BMJ Open

Evaluation of clinicians' knowledge and practices regarding medical radiological exposure: findings from a mixed-methods investigation (survey and qualitative study)

B Lumbreras,[1] J Vilar,[2] I González-Álvarez,[3] M Guilabert,[4] L A Parker,[5,6] M Pastor-Valero,[5,6] M L Domingo,[2] M F Fernández-Lorente,[3] I Hernández-Aguado[5,6]

To cite: Lumbreras B, Vilar J, González-Álvarez I, *et al*. Evaluation of clinicians' knowledge and practices regarding medical radiological exposure: findings from a mixed-methods investigation (survey and qualitative study). *BMJ Open* 2016;**6**:e012361. doi:10.1136/bmjopen-2016-012361

► Prepublication history and additional material is available. To view please visit the journal (http://dx.doi.org/10.1136/bmjopen-2016-012361).

Received 20 April 2016
Revised 26 August 2016
Accepted 13 September 2016

For numbered affiliations see end of article.

Correspondence to
Dr B Lumbreras;
blumbreras@umh.es

ABSTRACT

Objectives: To assess the impact of initiatives aiming to increase clinician awareness of radiation exposure; to explore the challenges they face when communicating with patients; to study what they think is the most appropriate way of communicating the long-term potential risks of medical radiological exposure to patients.

Design: A quantitative and qualitative evaluation through a survey and focal groups.

Setting: San Juan Hospital and Dr Peset Hospital (Southeast Spain) and clinicians from Spanish scientific societies.

Participants: The surveys were answered (a) in person (216: all the radiologists (30), urologists (14) and surgeons (44) working at both participant hospitals; a sample of general practitioners from the catchment area of one hospital (45), and a consecutive sample of radiologists attending a scientific meeting (60)) or (b) electronically through Spanish scientific societies (299: radiologists (45), pneumologists (123), haematologists (75) and surgeons (40)). Clinicians were not randomly selected and thus the results are limited by the diligence of the individuals filling out the survey.

Primary and secondary outcome measures: Clinicians' knowledge and practices regarding medical radiological exposure, and what they considered most appropriate for communicating information to patients.

Results: Nearly 80% of the clinicians surveyed had never heard of the European recommendations. Fewer than 20% of the clinicians surveyed identified correctly the radiation equivalence dose of intravenous urography or barium enema. It was reported by 31.7% that they inform patients about the long-term potential risks of ionising radiation. All participants agreed that the most appropriate way to present information is a table with a list of imaging tests and their corresponding radiation equivalence dose in terms of chest X-rays and background radiation exposure.

Conclusions: Medical radiological exposure is frequently underestimated and rarely explained to patients. With a clear understanding of medical radiological exposure and proper communication tools, clinicians will be able to accurately inform patients.

Strengths and limitations of this study

- This is the first study to investigate what the clinicians who participated in this study thought to be the most appropriate tool for communicating medical radiological exposure to patients. The results show that these clinicians preferred to communicate this information verbally supported by a table showing the radiation equivalence dose.
- The strength of this study lies in the application of qualitative methodology together with analysis of quantitative information to understand the hurdles clinicians face when communicating medical radiological exposure to patients in their daily clinical practice.
- The clinicians who answered the survey electronically may be more interested in medical radiological exposure than those who did not.
- We designed our own survey for evaluating medical doctor knowledge and awareness of medical radiological exposure and cannot rule out any issues with validity.

INTRODUCTION

An increase in the use of medical imaging in clinical practice[1] fuels concern about radiation exposure and long-term potential risks of ionising radiation from medical imaging.[2] European Union (EU) legislation sets out a series of directives regarding radiation

protection and now includes the safe use of ionising radiation in medical practice. The revised 'Basic Safety Standards Directive' was adopted in 2013 by all member states,[3] who must bring into force laws, regulations and other administrative provisions to comply with this directive by 6 February 2018.

One key innovation in the revised directive is the need to record the radiation dose received by each patient undergoing a medical imaging test, with particular attention paid to CT or procedures involving interventional radiology.[3] The transposition of the directive into national law will require the participation of all stakeholders involved, but clinicians themselves have a key role. For example, if they are to discuss the potential risks and benefits of carrying out a new imaging test with their patients, they will need a clear understanding of the effective dose received from each test. Previous studies have reported suboptimal knowledge about radiation among clinicians,[4–6] which explains in part why they tend not to undertake this discussion with their patients.[7]

In the last few years, several initiatives have strived to increase clinician awareness of radiation exposure and protection.[8–11] One such example is the EU *Guidelines on radiation protection, education and the training of medical professionals.*[12] Unfortunately, there are no data about the impact of these initiatives. Hence, it is essential to assess the impact of these proposals on the level of clinicians' awareness of the data currently available on radiation exposure and the main barriers that they experience when translating them in terms of the benefits and potential risks to their patients. Moreover, exploring variation in their awareness and practices regarding medical radiological exposure according to factors such as medical specialty or professional category will be useful for designing targeted strategies to reduce unnecessary radiation exposure and to improve compliance with the EU's Basic Safety Standards Directive.

Most of the studies carried out in this area have centred on quantitative evaluations of clinicians' knowledge about excess radiation exposure associated with imaging, using surveys.[4–6 13] Although useful, such studies can miss important aspects, such as perceived difficulties in discussing the risks and benefits of imaging with patients. Moreover, other potential challenges faced when trying to integrate questions of medical radiological exposure into their daily practice are more appropriately addressed using qualitative methodology. For example, radiologists and clinicians can easily reflect on whether their conduct and attitudes contribute positively to patients' perceptions of benefits and medical radiological exposure of imaging tests and thus to patient cooperation.[14] A previous qualitative study showed that displaying clinically relevant radiation exposure information may improve the discussion with patients when ordering a new test.[15] However, although some authors have detailed different strategies to improve communication about medical radiation benefits and potential risk,[7] there are no data on what clinicians think is the most appropriate way to communicate this potential risk to patients.

In this study we use both quantitative and qualitative methodology to assess the impact of several initiatives aiming to increase clinician awareness of radiation exposure. We (1) assess current knowledge and practices regarding medical radiological exposure in a sample of clinicians who order imaging tests in their daily practice, (2) explore the challenges they face when addressing the potential risk to the health of their patients, and (3) study what they think is the most appropriate way to inform patients about medical radiological exposure.

MATERIALS AND METHODS

Design

We carried out a quantitative and qualitative evaluation using a survey and focal groups to achieve a comprehensive picture of clinicians' knowledge of and attitudes to medical radiological exposure.

Quantitative study

Participants

We chose radiologists and clinicians (both residents and consultants) from a selection of medical specialties that tend to require a substantial number of imaging tests,[16] such as respiratory medicine, urology, surgery, general practice and haematology.

Procedure

Radiologists and the other participating physicians were contacted and invited to take part in the study using different sources: in person or through scientific societies or scientific meetings.

To collect the information of interest, we designed a survey to be administered either through a Google spreadsheet, for those contacted through their respective scientific societies, or in person. Below, we present in detail the procedure used by each medical specialty.

- Radiologists: all the radiologists working at San Juan Hospital, Alicante (14/14, 100%) and Dr Peset Hospital, Valencia (16/16, 100%) and a consecutive sample of radiologists attending the 32nd Spanish National Meeting on Radiology in 2014 were contacted and surveyed in person (60/2000, 3%). (We included in parentheses the total number of radiologists working in each hospital and radiologists attending the national meeting.)
- The rest of the radiologists (45/3000, 1.5%), pneumologists (123/2010, 6.2%) and haematologists (75/2000, 3.8%) answered the survey using the Google spreadsheets. (We included in parentheses the total number of clinicians belonging to each scientific society.)
- All urologists working at both participating hospitals (San Juan Hospital, Alicante and Dr Peset Hospital, Valencia) were contacted and answered the survey in person (14/14, 100%) (We included in parentheses the total number of urologists working in each hospital.)

- Surgeons were surveyed either in person (44/44, 100%) (working at both participating hospitals (San Juan Hospital, Alicante and Dr Peset Hospital, Valencia) or using the Google spreadsheets (40/5000, 0.8%). (We included in parentheses the total number of surgeons working in both hospitals and the total number of surgeons belonging to their scientific society.)
- General practitioners (GPs): general practice medical doctors working in primary care centres associated with Dr Peset Hospital answered the survey in person (45/150, 30%).

To assess the possibility of selection bias due to the different procedures used to answer the survey, we compared the characteristics and results of physicians who answered the questionnaire electronically with those who completed it in person; there were no statistically significant differences. We compared clinical and demographic characteristics (table 1), training, awareness and practice regarding medical radiological exposure (table 2), practices and opinions regarding shared decision making with patients (table 3), and clinicians' responses regarding the radiation equivalence to chest X-ray of different medical imaging tests (figure 1) using the Pearson χ^2 test for categorical variables and the Mann-Whitney U test for continuous variables, with $p<0.05$ considered significant. All the surveys were completed between April 2014 and April 2015.

Survey design

We developed a survey ad hoc that included the following items grouped into three different categories: (1) personal data, such as sociodemographic characteristics, number of years in practice and professional category (consultant or resident); (2) data related to doctors' knowledge, such as previous formal training in medical radiological exposure, awareness of current European recommendations,[8] knowledge about radiation exposure associated with different diagnostic examinations; (3) attitudes to informing patients about medical radiological exposure and their responsibility to educate patients (see online supplementary annex I). The survey was piloted on a number of medical staff before use, and adaptations were made to improve its clarity. The pre-piloted survey was completed by four radiologists and one clinician working at San Juan Hospital. After the pilot, a question related to the clinician's context of training on radiation exposure was included ('If yes, context of training: During undergraduate training () During hospital residence () At work () Other (explain)), and questions 4–7, which ask about doses associated with diagnostic examinations, were transformed into multiple-choice questions to facilitate answering and analysis of the questionnaire.

This modified questionnaire was piloted on a different sample of three radiologists and one clinician working at the same hospital.

Statistical analysis

All information that identified the survey participants was removed before analysis. Basic descriptive statistics were obtained for each question using SPSS V.22.0. Cumulative frequency and percentage values for all responses were estimated. Associations between groups

Table 1 Clinical and demographic characteristics of the 515 clinicians included in the survey according to medical specialty

Variable	Total (N=515)	Radiology (N=135)	Clinical services* (N=334)	General practice (N=46)	p Value
Sex, n (%)					<0.001
Men	238 (46.4)	64 (47.4)	168 (50.3)	6 (13.0)	
Women	275 (53.6)	71 (52.6)	164 (49.1)	40 (87.0)	
NA	2 (0.4)		2 (0.6)		
Age, median (IQR)	42.0 (32.0–52.75)	35 (29–51)	45 (34–53)	31 (26–42)	<0.001
Professional level, n (%)					<0.001
Resident	113 (21.9)	51 (37.8)	35 (10.5)	27 (58.7)	
Consultant	380 (73.8)	78 (57.8)	292 (87.4)	10 (21.7)	
NA	22 (4.3)	6 (4.4)	7 (2.1)	9 (19.6)	
Years of practice, median (IQR)	15.0 (6.0–25.0)	9 (4–24)	18 (8–26)	4 (2–15)	<0.001
Type of health facility, n (%)					0.247
Public	405 (78.6)	100 (74.1)	265 (79.3)	40 (87.0)	
Private	32 (6.2)	11 (8.1)	19 (5.7)	2 (4.3)	
Both public and private	71 (13.8)	21 (15.6)	48 (14.4)	2 (4.3)	
NA	7 (1.4)	3 (2.2)	2 (0.6)	2 (4.3)	
Questionnaire response method, n (%)					<0.001
Electronically	299 (58.1)	45 (33.3)	253 (75.7)	1 (2.2)	
In person	216 (41.9)	90 (66.7)	81 (24.3)	45 (97.8)	

*Including respiratory medicine, surgery, haematology, urology or other (cardiology, neurology, oncology, otolaryngology, digestive medicine, internal medicine).
NA, not available.

Table 2 Training, awareness and practices regarding medical radiological exposure according to medical specialty

Variable	Total frequency (N=515)	Radiology (N=135)	Clinical services (N=334)	General practice (N=46)	p Value
Ever received training on radiation exposure associated with medical imaging					<0.001
Yes	327 (63.5)	125 (92.6)	167 (50.0)	35 (76.1)	
No	187 (36.3)	9 (6.7)	167 (50.0)	11 (23.9)	
NA	1 (0.2)	1 (0.7)			
Context of training (if received)					<0.001
During undergraduate training	82 (25.1)	10 (8.0)	64 (38.3)	8 (22.9)	
During hospital residence	96 (29.4)	59 (47.2)	30 (18.0)	7 (20.0)	
At work	45 (13.8)	15 (12.0)	26 (15.6)	4 (11.4)	
Multiple courses in more than one context	104 (20.2)	41 (32.8)	47 (28.1)	16 (45.7)	
Awareness of the European recommendations on radiation protection and safety					<0.001
Yes	105 (20.4)	57 (42.2)	41 (12.3)	7 (15.2)	
No	405 (78.6)	75 (55.6)	292 (87.4)	38 (82.6)	
NA	5 (1.0)	3 (2.2)	1 (0.3)	1 (2.2)	
Awareness of the regulation regarding the need to justify all radiological tests					<0.001
Yes	138 (26.8)	81 (60.0)	44 (13.2)	13 (28.3)	
No	374 (72.6)	53 (39.3)	289 (86.5)	32 (69.6)	
NA	3 (0.6)	1 (0.7)	1 (0.3)	1 (2.2)	
If yes, adherence to this regulation in daily practice					0.577
Yes	98 (71.0)	56 (69.1)	33 (75.0)	9 (69.2)	
No	37 (26.8)	24 (29.6)	9 (20.5)	4 (30.8)	
NA	3 (2.2)	1 (1.2)	2 (4.5)	0	

Values are n (%).
NA, not available.

were analysed using the Pearson χ^2 test, with p<0.05 considered significant. The effect of diverse explicative variables was considered by means of a stratified analysis, and unconditional logistic regression was used (95% CIs). A multivariate logistic regression model was built applying a stepwise procedure to enter variables into the model.

Qualitative study

Participants

Two focus groups were conducted separately in two hospitals in the Autonomous Community of Valencia, Spain (San Juan de Alicante Hospital and Doctor Peset Hospital in Valencia) in May 2015. The focus group in San Juan de Alicante Hospital was composed of clinicians from the following specialties: radiology, haematology, neurology, urology, respiratory medicine, accident and emergency, and surgery. In the Doctor Peset Hospital, the focus group included clinicians from the specialties of radiology, neurology, oncology, cardiology, respiratory medicine and orthopaedics.

Procedure

The participating clinicians represented a convenience sample from the two centres. The group was not intended to be a representative sample, but the purpose was, rather, to obtain a general sense of their knowledge on radiation exposure and discover what, in their opinion, is the most important information clinicians should communicate to patients when they order an imaging test. To do this they were informally invited to join the focus group by the researchers of the study. The two groups used an identical protocol and procedure, which began with a short presentation by the head of the radiology department in each hospital and a presentation of the results previously obtained in the quantitative surveys. The physicians were asked to describe their specialty and the care setting in which they worked (inpatient, outpatient, accident and emergency). The focus group discussions lasted between 45 and 60 min and were audio-recorded.

Focus group guides

The research team developed a semistructured focus group protocol to guide the discussion based on a literature review of exposure radiation topics and the main results obtained in the quantitative survey. The protocol was divided into two main themes: (a) the information that clinicians thought patients should receive before undergoing an imaging test—for instance, specific information about medical radiation exposure, information on alternative tests, and patient participation in decisions; (b) the participants assessed three potential information sheets to be given to patients detailing the radiation

Table 3 Practices and opinions regarding shared decision-making and discussing medical radiation exposure with patients

Variable	Total (N=515)	Radiology (N=135)	Clinical services (N=334)	General practice (N=46)	p Value
Do you inform patients about medical radiation exposure?					0.002
No	337 (65.4)	89 (65.9)	230 (68.9)	18 (39.1)	
Yes, always	163 (31.7)	41 (30.4)	96 (28.7)	26 (56.5)	
Yes, sometimes	4 (0.8)	1 (0.7)	2 (0.60)	1 (2.2)	
NA	11 (2.1)	4 (3.0)	6 (1.8)	1 (2.2)	
If yes, type of information given					0.001
Oral	94 (56.3)	13 (31.0)	60 (61.2)	21 (77.8)	
Written	28 (16.8)	12 (28.6)	15 (15.3)	1 (3.7)	
Both oral and written	43 (25.7)	17 (40.5)	22 (22.4)	4 (14.8)	
NA	2 (1.2)	0	1 (1.0)	1 (3.7)	
Amount of information given					0.422
Very little	18 (3.5)	4 (9.5)	11 (11.2)	3 (11.1)	
Not much	75 (14.6)	15 (35.7)	45 (15.9)	15 (55.6)	
Just enough	69 (13.4)	22 (52.4)	39 (39.8)	8 (29.6)	
A lot	1 (0.2)	1 (2.4)	0	0	
Too much	2 (0.4)	0	2 (2.0)	0	
NA	2	0	1 (1.0)	1 (3.7)	
Opinion regarding patients' understanding					0.287
Very difficult to understand	4 (2.4)	2 (4.8)	2 (2.0)	0	
Difficult to understand	24 (14.4)	8 (19.0)	15 (15.3)	1 (3.7)	
Can be understood without too much difficulty	56 (33.5)	17 (40.5)	28 (28.6)	11 (40.7)	
Easy to understand	78 (46.7)	15 (35.7)	50 (51.0)	13 (48.1)	
Very easy to understand	2 (1.2)	0	1 (1.0)	1 (3.7)	
NA	3 (1.8)	0	2 (2.0)	1 (3.7)	
Do you share the decision to order an imaging test with the patient?					<0.001
No	120 (23.3)	52 (38.5)	58 (17.4)	10 (21.7)	
Yes	108 (21.0)	16 (11.9)	67 (20.1)	25 (54.3)	
Sometimes	4 (0.8)	2 (1.5)	0	2 (4.3)	
NA	283 (55.0)	65 (48.1)	209 (62.6)	9 (19.6)	

Values are n (%).
NA, not available.

exposure associated with imaging to determine which they felt would be easiest for the patients to understand.

These information sheets (see online supplementary annex II) were: (a) the official information given in current clinical practice in these hospitals; (b) an adapted radiation equivalence table[7] showing the effective radiation dose received during the different imaging tests under study expressed as radiation exposure units (u) equivalent to one chest X-ray (the table also showed the radiation equivalence of each test corresponding to 1 year's natural background radiation exposure in different geographical locations); (c) a figure showing a visual representation of medical radiation exposure from each imaging test (compared with background radiation exposure), designed by the authors.

Data analysis

Demographic data were summarised for all study participants using descriptive statistics. Audio-recordings were transcribed literally, and notes from the interviewers were used for later analysis. All personal identifiers were removed.

First, a careful transcript reading was carried out, and the text was then split up into meaningful information units. These units were coded following a mixed strategy (emerging and predefined codes according to the study objectives), and categories were developed based on grouping codes with the same theme.

Finally, the points of agreement and disagreement were analysed, and triangulation (cross-validation) of the results was performed to qualitatively analyse the degree of agreement.

RESULTS

Quantitative study

A total of 515 medical doctors completed the survey (table 1); 299 (58.1%) submitted the questionnaire electronically and 216 (41.9%) in person. Just over one-quarter of the respondents were radiologists (135, 26.2%), nearly one in ten were GPs, and the rest were from other hospital-based clinical specialties such as respiratory medicine (123, 23.9%), surgery (84, 16.3%), haematology (75, 14.6%) or urology (14, 2.7%). Overall, the clinicians were experienced, with a median of 15 years of clinical practice. Nearly three-quarters of

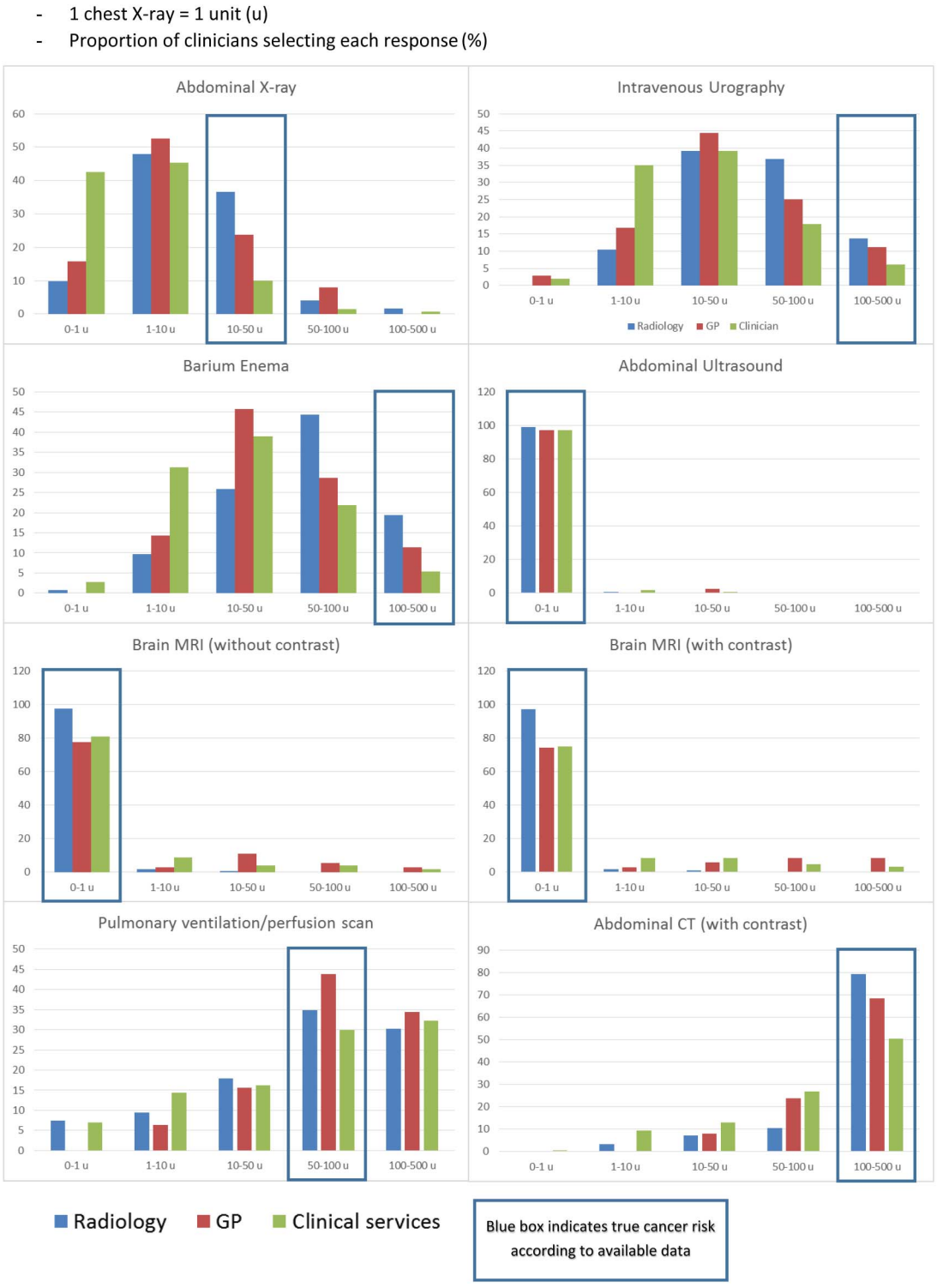

Figure 1 Clinicians' responses to questions regarding radiation equivalence to chest X-ray of different medical imaging tests.

the respondents had finished their residency and were classified as consultants or higher. The majority worked in health facilities pertaining to the National Health Service. There were significant differences in the characteristics of the radiologists, GPs and other clinical specialties. Generally speaking, the non-radiology hospital specialists tended to be older and more experienced and a lower proportion of them were residents (table 1). Moreover, they were more likely to have completed the questionnaire online compared with the radiologists and GPs.

Over half of the survey participants (63.5%) reported that they had received training on the radiation exposure associated with medical imaging (table 2). This varied greatly according to medical specialty given that nearly all radiologists (92.6%) had received the training,

in contrast with the other hospital-based clinical services (50.0%) and GPs (76.1%).

Nearly 80% of the clinicians surveyed had never heard of the European recommendations on radiation protection and safety, and accordingly only 26.8% of them were aware of the regulation regarding the need to justify all radiological tests (table 2). Even among radiologists, only 42.2% claimed to have heard of the European recommendations, although more of them (60%) knew of the requirement to justify the use of all radiological tests (table 2). Among the 138 hospital clinicians surveyed who reported that they were aware of the regulation regarding the need to justify all radiological tests, 98 (71.0%) of them said they actually adhered to this regulation in their daily clinical practice. There were no differences between radiologists, GPs and the hospital-based specialties (p=0.577). When asked about any difficulty regarding justifying all radiological tests they ordered in their daily practice, only 43 clinicians responded. The most common challenge faced was conflicts between the radiologist and the clinician ordering the test (19, 43%), while eight clinicians stated that sometimes they felt pressured to order the test by patients (18%), and six (14%) mentioned avoiding legal problems. Overall, the differences observed in receiving training on medical radiological exposure or being aware of the European guidelines was highest among radiologists compared with other clinical services or GPs, and these differences remained significant after adjustment for age, years of clinical practice, professional category and method of responding to the questionnaire (table 4).

The clinicians were asked to consider the amount of radiation absorbed by patients undergoing different medical imaging tests and to judge it in terms of equivalence to the number of chest X-rays, using a multiple-choice tick-box method. Figure 1 summarises the results. In most cases, clinicians underestimated radiation doses. Fewer than 20% of the clinicians surveyed responded correctly for intravenous urography or barium enema, all estimating that the radiation dose involved was significantly lower than available estimates. Of the imaging tests with no radiation dose, the clinicians were much more likely to select the correct level, although surprisingly some of the hospital specialists and GPs believed that MRI was associated with radiation, especially if it involved contrast. Abdominal CT and pulmonary ventilation/perfusion scan generated a much more varied response from the clinicians, and there was clearly some awareness among them that these tests involved a considerable amount of radiation.

There were no significant differences between the medical specialties: generally speaking, all clinicians tended to underestimate the radiation dose involved in imaging tests.

Overall, 31.7% of the clinicians surveyed reported that they always inform the patients about medical radiation exposure (table 3), although this proportion was

Table 4 Multivariable model relating medical specialty to training, awareness and practices regarding medical radiological exposure

	Radiology	Clinical services			General practice			
	OR	OR (95% CI)	p Value	AdjOR* (95% CI)	p Value	OR (95% CI)	p Value	AdjOR* (95% CI)	p Value
Ever received training on radiation exposure associated with medical imaging	1	0.07 (0.03 to 0.15)	<0.001	0.09 (0.04 to 0.19)	<0.001	0.23 (0.09 to 0.607)	0.003	0.21 (0.06 to 0.77)	0.018
Awareness of the European recommendations on radiation protection and safety	1	0.18 (0.10 to 0.29)	<0.001	0.19 (0.11 to 0.33)	<0.001	0.24 (0.10 to 0.58)	0.002	0.31 (0.12 to 0.80)	0.015
Awareness of the regulation regarding the need to justify all radiological tests	1	0.10 (0.06 to 0.16)	<0.001	0.14 (0.08 to 0.23)	<0.001	0.27 (0.139 to 0.55)	<0.001	0.22 (0.09 to 0.53)	0.001

*Adjusted for sex, age, years of clinical practice and professional level.

significantly higher among GPs (56.5%). This good practice by GPs remained after adjustment for sex, age, years of clinical practice, professional level and questionnaire response method (adjusted OR 4.32; 95% CI 1.75 to 10.77; p=0.002). Clinicians who had received training on radiation exposure associated with medical imaging were more likely to inform the patient about medical radiation exposure (adjusted OR 1.94; 95% CI 1.13 to 3.33; p=0.016; adjusted for sex, age, years of clinical practice, professional level, questionnaire response method and medical specialty), as were those who were aware of the European recommendations on radiation protection and safety (data not shown). The information provided tended to be oral, although 43 (25.7%) clinicians said they provided both oral and written information to their patients regarding medical exposure. Nearly half of those that gave information to their patients judged it to be 'not much' and 'easy to understand', and among the 105 (63%) who commented on the impact of the information on the patient, half felt if had no effect (51, 49%), some felt it made patients feel calm or safe (17.16%), while others felt that discussing the long-term potential risk of radiation leads to fear (24, 23%) or mistrust (13, 8%) (data not shown).

Qualitative study

Overall, 22 radiologists and other clinical specialists participated in the two focus groups; 12 were female (55%). Most of the clinicians admitted to ordering unnecessary imaging tests because patients requested them. With regard to why patients request medical imaging, the clinicians stated:

> Patients tend to be more reassured by the number of imaging tests they receive rather than the doctor's medical opinion

> They think that imaging tests are beneficial because they have always been used

Overall, the clinicians considered that is was important for patients to be informed about the benefits from tests but recognised the difficulty of talking about medical radiation exposure without creating undue concern. Although this point generated intense discussion, all finally agreed that it is first necessary to explain the benefits of the test:

> First of all, the patient should know that the image test improves his/her health, and after, patients should be informed about whether the imaging test they are going to have involves radiation exposure

> If we talk with patients about test benefits and risks, this can even help avoid unnecessary tests

Although it was not a universally accepted topic, there was significant concern regarding whether health professionals themselves know that the combined exposures (background exposure and medical imaging) add up throughout our lifetime and increase our risk of cancer over time:[17]

> Neither the doctors nor the patients know that each exposure to radiation builds up in our body

All participants agreed on the importance of giving information to patients to allow them to participate in the final decision when an imaging test is being ordered. Providing different clinical management alternatives was seen as an important component in the process:

> I think that alternatives are important. The patients must be given alternative options

Informing the patients that combined exposures add up throughout our lifetime was also judged as relevant:

> Both patients and doctors should consider how much radiation patients have received during their lives in order to take responsible decisions

It was agreed that the explanation should be simple in order to avoid confusion and given the clinicians' limited time:

> If we give them too much information, it takes too much time

Finally, the focus groups discussed what the clinicians thought was most appropriate for communicating the radiation dose to patients. Equivalence to X-rays and natural radiation was considered the most appropriate:

> I think it is very difficult, but the best way could be through a comparison with the equivalent in chest X-rays

> An X-ray can be compared with the natural background dose of radiation, in other words, the dose is similar to 3 or 4 days of exposure to natural radiation

All of the participants agreed that the most appropriate way to present information was a table showing a number of imaging tests and their corresponding radiation equivalence in terms of chest X-rays and background radiation exposure.

Although all the participants considered that the written information is essential, they agreed that it should be accompanied by patient–doctor discussion and stressed that this does not always occur in practice:

> What is happening in many hospitals is that they ask the patients to sign the informed consent without any type of explanation about medical radiation exposure

DISCUSSION

This study highlights the difficulties in translating the new European Directive 2013/59/Euratom[3] into clinical practice, particularly the new requirements concerning

the need to consider radiation exposure when ordering imaging tests and the requirement to inform the patient about the medical radiation exposure. The member states had 4 years to transpose this directive into national legislation, including relevant aspects such as radiation protection education, training and provision of information. However, 2 years later in 2015, improvements in the knowledge of practising clinicians on medical radiation exposure remains insufficient to manage constructive discussions with patients about the benefits and potential risks of medical imaging tests. The use of quantitative and qualitative methods to address this problem shows the low clinician awareness of radiation exposure and protection and the lack of effective patient–clinician discussions about it. To our knowledge, this is the first study to analyse what clinicians think is the most appropriate way to inform patients about medical radiation exposure. Our results show that the clinicians' preferred method is to use a table showing radiation equivalence in terms of X-rays and background exposure.

The results of the survey confirm that clinicians are, in general, unaware of radiation exposure associated with imaging tests. Although a high percentage of clinicians (63.3%) indicated that they had received formal training on medical radiological exposure, it was alarming that they did not know about current European regulations related to radiation exposure. Furthermore, the proportion of clinicians who correctly identified the radiation dose estimates was worryingly low. Fewer than one in four of the clinicians surveyed knew the radiation dose associated with a barium enema or urography.

Our results are similar to those of studies[6 13 18 19] carried out before 2013, when the new directive was approved. The value of this study is that it shows that the surveyed participants still underestimated the radiation exposure from a CT examination compared with an X-ray after several initiatives aiming to increase clinician awareness of radiation exposure had been carried out. Lee *et al*[6] showed that only 13% of the radiologists correctly estimated the dose from CT. In other studies[12 13] assessing the knowledge of non-radiological physicians, ~ 34% of them correctly estimated the effective dose from a thoracic CT scan. In contrast, another study[20] showed inadequate knowledge among radiologists, but more so among non-radiologists. In our study, radiologists produced the highest percentage of correct dose estimates in all the imaging tests, although their knowledge was not as good as expected.

This better result for radiologists reflects the formal training they received during their residency at the hospital. Physicians from other specialties should therefore receive special training in medical radiological exposure. Most previous studies have focused on clinicians' knowledge about radiation exposure from CT. However, according to our study, clinicians have less knowledge on radiation exposure associated with other diagnostic imaging tests such as urography or barium enema, which are also associated with significant radiation exposure.

Awareness of radiation exposure is crucial when ordering an imaging test: if clinicians underestimate the radiation dose, patients could be exposed to unwarrantable ionising radiation. Moreover, clinicians should take into account the patient's age, since red bone marrow and brain are highly radiosensitive tissues, especially in childhood.[21] However, if they overestimate the radiation dose and avoid medical imaging, patients may not receive pertinent tests, thereby delaying timely diagnosis, with potentially serious consequences.[22]

In accordance with previous studies,[4] our results suggest that clinicians do not regularly discuss medical radiation exposure with patients. The qualitative study showed, however, that clinicians think that the general population believes that all tests are beneficial. Therefore, empowering clinicians to discuss the risks as well as the benefits of the imaging tests is essential.

In this sense, and according to the qualitative study, clinicians preferred communicating facts about medical radiation exposure verbally with the support of a table showing the radiation equivalence (referring to exposure in terms of X-rays or background exposure) rather than using a figure or text. However, clinicians expressed significant concern about whether health professionals themselves know that the combined radiation exposures add up throughout our lifetime, which could limit communication with the patient. Moreover, patients should be given alternative options, detailing the potential risks and benefits associated with each option.

This study has some limitations. As there is a lack of any validated tool for evaluating medical doctor knowledge and awareness of medical radiological exposure, we designed our own and cannot rule out any issues with validity. However, it reflects the opinions and attitudes of doctors who perform or prescribe imaging studies with ionising radiation.

As with all surveys, the results are limited by the diligence of the individuals completing the survey. Clinicians were not randomly selected for inclusion in the study. We selected all the radiologists, urologists and surgeons working at both participating hospitals (San Juan Hospital, Alicante and Dr Peset Hospital, Valencia) and the GPs working in all primary care centres associated with Dr Peset Hospital (including residents and attending) to answer the survey in person. However, clinicians who answered the survey electronically may have been more interested in medical radiological exposure than those who did not, in which case, the results could be even worse.

We assessed physicians' knowledge of medical radiation exposure, but we did not consider the evaluation of their awareness of the benefits of diagnostic imaging. As previous authors have stated,[23] we need to describe the risk of imaging tests in the context of their clinical benefit. According to the evidence,[24] in many cases the numerical benefits of medical radiation exposure may outweigh the risks.

The generalisability of the results could be affected by having only two recruitment centres for some of the specialists included in the study. However, the two recruitment centres were general hospitals with physicians of different levels of clinical hierarchy.

Qualitative methods often rely on small sample sizes to allow participant accounts to be analysed in sufficient detail for the results to be meaningful. However, the participants in this study were from a mix of medical specialties from two different health centres.

There are many situations in which quantitative analysis does not cover the entire reality, lacking some relevant information.[10] Analysis of clinician–patient discussions may be limited if we only apply quantitative methods. Qualitative methods can give us an overview of clinicians' points of view when ordering medical imaging examinations involving ionising radiation, allowing us to detail barriers related to communication with patients in clinical practice.

In conclusion, given the key role of clinicians in complying with the European legislation before 2018, there is an urgent need to educate them about medical radiation exposure. Increased clinician awareness will allow them to make informed decisions when ordering imaging tests and to limit the amount of radiation that patients receive. Communication between patients and medical staff about radiation exposure is currently lacking. Without a clear understanding of medical radiation exposure, clinicians will never be able to accurately inform patients about the benefits/long-term potential risks, even though they cite it as an important part of the imaging test ordering process in clinical practice.

Author affiliations
[1]Department of Public Health, History of Science and Gynecology, Miguel Hernández University, and CIBER en Epidemiología y Salud Pública, Alicante, Spain
[2]Radiodiagnostic Department, Peset Hospital, Valenciana, Spain
[3]Radiodiagnostic Department, San Juan Hospital, Valenciana, Spain
[4]Psychology Department, Miguel Hernández University, Alicante, Spain
[5]Public Health Department, Miguel Hernández University, Alicante, Spain
[6]CIBER en Epidemiología y Salud Pública, Spain

Acknowledgements We acknowledge the collaboration of the following Spanish societies: Spanish Society of Surgery, Spanish Society of Hematology, Spanish Society of Pneumology and Thoracic Surgery and Spanish Society of Radiology. We also acknowledge Jorge Vilar for thoughtful criticism of the revised version.

Contributors BL, IH-A, JV and IG-A conceived and designed the study and obtained funding. BL, LAP, MPV, JV, IG-A, MLD, MFF-L and MG acquired the data. BL prepared the data, and BL, LAP and MG interpreted statistical analyses. BL coordinated the data management. BL, LAP and MG conducted the statistical analyses and drafted the data tables. All authors cowrote the manuscript. All authors critically revised the paper for important intellectual content and approved the final version.

Funding This study was supported by the Fondo de Investigaciones Sanitarias, Instituto de Salud Carlos III (Plan Nacional de I+D+I) PI13/01576 and cofunded by the Fondo Europeo de Desarrollo Regional (FEDER). The funders were not involved in any aspect of the design of this study, preparation of results, or decision to submit for publication.

Competing interests None declared.

Patient consent Obtained.

Ethics approval Institutional review board approval for the study was obtained from Miguel Hernández University, Hospital San Juan, Alicante and Hospital Dr Peset, Valencia. Informed consent was sought from all study participants for the qualitative study.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement No additional data are available.

Transparency declaration The authors affirm that the manuscript is an honest, accurate and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

REFERENCES

1. Bhargavan M. Trends in the utilization of medical procedures that use ionizing radiation. *Health Phys* 2008;95:612–27.
2. Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. *JAMA* 2007;298:317–23.
3. European Council Directive 2013/59/Euratom on basic safety standards for protection against the dangers arising from exposure to ionising radiation and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. OJ of the EU. L13; 57: 1–73 (2014).
4. Stickrath C, Druck J, Hensley N, *et al*. Patient and health care provider discussions about the risks of medical imaging: not ready for prime time. *Arch Intern Med* 2012;172:1037–8.
5. Soye JA, Patersona A. A survey of awareness of radiation dose among health professionals in Northern Ireland. *Br J Radiol* 2008;81:725–9.
6. Lee C, Haims AH, Monico EP, *et al*. Diagnostic CT scans: assessment of patient, physician, and radiologist awareness of radiation dose and possible risks. *Radiology* 2004;231:393–8.
7. Dauer LT, Thornton RH, Hay JL, *et al*. Fears, feelings, and facts: interactively communicating benefits and risks of medical radiation with patients. *AJR Am J Roentgenol* 2011;196:756–61.
8. European Commission. *Radiation protection 118. Referral guidelines for imaging*. European Commission, Directorate-General for Energy and Transport, 2007. http://ec.europa.eu/energy/nuclear/radioprotection/(publication/doc/118_update_en.pdf (accessed March 2016).
9. American College of Radiology. ACR Appropriateness Criteria®. http://www.acr.org/secondarymainmenucategories/quality_safety/app_criteria.aspx (accessed Mar 2016).
10. Diagnostic imaging pathways. *A clinical decision support tool and educational resource for diagnostic imaging*. Government of Western Australia, Department of Health. http://www.imagingpathways.health.wa.gov.au/includes/index.html (accessed Mar 2016).
11. Fernandez Soto JM, Vaño E, Guibelalde E. Spanish experience in education and training in radiation protection in medicine. *Radiat Prot Dosimetry* 2011;147:338–42.
12. EC 2000. *'Guidelines on education and training in radiation protection for medical exposures'. Radiation protection 116*. Luxembourg: European Commision, Directorate General Environment, Nuclear Safety and Civil Protection, 2000. http//ec.europe.euenergy/nuclear/radiation_protection/doc/publication/116.pdf
13. Rehani MM, Berris T. International Atomic Energy Agency study with referring physicians on patient radiation exposure and its tracking: a prospective survey using a web-based questionnaire. *BMJ Open* 2012;2:e001425.
14. Freudenberg LS, Beyer T. Subjective perception of radiation risk. *J Nucl Med* 2011;52(Suppl 2):29S–35S.
15. Kruger JF, Chen AH, Rybkin A, *et al*. Clinician perspectives on considering radiation exposure to patients when ordering imaging tests: a qualitative study. *BMJ Qual Saf* 2014;23:893–901.
16. Lumbreras B, González-Alvárez I, Lorente MF, *et al*. Unexpected findings at imaging: predicting frequency in various types of studies. *Eur J Radiol* 2010;74:269–74.

17. Lockwood D, Einstein D, Davros W. Diagnostic imaging: radiation dose and patients' concerns. *J Radiol Nurs* 2007;4:121–4.
18. Heyer CM, Peters S, Lemburg S, *et al*. Awareness of radiation exposure of thoracic CT scans and conventional radiographs: what do non-radiologists know? *Rofo* 2007;179:261–7.
19. Puri S, Hu R, Quazi RR, *et al*. Physicians' and midlevel providers' awareness of lifetime radiation-attributable cancer risk associated with commonly performed CT studies: relationship to practice behavior. *AJR Am J Roentgenol* 2012;199:1328–36.
20. Lee RK, Chu WC, Graham CA, *et al*. Knowledge of radiation exposure in common radiological investigations: a comparison between radiologists and non-radiologists. *Emerg Med J* 2012;29:306–8.
21. Pearce MS, Salotti JA, Little MP, *et al*. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet* 2012;380:499–505.
22. Davies HE, Wathen CG, Gleeson FV. The risks of radiation exposure related to diagnostic imaging and how to minimise them. *BMJ* 2011;342:d947.
23. Westra SJ. The communication of the radiation risk from CT in relation to its clinical benefit in the era of personalized medicine: part 2: benefits versus risk of CT. *Pediatr Radiol* 2014;44(Suppl 3):525–33.
24. Zanzonico P, Stabin MG. Quantitative benefit-risk analysis of medical radiation exposures. *Semin Nucl Med* 2014;44:210–14.