahead of them than adults. CT examinations of patients under 15 years of age contribute to only 4% of all CT scans by number but are associated with approximately 20% of the total potential cancer mortality from CT examinations (7). A young child undergoing a CT scan has an increased lifetime risk of fatal cancer of approximately 1 in 1000 (0.18% for an abdominal CT and 0.07% for a head CT) (7).

The concern about exposing children to increasing amounts of medical radiation each year has greatly increased the number of publications regarding pediatric dose issues. This trend has increased the level of radiation awareness among pediatric radiologists. However, the level of knowledge of the pediatricians who request these radiologic exams, including CT, is unclear. Although there are several published studies regarding the radiation awareness of physicians caring for adult patients (8–12), to our knowledge, there is currently only one study, published in 2006 from Canada (13), that focuses on the radiation knowledge of pediatricians, who care for the most vulnerable population.

The present study was designed to investigate the current understanding of radiation doses and risks among a sample group of pediatricians and to assess the impact of the latest efforts to improve radiation awareness in the form of publications, campaigns, and news media. Our approach of comparing different groups of pediatricians, i.e., residents to specialists and doctors working in government hospitals to doctors working in university hospitals, was novel and yielded interesting results.

Materials and methods

The study was approved by the Regional Research Ethics Board. Over a period of nine months, a multiple-choice survey comprising 16 questions

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was distributed to 237 pediatric physicians and surgeons working in 10 hospitals (four university hospitals, five government hospitals, one private hospital). The names of the hospitals and the numbers of respondents are given in Table 1. The group consisted of academic staff (attending doctors) at university hospitals, department chiefs, fellows, practicing pediatricians, and both senior and junior residents, all of whom are in charge of evaluating pediatric patients and making requests for CT examinations. We refer to the entire group as 'pediatricians'. We visited the departments of the university or government hospitals, and a number of surveys were given during pediatric meetings. The questionnaires were completed either on an individual basis or in small groups in the company of the first (A.S.E.) or second (C.U.) author. Participants had no access to external references, and all agreed to complete the survey.

The questionnaire was multiple-choice and was divided into three main sections. The first three questions were directed toward obtaining demographic information. The second section assessed basic knowledge on the fundamentals of ionizing radiation, including radiation risks and protection. The third section assessed the participants' ability to estimate the radiation dose of common radiological procedures. For this purpose, the effective dose of a posteroanterior chest X-ray for a 5-year-old child (0.006 mSv) was considered to be 1 unit (13). The effective dose was defined as the sum of the weighted equivalent radiation doses in all of the organs and tissues of the body, and it was used to provide a single number to represent the total cancer risk (secondary to a certain radiological procedure). The doses for various radiological exams were compared with the number of chest X-ray equivalents, a method used in previous reports (8–13) that is considered user-friendly. The responses were standardized using a chart to mark the respondent's estimate of radiation exposure for eight procedures (Fig. 1, Q16).

For conventional X-rays and voiding cystourethrograms (VCUGs), doses corresponding to our current departmental parameters, which are compatible with the literature (13, 14), were accepted as the reference values for calculating the relative chest X-ray equivalent units (Table 2). In general, the parameters used for conventional pediatric

radiograms did not differ much between centers. This was not the case, however, for pediatric CT examinations. There was a wide variability of selected imaging parameters and the type of CT equipment used (i.e., single or 4 to 64 multidetector), which results in

different patient doses. For this reason, we used the mean values of the doses reported in the literature to establish reference doses for pediatric CT exams (13, 15–17) (Table 3).

In Fig. 1, a sample survey that contains the correct answers is presented.

Table 1. List of hospitals and the numbers of respondents included in the study

Hospital name	Respondents	Residents	Specialists
Hacettepe University	13	12	1
Ankara University	12	9	3
Gazi University	39	13	16
Kırıkkale University	12	7	5
Subtotal (University Hospitals)	76	41	35
S. B. Dr. Sami Ulus Children's Hospital	81	47	34
Etlik SSK Hospital	9	2	7
Dişkapi SSK Hospital	53	30	23
S. B. Ankara Hospital	8	5	3
S. B. Atatürk Hospital	7	4	3
Subtotal (Government Hospitals)	158	87	71
Private Clinic	3	0	3
TOTAL	237	129 (54.4%)	108 (45.6%)

Table 2. Estimated effective doses of conventional radiography for a 5-year-old child derived from our departmental practices, which are consistent with the literature

Type of exam	Technical parameters	Effective dose (mSv)	CXR equivalents
PA CXR	82 kVp, 5 mAs, 2.5 mm Al filtration	0.006	1
AP pelvis radiograph	68 kVp, 6.4 mAs, 2.5 mm Al filtration	0.06	10
VCUG	5 spot exposures and 1–2 min fluoroscopy	0.4	317

PA, posteroanterior; AP, anteroposterior; CXR, chest X-ray; VCUG, voiding cystourethrogram.

Table 3. Reference CT effective doses and the number of chest equivalents for a 5-year-old child, as derived from the literature

Study	abd/pelvis	Cranial (2 phases)	Chest	Neck/chest/abd	Comments
Shrimpton, et al. UK, 2003 (15)	-	3 mSv	3.6 mSv	-	SSCT and MSCT
Pages, et al. Belgium, 2003 (16)	2.3–19.9 mSv	0.4–2.3 mSv	1.1–6.6 mSv	-	SSCT and MSCT
Thomas, et al. USA, 2006 (13)	8.3 mSv	7 mSv	3.6 mSv	10.4 mSv	MSCT
Thomas and Wang, USA 2008 (17)	8.4 mSv	4.8 mSv	3.7 mSv	-	MSCT
Mean effective dose	9.7 mSv	3.5 mSv	3.7 mSv	-	
No. CXR equivalents	1620	583	620	1733	

abd, abdomen; CXR, chest X-ray; SSCT, single-slice CT; MSCT, multi-slice CT.

Pediatric Imaging Survey

I. Demographics

1. Current hospital you are working at:
 - a. Children's hospital (government)
 - b. Another government hospital
 - c. University hospital
 - d. Private practice
2. What is your job title?
 - a. Chief of the department / assistant chief
 - b. Attending in a university hospital
 - c. Fellow / staff / pediatrician
 - d. Resident
3. Clinical Experience
 - a. Junior resident (less than 3 years)
 - b. Senior resident (more than 3 years)
 - c. Specialist less than 5 years
 - d. Specialist 5–10 years
 - e. Specialist 10–20 years
 - f. Specialist more than 20 years

II. General Radiation Knowledge

4. The public is faced with ionizing radiation both from natural and man-made sources. Of these, medical radiation contributes to:
 - a. 1.5%
 - b. 5%
 - c. 15%
 - d. 50%**
 - e. 90%
 - f. I don't know
5. Have you ever heard of the ALARA principle in radiology?
 - a. Yes
 - b. No
6. There is a limit of radiation dose that a radiation worker is allowed to receive in one year (20 mSv/year in IRR99). What is the annual dose a patient is allowed to receive in mSv?
 - a. 10
 - b. 20
 - c. 50
 - d. 100
 - f. Unlimited**
7. How does the radiosensitivity of a 5 year-old compare to an adult?
 - a. the same
 - b. less
 - c. 2 times more
 - d. 5 times more
 - e. 10 times more**
 - f. 15 times more
8. Did you know that while imaging pediatric patients with CT, technical parameters should be altered to reduce the dose, but many imaging utilities are still using adult doses or are not making enough adjustments?
 - a. Yes
 - b. No
9. While performing a fluoroscopic exam including the abdomen (for example, a VCUG), gonads are of special consideration because they are accepted as the most radiosensitive organs in the pediatric population. Which of the following comes next?
 - a. Urinary bladder
 - b. Kidney
 - c. Stomach**
 - d. Liver

Figure 1. Survey of medical radiation effects and doses. The correct answers are marked in bold. ALARA, as low as reasonably achievable; VCUG, voiding cystourethrogram; DMSA, 99mTc-dimercaptosuccinic acid; PET-CT, positron emission tomography-computed tomography; CXR, chest X-ray; AP, anteroposterior; abd, abdomen; US, ultrasonography; CT, computed tomography; MRI, magnetic resonance imaging.

10. Which of the following procedures result in emitting radiation for a prolonged period of time?
 - a. VCUG
 - b. DMSA**
 - c. PET-CT**
 - d. Abdominopelvic CT
 - e. MRI scan
 - f. Barium study
11. What is the approximate estimated risk of excess cancer for a 1-year old child undergoing any CT exam?
 - a. 1/1 000 000
 - b. 1/100 000
 - c. 1/10 000
 - d. 1/1000**
 - e. 1/100
 - f. I don't know
12. According to you, should we routinely discuss the radiation risks with the patient's family prior to a CT exam?
 - a. Yes
 - b. No
 - c. I am not sure
13. (Answer in affirmative to question 12 if you have chosen 'no'.)
Which of the following ideas affected your decision? (You can mark more than one choice)
 - a. The decision should be left to the doctor because of lack of education of the patients' families
 - b. I think CT does not cause a radiation dose that can pose a meaningful risk to the health of patients
 - c. There is not enough time for that because of work overload
 - d. This can cause excess anxiety in the patient's family and can result in cancellation of a very much required radiological procedure
14. Have you ever received any specific education on radiation in medical imaging?
 - a. Yes
 - b. No
15. If your answer to 14 is yes, specify
 - a. Formal education (course, workshop, lecture, radiology rotation)
 - b. Informal education (interclinical discussion, personal reading, media news, etc.)

III. Radiation Dose Estimations

16. For each of the following procedures estimate the approximate dose of radiation to a 5-year-old in terms of equivalent number of chest X-rays (for example: the dose of a CXR=1 CXR equivalent).

Dose in CXR equivalents	0	1	10	100	200	300	600	1000↑
a. X-ray AP pelvis			x					
b. VCUG						x		
c. US abd	x							
d. CT abd+pelvis								x
e. CT cranial							x	
f. CT chest							x	
g. CT (neck+chest+abd+pelvis)								x
h. MRI cranial	x							

Figure 1. (continued) Survey of medical radiation effects and doses.

A multiple-choice format was used in this survey to enable faster completion and to facilitate the evaluation of the answers.

Statistical analysis

The data were entered into a password-protected database for statistical analysis using a commercially available software (Statistical Package for Social Sciences, version 11, SPSS Inc., Chicago, Illinois, USA). A scoring system previously used by other authors (13) was used to achieve a general understanding of the actual knowledge of radiation doses and for easier comparison between groups. For each respondent, a total estimation score was calculated from the responses to question # 16, excluding questions c and h (dose estimations for ultrasonography [US] and magnetic resonance imaging [MRI]). The correct answer and the overestimates were scored as zero. For underestimations, the scores ranged between 1 and 7, with the answer 'one' below the correct answer being scored as 1 and the answer 'two' below the correct answer scored as 2, for example.

The correct answer rates and total estimation scores of residents were compared to those of specialists (doctors other than residents), and university hospital doctors were compared to government hospital doctors. The impacts of the awareness of the ALARA (as low as reasonably achievable) principle for minimizing radiation exposure and of education were investigated, and the correlation between the degree of clinical experience within each group and survey success was assessed. Because only three of the respondents worked in a private hospital, they were not considered a group.

Statistical analysis was performed using chi-squared and Fisher's exact tests. The means of continuous measurements were compared by independent-samples t-test or analysis of variance. The normality of the continuous variables was assessed prior to the application of parametric methods. A *P* value of less than 0.05 was considered statistically significant. Spearman's rho correlation test was used to assess the association between the years of clinical experience and the radiation estimation scores.

Results

Demographics

Of the 237 respondents, 66.7% worked in government hospitals

(including 37.5% working in dedicated children's hospitals), 32.0% worked in university hospitals, and 1.3% worked in private practice. Specialists and residents comprised 45.6% and 54.4% of the total respondents, respectively. Specialists practicing for fewer than 5 years comprised 10.5%; those practicing 5 to 10 years comprised 13.9%, those practicing for 10 to 20 years comprised 15.7%, and those practicing for more than 20 years comprised 5.5% of the total respondents. Junior residents practicing for fewer than three years and senior residents practicing for more than three years comprised 21.1% and 33.3% of the respondents, respectively.

General radiation knowledge

Starting with the percentage of background radiation for which medical radiation is responsible (Q4: correct answer, 50%) (18), 12.7% of the answers were correct, 56.1% of the respondents underestimated the answer, 3.8% overestimated the answer, and 27.4% responded 'Do not know'.

The vast majority (93.5%) of the respondents had not heard of the ALARA principle (Q5), and 89.0% did not know that there is currently no annual dose limit set for patients (Q6).

While the majority (76.3%) of the pediatricians knew that children were more sensitive than adults to the negative effects of radiation (Q7: correct answer, 10 times more radiosensitive) (5, 6), 43% underestimated the degree of sensitivity, 7.9% thought children were less radiosensitive, and 15.9% thought adults and children had similar radiosensitivities. Most (60.3%) of the respondents did not know that many imaging facilities still use adult doses or do not make adequate adjustments for pediatric patients (Q8) (19–20).

The majority of the respondents (75.9%) were not aware of the relatively high radiosensitivity of the gastrointestinal tract (Q9: correct answer, stomach). The respondents appreciated that patients undergoing MRI or abdominal CT do not emit radiation for a prolonged period of time, but many respondents incorrectly answered that barium studies (27%) and voiding cystourethrograms (35%) involve the emission of ionizing radiation. Only 27.0% knew that PET-CT involved radiation emitted from the

patient. A majority of the respondents (86.9%) correctly answered that the patients emit radiation after undergoing a 99mTc-dimercaptosuccinic acid (DMSA) exam (Q10).

When asked about the excess lifetime cancer risk for a 1-year-old child undergoing any CT exam (Q11: correct answer, 1/1000) (7), 44.7% answered 'Do not know'. Of the respondents who attempted to answer, the majority (64.2%) underestimated the risk, and 11.8% answered that there was no increased risk. Only 18.1% of the doctors gave the correct answer, while only 5.9% of the doctors overestimated the risk, selecting a 1/100 chance.

The next question asked whether the risk of ionizing radiation should be discussed with the patients' families (Q12). Most of the respondents (76.2%) responded that risk should be routinely discussed, 12% were not sure, and 11.8% did not think that discussing the risk was appropriate at any risk level for reasons given in the next question (Q13). Four possible ideas for rejecting discussion were given as possible answers to this question, and the respondents could choose more than one statement. The leading concern of the 28 respondents (who marked a total of 45 choices) was the possibility of inducing anxiety in the patient's family, resulting in the cancellation of a required radiological procedure (35.6%). The next most common responses were that the doctors should make the decision because the patient's family lacked education (24.5%), that there was no meaningful risk (22.2%), and that work overload was an obstacle (17.7%).

The last two questions of this section were about education. Only 5.1% of the respondents recalled being educated on radiation exposure in medical imaging (Q14). The follow-up question (Q15) revealed that when education was received, it was more commonly (3.1%) formal education in the form of a course, workshop, lecture, or structured radiology rotation. A small percentage (2.2%) of respondents had received informal education through personal reading, unofficial discussions with their colleagues, or the news media.

Estimation of relative radiation doses

A total of 75.2% of all estimations were underestimates, and 19.4% were

correct answers. The percentage of underestimates did not differ for CT (74.8%; $P > 0.05$). The distribution of the answers is shown in Table 4.

Estimation of the radiological dose from CT of the neck+chest+abdomen+pelvis was the most accurate, with 45.7% correct answers. Estimation of the dose from cranial CT was the least accurate, with only 11.2% correct answers.

Of the 237 pediatricians, 17 (7.1%) and 26 (10.9%) did not know that US and MRI, respectively, do not involve ionizing radiation.

Comparison of groups

General radiation knowledge (Q4–11) was not significantly different between residents and specialists. Within the resident group, the level of clinical experience did not affect the outcome. Within the specialist group, 11.9% of the specialists with less than five years of experience were aware of the ALARA principle (Q4) compared to 3.3% of the specialists with more than five years of experience (chi-squared=6.747; $P = 0.009$).

General radiation knowledge (Q4–6, 8–11) was not significantly different between the pediatricians of university and government hospitals. Compared to doctors working in university hospitals (10.8%), more doctors working in government hospitals (32%) gave the correct answer when asked to compare the radiosensitivity of a 5-year-old child with that of an adult (Q7; chi-squared=19.000; $P = 0.002$). A greater number of respondents from university hospitals (32.4%) compared to government hospitals (9.3%) thought that adults and children have the same radiosensitivities.

Table 5 summarizes the total estimation scores for the different groups. The total estimation scores (Q16) of residents (7.5 ± 5.1) were better than those of specialists (11.0 ± 6.3 ; $P < 0.001$). The total estimation scores were not significantly different ($P > 0.05$) between pediatricians from university and government hospitals. There was a weak statistical correlation between clinical experience and overall estimation scores ($r=0.273$; $P < 0.001$); that is, as clinical experience increased, the overall score increased, and the rate of correct estimations decreased.

There was no statistically significant association between overall correct

answers or radiation estimation scores and familiarity with the ALARA principle or having received formal education in radiology dosing. Working in a dedicated children's hospital compared to other government hospitals did not make a statistically significant difference.

Discussion

Radiological examinations are extremely important and are required for the diagnosis and treatment of many diseases in children. Although there is a general understanding that approximately 30% of all radiological exams are not clinically helpful (21), radiation doses have increased seven-fold in the United States since the early 1980s, based on a report from the National Council on Radiation Protection and Measurements in March 2009 (18). Most of this dose increase is due to the 10% increase in the number of CT exams performed per year (11). CT constitutes approximately 11% of the radiation-based imaging examinations

in the US, but it contributes to more than two-thirds of the medical radiation dose to the population (22–23). Children are the most vulnerable population to the deleterious effects of radiation, yet they are increasingly being subjected to more radiation due to the availability of faster and more accurate CT scans.

Despite the increased use of radiation in medicine and the increasing number of papers (2, 4, 7, 19–21, 23) and campaigns (3, 24) regarding pediatric radiation issues, the general impression is that there has not been an equal increase in the radiation awareness of physicians. To date, physician-based surveys have reported an underestimation of the relative radiation doses of radiological examinations in adults (8–12). A study from Canada (13) is the only study that has focused on the caregivers of children, and it yielded similar results. We aimed to evaluate the radiation awareness of pediatricians by collecting broader-based data from a group we referred to as 'pediatricians'

Table 4. Distribution of the effective dose estimations in percentage

Dose in CXR equivalents	0	1	10	100	200	300	600	1000†
a. X-ray AP pelvis	0.4%	75%	20.6% ^a	3%	0.4%			0.4%
b. VCUG	2.6%	4.8%	36.6%	32.6%	13.7%	7% ^a	2%	1%
c. US abd	93.4% ^a	2.2%	0.9%	1.3%	0.9%	0.4%		0.9%
d. CT abd+pelvis	0.4%	2.2%	4.8%	16.9%	17.3%	25.5%	20.3%	12.6% ^a
e. CT cranial		1.7%	10.3%	20.7%	25%	22%	11.2% ^a	9.1%
f. CT chest		2.2%	7%	18.7%	22.6%	27.4%	12.6% ^a	9.6%
g. CT (neck+chest+abd+pelvis)		1.3%	3%	5.2%	13.8%	13.8%	17.2%	45.7% ^a
h. MRI cranial	88.6% ^a	2.1%	1.7%	2.1%	1.3%	1.7%	2.5%	

^aThe percentages corresponding to the correct answers which are marked in bold in Fig. 1.

AP, anteroposterior; CT, computed tomography; CXR, chest X-ray; MRI, magnetic resonance imaging; US, ultrasonography; VCUG, voiding cystourethrogram; abd, abdomen.

Table 5. Total estimation scores of different groups

Groups	Total estimation scores
Specialists	11.0±6.3
Residents	7.5±5.1
University hospitals	9.7±6.2
Government hospitals	9.0±5.8
ALARA awareness +	11.8±6.1
ALARA awareness -	8.9±5.9
Education +	8.4±3.9
Education -	9.1±6.0

to determine if the latest efforts in educating physicians have resulted in significant progress.

We had a 100% response rate due to one-on-one interactions with the doctors. We were pleased to learn that pediatricians are very interested in the subject and that most of them wanted to be educated about the correct answers after completion of the survey.

The level of understanding of the basic concepts behind radiological examinations and the knowledge of radiation risks and protection were poor. The majority of the pediatricians (85.5%) either did not know or underestimated the contribution of medical radiation to the total radiation exposure of patients. The answers to the survey revealed that most pediatricians were not aware of the recent increase in the percentage of medical radiation exposure. Based on the results of previous surveys (8, 13), we were not surprised that 89% of the pediatricians were not aware of the ALARA principle. Nonetheless, based on our daily clinical interaction with pediatricians, we think that they are likely aware of the concept of exposing the patient to the smallest possible dose of radiation but just not familiar with the English acronym ALARA.

The answers to Q6 through Q8 indicated that the majority of the pediatricians were misinformed about the degree of radiosensitivity of children, pediatric CT applications in different centers, and the fact that there is a dose limit for radiation workers (25) but no yearly radiation dose limit for patients. This misinformation might result in pediatricians' requesting more than the necessary number of radiological examinations and exposing their patients to more radiation risk. Most pediatricians would not hesitate to order a multiphasic liver CT or cardiac imaging from a nonpediatric center, although some of these tests could be replaced by other imaging modalities, such as US, MRI, or ECHO. The majority of the respondents did not appreciate the high radiosensitivity of the gastrointestinal tract, which is important, as a large number of children undergo gastrointestinal fluoroscopic procedures for less-than-necessary indications, and the use of gonad protection is not sufficient to overcome the risks.

Although the respondents appreciated that CT and MRI do not involve a

prolonged emission of radiation, there seems to be general confusion about which procedures emit radiation and which do not. This is important because pediatricians could play a bigger role in providing information to the children's families, such as instructing parents to isolate their child from a pregnant mother for a period of time after certain types of radiation-emitting examinations.

While making dose estimations, 6.6% of the respondents marked US and 11.4% marked MRI as techniques involving ionizing radiation. As recently as 2007, a survey from Turkey revealed that 4% and 27.4% of doctors, including interns, thought that abdominal US and MR involved radiation, respectively (12). The awareness about MRI was better than the results of this survey in the present study. This difference is likely due to the characteristics of the study group, which included only postgraduate respondents, rather than the time interval between the two surveys.

Approximately two-thirds of the respondents underestimated the excess lifetime cancer risk for a 1-year-old child undergoing any CT exam. This means that most of the time, the pediatricians are exposing their patients to more risk than they expect, even though two-thirds of the respondents believed that the risks should be routinely discussed with the patient's family when a radiological exam is requested. Therefore, before providing information, the pediatricians themselves need to be accurately educated on the issue.

For the small group of pediatricians (11.8%) who believed that the risks should not be discussed under any circumstances, the main concerns were the possible stimulation of parental anxiety and the undereducation of the families. The technique for obtaining informed consent is beyond the scope of this article, but we predict that a discussion including the words 'cancer' and 'death' might be challenging and cause anxiety regardless of the level of education. There is a risk that a much-needed exam might be canceled by an overly anxious family if the necessity of the exams versus the risks are not properly communicated.

The number of respondents who had received formal education (2.9%) or any kind of education (5.0%) was low,

even lower than that reported by previous surveys (14%–37%) (8, 11, 13).

Effective dose estimations and comparisons of groups yielded the five following significant results:

1. Pediatricians working in government hospitals had a better understanding of children's radiation sensitivity (Q7). Working in a university hospital did not necessarily result in a better awareness of radiosensitivity. As there was no statistically significant difference regarding the overall correct answers on general radiation knowledge (except for Q7 in which pediatricians working in university hospitals did worse) or radiation dose estimation scores between pediatricians in university and government hospitals, we conclude that working in a more academic environment does not compensate for the lack of a structured education, specifically on radiation issues.
2. The underestimation of radiation doses of common radiological procedures (75.2%) was significantly less than that reported by previous surveys (87%–97%) (8–13). Specifically, the proportion of dose underestimation regarding CT exams did not change (74.8%), contrary to previous surveys, which reported that the highest proportion of underestimations were associated with CT examinations (13). Although still insufficient, this seems to be an improvement in the general radiation dose awareness of pediatricians, which can be attributed to the increased number of articles regarding radiation risks and doses, mostly from pediatric CT examinations (2–4, 15).
3. Residents were better than specialists at estimating radiation doses.
4. In general, there was a weak statistical correlation between clinical experience and overall estimation score ($r=0.273$; $P < 0.001$). As experience increased, the scores increased, and the rate of correct estimation decreased.
5. The ALARA principle was better appreciated by specialists with less than five years of experience compared to their more experienced (>five years) colleagues.

The results expressed above in points 3, 4, and 5 all point to the same fact that young doctors are better educated

on radiation doses and the ALARA principle than doctors with more clinical experience. Although this appears to be a contradiction, it makes sense because the new generation has grown up in an environment in which medical radiation issues are discussed, and they are particularly more familiar with the usage and recent developments of CT. It is encouraging that the new generation has a better understanding of radiation doses.

Although residents scored better than specialists on radiation dose estimation when resident and specialist groups were compared regarding general radiation knowledge (Part 2), the difference was not statistically significant. This gives us the impression that improvements in radiation awareness have focused mainly on CT doses and should be broadened to general radiation rules.

The fact that 95% of the respondents stated that they had not received any kind of formal or informal education may explain the poor knowledge of the pediatricians on radiation issues. There was, however, no statistically significant association between overall correct answers or radiation estimation scores and familiarity with the ALARA principle or having received a formal education on radiation exposure. The type of postgraduate 'formal education' that is administered today is apparently not adequate. The better estimation scores of the residents led us to conclude that the earlier a certain type of information is introduced into the curriculum, the better it is processed. In fact, the European Union has recommended 20 to 40 hours of radiation protection courses in medical schools (11). Previous studies (8, 11) also concluded that core knowledge should be introduced in medical school and should continue during postgraduate training.

We, as radiologists, should step forward at this point and take responsibility for the continuing postgraduate education of medical students and our clinical colleagues through lectures, courses, and interclinical discussions or via a gatekeeping role in daily practice when we receive examination requests, particularly for pediatric patients. Our experience revealed that most pediatricians are very interested and open to receiving information. There is also a need for contributions by radiologists to the pediatric

literature to reach more pediatricians and to increase their awareness of radiation dosage and radiation risks in children.

Our experience revealed that most pediatricians are very interested and open to receiving information. There is also a need for contributions by radiologists to the pediatric literature to reach more pediatricians and to increase their awareness of radiation dosage and radiation risks in children. Based on the overall decrease in the underestimation of radiation doses by the residents and their relatively better answers, we conclude that the current radiation awareness of pediatricians is better than it was four years ago (13) and that the latest efforts in the form of campaigns, reports, publications, and news media are actually paying off. Although the overall radiation awareness of pediatricians remains inadequate, we appear to be on the right track.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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