

Gonad shielding in paediatric pelvic radiography: disadvantages prevail over benefit

Marij J. Frantzen · Simon Robben · Alida A. Postma ·
Johannes Zoetelief · Joachim E. Wildberger ·
Gerrit J. Kemerink

Received: 4 June 2011 / Revised: 24 July 2011 / Accepted: 9 September 2011
© The Author(s) 2011. This article is published with open access at Springerlink.com

Abstract

Objective To re-evaluate gonad shielding in paediatric pelvic radiography in terms of attainable radiation risk reduction and associated loss of diagnostic information.

Methods A study on patient dose and the quality of gonad shielding was performed retrospectively using 500 pelvic radiographs of children from 0 to 15 years old. In a subsequent study, 195 radiographs without gonad shielding were included. Patient doses and detriment adjusted risks for heritable disease and cancer were calculated with and without gonad shielding.

Results For girls, gonad shields were placed incorrectly in 91% of the radiographs; for boys, in 66%. Without gonad shielding, the hereditary detriment adjusted risk for girls ranged between 0.1×10^{-6} and 1.3×10^{-6} and for boys between 0.3×10^{-6} and 3.9×10^{-6} , dependent on age. With shielding, the reduction in hereditary risk for girls was on average $6 \pm 3\%$ of the total risk of the radiograph, for boys $24 \pm 6\%$. Without gonad shielding, the effective dose ranged from 0.008 to 0.098 mSv.

Conclusions With modern optimised X-ray systems, the reduction of the detriment adjusted risk by gonad shielding is negligibly small. Given the potential consequences of loss of diagnostic information, of retakes, and of shielding

of automatic exposure-control chambers, gonad shielding might better be discontinued.

Keywords Radiography · Paediatric · Pelvis · Gonads · Radiation risk

Introduction

Protection of the gonads against diagnostic X-rays gained ground in the 1950s [1–4]. Among the reasons were the increased radiation awareness caused by the genetic effects observed in irradiated fruit flies and the higher cancer incidence in the atomic bomb survivors. Both effects are supposed to be induced without a threshold dose [5, 6].

Gonad shielding in radiology has become common practice and is recommended by national and international bodies [7, 8]. The conditions for its application given in [8] are: “(a) The gonads will lie in the primary X-ray field or within close proximity (5 cm); (b) the clinical objectives of the examination will not be compromised; (c) the patient has a reasonable reproductive potential”.

Gonad shielding may be quite effective as it can lower the dose to the testes by about 95% and the dose to the ovaries by about 50% [7]. The lower level of protection in females is mainly due to the large spread in the position of the ovaries, including areas far from the midline lying anterior to pelvic anatomy that has to be visible in the image [7, 9]. In the early years the attainable dose reduction was also high in an absolute sense, because the doses needed for imaging were high. In his 1953 review on the potential hazards of the use of X-rays in paediatrics, Miller [6] reported a patient entrance dose of about 12 mGy for a radiograph, and an entrance dose rate of 100–200 mGy/min during fluoroscopy. Fluoroscopy at that time was performed

M. J. Frantzen · S. Robben · A. A. Postma · J. E. Wildberger ·
G. J. Kemerink (✉)
Department of Radiology, Maastricht University Medical Center,
P. Debijelaan 25,
6229 HX Maastricht, The Netherlands
e-mail: gerrit.kemerink@mumc.nl

J. Zoetelief
Faculty of Applied Sciences, Delft University of Technology,
Lorentzweg 1,
Delft 2628 CJ, The Netherlands

with the classical fluorescent screen, and it was often used instead of radiography, easily resulting in entrance doses of a few hundred mGy. Other investigators [10–12] reported similar dose values, but efforts to reduce patient dose were underway [13].

Unfortunately, the use of gonad protection is not only advantageous, as becomes clear from many evaluations that show that gonad shielding is poor in daily practice [14–21]. It appears to be very difficult to place the X-ray shield correctly, i.e. fully covering the target area but none of the bony pelvic structures. As a consequence, many images are suboptimal or worse, leading to loss of diagnostic information that impairs the radiologist's work. Moreover, the dose reduction can be limited as well, or there may even be a dose increase.

Since the introduction of gonad shielding there have been major advances in X-ray imaging technology and radiation biology. The improved technology and optimisation of imaging protocols have resulted in much lower doses [22–31], while the risk for heritable disease has been found to be lower than previously assumed [32]. The question then arises whether today's reduction in radiation risk by applying gonad shielding is still worthwhile in view of its negative consequences. This balance has not been drawn up so far and as the outcome might have a large impact on daily practice, we decided to re-evaluate the benefit of gonad shielding in terms of attainable radiation risk reduction and associated loss of diagnostic information.

Materials and methods

Optimisation as the incentive for this study

The three pillars of the radiation protection model of the International Commission on Radiological Protection (ICRP) are justification, optimisation and dose limits [32]. To comply with the second obligation, optimisation, X-ray procedures should be re-evaluated from time to time. We performed such an evaluation of pelvic radiography in children, using data already available in our Picture Archiving and Communication System (PACS) (Kodak Carestream Health, Rochester, NY). Organ and effective doses, and the effect of gonad shielding on these doses, were calculated using PCXMC, a Monte Carlo program for estimating patient doses in medical X-ray examinations (STUK—Radiation and Nuclear Safety Authority, Helsinki, Finland). These calculations showed that gonad shielding (1 mm Pb_{eq.}, Dr. Goos-Suprema, Heidelberg, Germany) gave a trivial reduction of the already very small radiation risk. At the same time, we often observed a serious loss of diagnostic information caused by improper gonad shielding. On the basis of these findings the radiological staff unanimously decided to discontinue gonad shielding in

paediatric pelvic imaging using X-rays. Realising that our results might be of wider interest and appropriate for publication, we extended our initial investigation with more data, obtained both before and after discontinuation of gonad shielding. This extended study is the subject of this article; with respect to its execution the Medical Ethics Committee of the Maastricht University Medical Center formally acknowledged that no medical ethical approval was required.

Patients and X-ray projection

In the first retrospective study we investigated gonad shielding and patient dose in children aged 0–15 years. The children had a standard anterior-posterior (AP) pelvic radiograph in 2007 or 2008, mostly in relation to congenital hip dysplasia. The projection covered the region from the iliac crests to 2 cm below the trochanter minor on the femur. Following the majority of other investigators [22–26, 33, 34], we distinguished age groups of 0–1 years, 1–5 years, 5–10 years and 10–15 years. Additional radiographs were evaluated in the second retrospective study in 2010 after we had stopped the application of gonad shields.

Image acquisition and storage

The pelvic radiographs had been acquired in three rooms, each equipped with an X-ray system using a digital flat panel detector (AXIOM Aristos FX Plus; Siemens, Erlangen, Germany). These systems have pre-programmed protocols, which set the high voltage (kV_P), additional filter, focus to image-detector distance, and either a fixed tube current-exposure time product (mAs value) or the automatic exposure control (AEC). The protocol indicates whether the bucky anti-scatter grid has to be present or absent, but grid insertion or removal has to be done manually. We have no special team of technicians for paediatric radiology within our department.

For the younger patients, age-dependent protocols with fixed technique parameters are used. For the 10–15 age group different protocols are applied because the children of this age vary strongly in size. For the smaller patients no grid and no AEC are used, for the group of more adult sized patients they often are.

After acquisition, the images are “shuttered”, i.e. irrelevant edges of the images are removed digitally. Subsequently the images are sent to our PACS in Digital Imaging and Communications in Medicine (DICOM) format. The DICOM header contains retrievable information on the exposure [e.g. kV_P, filter, mAs value, use of the grid and the air kerma-area product (KAP)]. Information on the use of the AEC is not stored, neither is the size of the unshuttered field of view.

Evaluation of gonad shielding

Because the quality of gonad shielding potentially has a large impact on the diagnostic information in the image and the dose reduction as well, the shielding was visually evaluated (by M.J.F.). For boys, the gonad shield had to fully cover the testes, while all bony pelvic parts remained uncovered. For girls, the central section of the pelvis had to be covered, again without shielding parts of the pelvic bones, with the exception of the sacrum to just below the sacro-iliac joints. The radiograph made during the patient's very first visit to the department was obtained without shielding.

Judging from the presence of poor images, retakes had been limited to the absolute minimum. In the evaluation, we therefore identified also all images in which important diagnostic landmarks were not visible due to shielding. Specifically we considered assessability of Shenton's line, Perkin's lines and the acetabular angle (see Fawcett et al. [20], their Fig. 3); these studies were labelled as "retake required", although no retake was obtained in reality. Unfortunately, the real number of retakes could not be determined.

We also estimated the fraction of the testes that was actually shielded (percent coverage) by visual inspection of the radiographs. The corresponding testes dose reduction was calculated with PCXMC as the dose to the testes due to an exposure with the size of the gonad shield, with the field overlaying "percent coverage" of the testes in the cranial-caudal direction. For girls, we assumed that protection is not very sensitive to positioning of the shield (in a statistical sense at least), because of the large spread in the position of the ovaries [9].

Determination of patient dose

In the first dosimetric study (data from 2007 and 2008) gonad shielding was standard, in the second study (data from 2010) shielding was absent.

Together with the discontinuation of the gonad shielding, we continued to optimise our protocols. In the first place, more guidance for the imaging of larger children (10–15 years) was introduced because of large differences in exposure within this group. Secondly, following the European Guidelines [35], we added an additional copper filter of 0.1 mm for the two intermediate age groups. For the youngest patients (0–1 years) the decrease in image quality was considered too large by the paediatric radiologist; for the 10–15 age group, the filter was already used.

The basic filtration of the X-ray beam (i.e. in the absence of 0.1 mm Cu) was determined from the measured half-value layer in aluminium. Since most authors had reported the entrance dose as a dose-in-air including backscatter [22, 23, 25–31], we followed this convention. We estimated backscatter factors for the conversion of incident air kerma to

entrance dose for each age group and radiation quality using data from the NRPB report R279 [36]. These factors were 1.26, 1.35, 1.39, 1.45 and 1.48 for the age groups 0–1 years, 1–5 years, 5–10 years, 10–15 years small children and 10–15 years large children, respectively. The incident air kerma was derived by PCXMC from the KAP and the estimated unshuttered image size. Note that the dose in tissue, used in two publications [24, 33], is about 5% higher than the entrance dose as used by most other investigators and us.

Input information for PCXMC comprises imaging technique settings (kV_p , filtration), KAP, image field size and projection. Note that these exposure parameters are generally independent of the use of gonad shielding, unless the shield was in front of an active AEC chamber. The effect of shielding is taken into account by subtracting a fraction of the gonad dose calculated for the no-shield exposure; under optimal circumstances this subtracted fraction amounts to 95% in male patients and 50% in female patients [7].

PCXMC has the option to adjust the size of the phantoms of all ages. The dose estimation in a specific age group of children will be illustrated using the 5–10 age group as an example. Rather than treating these children as a single group in the dose calculation, we considered 5- to 7.5-year-olds and 7.5- to 10-year-olds separately to reduce the potential effects of spread in patient size. By interpolation between data for child phantoms of different age present in PCXMC, we determined the weight and length of children of 6.25 and 8.75 years. Using the exposure parameters and interpolated patient size and weight for each subgroup, organ doses and effective dose were calculated with PCXMC for the 6.25- and 8.75-year-olds. The average dose for the 5–10 age group was then calculated by averaging the results for these two subgroups. Doses for other age groups were estimated in a similar fashion (always using two subgroups).

The problem of the collimator settings not being stored in the DICOM header (necessary as input on field size) was addressed by determining the average difference in width and height of the original (unshuttered) and shuttered images for a limited set of images for which both types of data were retained. Considerable variations in measured differences existed, but on average 1 cm had to be added in all four directions to compensate for the shuttering. Although this correction for shuttering is necessarily approximate, its application was preferred over leaving it out as this systematically would overestimate the entrance dose. To derive the effective dose from organ doses, the tissue-weighting factors published in ICRP 103 were chosen in PCXMC.

As gonad shielding is applied to limit hereditary effects, the detriment adjusted risk for heritable disease was estimated (the 'detriment adjusted risk' takes the various potential, negative consequences of the exposure into

Table 1 Summary of gonad shielding during paediatric AP pelvic radiography in the period 2007-2008

Age (years)	Male ($n^a=193$)			Female ($n^a=307$)		
	n^a	Shielding incorrect ^b (%)	Retakes required ^c (%)	n^a	Shielding incorrect ^b (%)	Retakes required ^c (%)
0-1	14	64	7	92	97	58
1-5	40	52	0	113	87	28
5-10	87	71	1	50	90	0
10-15	52	69	0	52	88	0

^a Number of radiographs

^b Shielding strictly according to standard rules (see text)

^c Because an important anatomical landmark was obscured, but retake was not actually taken

account, weighting for the seriousness of the corresponding harms; for the official definition see ICRP 103 [32]).

Cost-benefit calculation

Because we saw no solution to the problem of translating the loss of diagnostic information into a numerical risk that might be compared with the risk of radiation, we limited the quantitative risk analysis to radiation effects only.

Shortcomings of gonad shielding, which manifest themselves inevitably in daily practice, and which have an impact on the patient dose, are: (1) in males, an incomplete coverage of the testes, (2) the need for retakes because vital landmarks are obscured and (3) an increase in dose when an active AEC-chamber is (partly) shielded by the lead supposed to shield the gonads. Only point 1 was taken into account, the other two were not, because of missing information.

The detriment adjusted hereditary risk of a pelvic radiograph can be calculated using the nominal coefficient of $5.4 \times 10^{-3} \text{ Sv}^{-1}$ for persons of reproductive age [32]. For the computation of the total detriment adjusted risk, the risk coefficient for cancer ($5.5 \times 10^{-2} \text{ Sv}^{-1}$ for the whole population [32]) with an age-dependent correction for the higher cancer risk for children [37] is needed as well. These calculations further require the effective dose, the testes dose and the dose to the ovaries. The reduction of hereditary risk achieved by gonad shielding

was also expressed as a percentage of the total risk of a radiograph obtained without shielding.

Results

Gonad protection

In total, 500 AP pelvic radiographs with gonad protection were identified in the period 2007–2008. By keeping very strictly to the criteria for good diagnostic information, our scores for gonad protection left much to be desired (Table 1). For girls, in 91% the shielding was not applied strictly according to the rules; for boys, in 66%. In one case a poorly positioned shield covered an osteomyelitic lesion in a boy (Fig. 1). Rates of retakes that would be required if all essential landmarks had to be visible are also shown in Table 1.

Over the whole range of 0-100% coverage of the testes, the average dose reduction decreased with increasing age (and kV_p) from approximately 0.98 to 0.90 times the coverage. So for practical purposes, the fractional testes dose reduction is equal to the fractional coverage. The actual reduction in testes dose, taking this partial shielding into account, is for boys of 0–1 years 51%, 1–5 years 54%, 5–10 years 76% and 10–15 years 77%. For girls, the literature value of 50% was assumed as explained above.

Fig. 1 Conventional pelvic radiograph with testes shielding (*left*). An osteomyelitic lesion is clearly displayed (*arrow*) (*right*). Due to gonad shielding this was missed in the previous examination

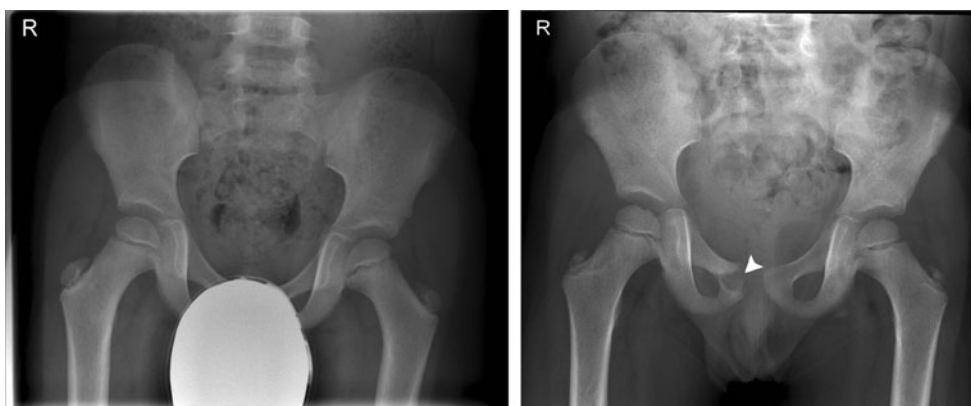


Table 2 Imaging technique settings in AP pelvic radiography^a

Age (years)	<i>n</i>	Filter ^b (mm Cu)	High voltage (kV)	mAs value ^c (mAs)	AEC (yes/no)	Grid (yes/no)
0-1	36	-	50	4.2	n	n
1-5	63	0.1	55	5.2	n	n
5-10	43	0.1	55/60	6.5	n	n
10-15 ^d	27	0.1	70	12	y/n	y/n
10-15 ^e	26	0.1	81	13	y	y

^aThe average focus-image receptor distance was 117±24 cm

^bInherent filtration was 3.3 mm Al-equivalent

^cTube current exposure time product

^dSmaller children, typically no grid and no AEC

^eLarger children, typically with grid and/or AEC

Patient dose

The 2010 study included 195 AP pelvic radiographs acquired without gonad shielding. The imaging technique settings used are shown in Table 2; part of these data were necessary in the dose calculations. The basic filtration of the X-ray beam was 3.3 mm Al. Table 3 presents the KAP, the incident air kerma, the effective dose (for a hermaphrodite), the gonad doses and the contribution of the gonads to the effective dose. Due to the absence of the Cu filter for the group of children of 0–1 years their dose is higher than that for the 1–5 age group. Note the relative spread in all doses in Table 3 will be a little higher than specified for the KAP due to the additional uncertainty in the X-ray beam area. The dose data from the 2007–2008 study were only slightly higher and are not shown.

Cost-benefit calculation

Table 4 gives for the different age groups an overview of the total and hereditary detriment-adjusted risks caused by pelvic radiographs. Note the very low absolute magnitude

of risks for boys and girls alike. For boys, there was an average reduction of the risk of heritable disease as percentage of the total risk of 24±6% when shielding was used; for girls, 6±3%. Assuming uncompromised protection of the gonads (according to ICRP 34, 95% gonad dose reduction in boys, 50% in girls [7]), without any dose increase by collateral effects, this reduction would be 33±5% in boys and 6±3% in girls. Taking the retakes into account that would be required according to the rules for properly shielded images, the total risk reduction for boys would hardly change (23±8%) with respect to not using a gonad shield, but for girls there would be an increase in total risk of 10±27%.

Discussion

The absolute magnitude of the reduction in hereditary risk, even assuming complete uncompromised shielding of the gonads, was very small. Several factors are responsible for this finding. First of all, technical developments and protocol optimisation have lowered the dose needed for a

Table 3 Mean dose data AP pelvic radiography in absence of gonad shielding (*n*=195)

Age (years)	KAP ^a (mGy·cm ²)	Incident air kerma (μGy)	Effective dose ICRP 103 (μSv)	Organ dose testicles (μGy)	Organ dose ovaries (μGy)	Contribution of gonads to effective dose (μSv)
0-1	18.8±7.8	87	13	97	20	5
1-5	16.6±6.3	46	8	56	14	3
5-10	49±28	84	15	111	24	5
10-15 ^b	168±125	223	40	319	98	17
10-15 ^c	369±156	484	98	725	249	39

^aAir kerma-area product

^bSmaller children, typically no grid and no AEC

^cLarger children, typically with grid and/or AEC

Table 4 Detriment adjusted risks caused by AP pelvic radiography with and without gonad shielding

Age (years)	Total risk without shielding		Hereditary risk without shielding		Hereditary risk with shielding	
	Boys per 10 ⁶	Girls per 10 ⁶	Boys per 10 ⁶	Girls per 10 ⁶	Boys per 10 ⁶	Girls per 10 ⁶
0-1	1.6	1.3	0.5	0.1	0.2	0.1
1-5	1.0	0.8	0.3	0.1	0.1	0.0
5-10	2.0	1.6	0.6	0.1	0.1	0.1
10-15 ^a	4.2	2.7	1.7	0.5	0.4	0.3
10-15 ^b	10.2	6.8	3.9	1.3	0.9	0.7

^a Smaller children, typically no grid and no AEC

^b Larger children, typically with grid and AEC

pelvic radiograph from about 10 mGy in the 1950s to a few tenths of a milligray today. Secondly, the risk coefficient for heritable disease is considerably lower than previously assessed.

For about 50 years, radiographers worldwide have been applying gonad shielding in radiography of the pelvis and abdomen. All available studies, including our own, show that gonad shielding is poor in clinical practice (Table 5). Impaired diagnostic information and limited gonad dose reduction are potential consequences. In unfortunate cases there can even be an increase in exposure due to the need for retakes or due to shielding an active AEC chamber, effects that could not be quantitatively included in this study due to the lack of adequate information. The risk reductions we calculated are thus likely to be too optimistic.

The patient doses incurred in our department are relatively low, but not exceptionally, as can be seen in Table 6, which presents data published in the past 20 years [22–30, 33, 34]. We identified more than 40 articles with pertinent data, but only studies giving doses for children of several ages were included. Note that the dose to a

superficially located organ like the testis will be similar to the entrance dose.

Table 6 also shows considerable spread in doses. Thirteen out of 15 reported entrance doses for 0 to 1-year-old children are lower than the diagnostic reference level (DRL) of 640 μ Gy given in the European Guidelines [35] for 4-month old infants, while 12 out of 15 values for 1 to 5-year-old children are below the DRL of 924 μ Gy for 5-year-olds. Smans et al. [31] reported data from a European survey that do not fit in Table 6 due to a different age grouping. Their doses include a low median value of 48 μ Gy for children younger than 1 year and quite a high mean value of $3,460 \pm 2,730$ μ Gy for 8 to 12-year-olds. The large spread and the many high values reported in the literature indicate that a lot is still to be gained by optimisation. This issue is currently being addressed in many countries by setting DRLs for frequently performed procedures, as recommended by the ICRP [32, 38]. Discontinuation of gonad protection should not be considered before optimisation has been performed and dose levels in the low range of Table 6 have been realised.

Table 5 Gonad shield positioning in pelvic radiography according to various studies

Ref.	Number of radiographs with shielding			Percentage with incorrectly placed shields		
	Boys	Girls	Total	Boys (%)	Girls (%)	Average ^a (%)
Kenny and Hill [14]	102	107	209	44	60	52
Wainwright [15]	76	40	116	38	59	45
McCarty et al. [16]	82	57	139	63	72	67
Sikand et al. [17]			110			26
Gul et al. [18]			678			31
Masud et al. [19]			100			78
Fawcett and Barter [20]	611	550	1161	26	48	36
McManus and Davis [21]	618	741	1359	59	71	66
This study	193	307	500	66	91	81

^a Taking the number of each sex into account

Table 6 Mean entrance doses in air, including backscatter, in pelvic radiography according to studies in the past two decades

Age (years)	Ruiz ^a et al. [33] (μGy) ^f	Martin et al. [22] (μGy)	Kyriou et al. [23] (μGy)	McDonald ^a et al. [24] (μGy)	Mooney and Thomas[25] (μGy) ^h	Hufton et al. [26] (μGy) ^j	Gogos ^b et al. [27] (μGy)	Azevedo et al. [34] (μGy)	Yakoumakis ^b et al. [28] (μGy) ^l	Kiljunen ^c et al. [29] (μGy)	Suliman ^d and Elshiekh [30] (μGy)	This study ^e (μGy)
1991	910	1994	1996	1996	1998	1998	2003	2006	2007	2008	2008	
0-1	1070	140	140	60	140	69	147	513	243	140	226	110
1-5	1295	410	350	80	360	234	123	797	-	420	309	62
5-10	2350	680	550	600	560	458	347	1286	354	-	388	116
10-15	3170	1230	1070	1200	1180	983	508	1816	652	2540	321	324 ⁿ /713 ^o

^a Entrance dose in tissue, which is typically 5% higher than entrance doses in air which includes backscatter

^b Age groups (years) 0-0.5, 0.5-2, 3-7, 8-12

^c Age groups (years) <0.5, 2.5-7.5, 12.5-17.5

^d Values at 1, 5, 10 and 15 years; averaged over 3 hospitals with similar data. Children of 15 years weighted only 27 kg

^e Backscatter factors from [36] applied to incident air kerma (from Table 3)

^f Centre I two rooms averaged

^g Centre II

^h 2.5 mm Al

ⁱ 5.5 mm Al filtration

^j Screen-film, average of two rooms

^k Computed radiography, average of two rooms

^l Hospital A

^m Hospital B

ⁿ Smaller children, typically no grid and no AEC

^o Larger children, typically with grid and/or AEC

Installation of a modern digital system is no guarantee for acceptable performance.

Patient dose reductions since the fifties were realised by using harder radiation, a larger focus-patient distance, the introduction of faster screens and films, and the discontinuation of fluoroscopy in favour of radiography. In fluoroscopy the introduction of the image intensifier was a major step. Recently the more sensitive digital detectors and the concomitant development of image processing software helped reduce patient dose.

Despite its limitations, gonad shielding has served its purpose in times when doses were high. Now it appears that its potential advantages are outweighed by the drawbacks. Too many images contain impaired diagnostic information. The high numbers of retakes required, but not actually taken, are symptomatic. Often the radiologist is forced to fill in the gaps with information from previous images. This is not without risk, as illustrated by the incident with the shielded osteomyelitic lesion (Fig. 1). This incident shows that even the peripheral zones of pelvic bones should not be covered.

The uncertainties in the derived doses still need to be considered. The KAP meters are calibrated on a regular basis and their accuracy is typically within 5-10%. PCXMC has only a limited number of mathematical phantoms, and the size of the individual patient may not correspond to that of the phantom closest in age. As a consequence, in some cases PCXMC's dose estimates will be too high, and in others too low, but the average dose estimate for patients within an age group will be fairly realistic. The correction for shuttering to obtain the true X-ray field size introduces an additional uncertainty in the dose estimates. To give an idea of its magnitude, assume that the uncertainty equals the fully applied correction of 1 cm in all directions. This would result in an uncertainty of the estimated area of $\pm 13\%$ for the smallest and $\pm 6\%$ of the largest fields. Note that for a given KAP the effect of a change in the beam area on the effective dose is likely to be small, but on the dose to the gonads (or any other single organ) it will have its full impact. Taking all considerations together, the accuracy of the average calculated dose should be better than about

20%. For individual patients the error may be larger, as indicated by the spread in KAP values in Table 3.

An important practical aspect for this discussion is the perception of radiation risks. The emphasis over the years on applying gonad shields has nurtured the conviction that major risks have to be countered. Workers and parents are so used to shielding that not using it is considered a major neglect. And it cannot be denied that there is an average risk reduction for boys of about 24% and of 6% for girls, so why stop protection? The answer is given by the ICRP, which advises that risks in the range 10^{-6} - 10^{-7} be considered as of no concern [39]. Only for the group of large boys of age 10–15 years is the potential reduction in hereditary (or total) risk 3.0×10^{-6} .

Radiographers should learn that the risks associated with the potential loss of diagnostic information outweigh the very small benefit of gonad shielding. Parents could be helped by showing them the risks of exposures that are commonly accepted as harmless. A few have been collected in Table 7 and they illustrate how small the effective dose (which also accounts for the gonad dose) of pelvic radiography in children is. The NCRP considers 10 μ Sv as a negligible annual effective dose [40]. As a final example of the risk of a normal life activity, a drive by car over 100 km, e.g. for a retake of the image in Fig. 1, has in the EU on average a risk of 1×10^{-6} for a fatal accident [41], the risk for an injury is much higher.

Conclusion

There are good arguments to stop gonad protection in pelvic radiography of children, provided modern equipment and properly optimised imaging protocols are used. The risk reduction for girls and young boys is marginal, for older boys there is room for discussion. Our staff decided upon images of constant good quality, for all children, rather than the minor benefit of gonad protection. Available resources for education and optimisation are better directed at applications with a potentially higher risk reduction.

Table 7 The effect of a few trivial activities in all-day life on effective dose^a

Action	Saving	Expense
Lowering radon (^{222}Rn) concentration at home with 1 Bq/m ³ [42] (e.g. by increasing ventilation; worldwide average conc. 40 Bq/m ³)	80 μ Sv/year	
Holidays on a cruise ship instead of on land [43]	2 μ Sv/day	
Large distance flying [44]		5 μ Sv/h
Visit of cave with relatively low radon concentration of 1 kBq/m ³ [45]		4 μ Sv/h
Person living in Cornwall (6.5 mSv/year due to radon only) going to London (1 mSv/year) [46]	15 μ Sv/day	
Living in The Netherlands (2 mSv/year)		5 μ Sv/day

^aApproximate data, exact values depend on several details

Open Access This article is distributed under the terms of the Creative Commons Attribution Noncommercial License which permits any noncommercial use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

References

- Abram E, Wilkinson DM, Hodson CJ (1958) Gonadal protection from X radiation for the female. *Br J Radiol* 31:335–336
- Ardran GM, Kemp FH (1957) Protection of the male gonads in diagnostic procedures. *Br J Radiol* 30:280
- Whitehead G, Griffiths JT (1961) The Leicester gonad protector: a device to afford localised protection from diagnostic x-irradiation. *Br J Radiol* 34:135–136
- Lorenz W (1958) Physical and technical problems of radiation protection in medical installations. *Fortschr Geb Rontgenstr Nuklearmed* 88:251–276
- Meggitt G (2008) Taming the rays—a history of radiation and protection. Raleigh, Lulu.com
- Miller RW (1953) Some potential hazards of the use of roentgen rays in pediatrics. *Pediatrics* 11:294–303
- International Commission on Radiological Protection (1982) Protection of the patient in diagnostic radiology (ICRP publication 34). *Ann. ICRP* 1982;9 (2–3), Pergamon, Oxford
- FDA. 21 CFR 1000.50 (1976) Recommendation for the use of specific area gonad shielding on patients during medical diagnostic x-ray procedures Available via <http://cfr.vlex.com/vid/1000-recommendation-gonad-shielding-patients-ray-19716085>. Accessed 27 Oct 2010
- Bardo DM, Black M, Schenk K, Zaritzky MF (2009) Location of the ovaries in girls from newborn to 18 years of age: reconsidering ovarian shielding. *Pediatr Radiol* 39:253–259
- Stanford RW, Vance J (1955) The quantity of radiation received by the reproductive organs of patients during routine diagnostic x-ray examinations. *Br J Radiol* 28:266–273
- Martin JH (1947) Radiation doses received by the skin of a patient during routine diagnostic X-ray examinations. *Br J Radiol* 20:279–283
- Billings MS, Norman A, Greenfield MA (1957) Gonad dose during routine roentgenography. *Radiology* 69:37–41
- Ardran GM (1956) The hazards from the increasing use of ionizing radiations II. The dose to the operator and patient in x-ray diagnostic procedures. *Br J Radiol* 29:266–269
- Kenny N, Hill J (1992) Gonad protection in young orthopaedic patients. *BMJ* 304:1411–1413
- Wainwright AM (2000) Shielding reproductive organs of orthopaedic patients during pelvic radiography. *Ann R Coll Surg Engl* 82:318–321
- McCarty M, Waugh R, McCallum H, Montgomery RJ, Aszkenasy OM (2001) Pediatric pelvic imaging: improvement in gonad shield placement by multidisciplinary audit. *Pediatr Radiol* 31:646–649
- Sikand M, Stinchcombe S, Livesley PJ (2003) Study on the use of gonadal protection shields during paediatric pelvic X-rays. *Ann R Coll Surg Engl* 85:422–425
- Gul A, Zafar M, Maffulli N (2005) Gonadal shields in pelvic radiographs in pediatric patients. *Bull Hosp Jt Dis* 63:13–14
- Masud S, Mehra A, Clothier JC (2008) Study on the use of gonadal shields in paediatric pelvic x-rays. *J Bone Joint Surg Br* 90-B (Suppl II):338
- Fawcett SL, Barter SJ (2009) The use of gonad shielding in paediatric hip and pelvis radiographs. *Br J Radiol* 82:363–370
- McManus A, Davis N (2010) The gonad shield in pelvic X-rays covering a multitude of sins? Available via <http://www.epos.efort.org/public/Sorrentoeposters/3958.ppt>. Accessed 27 Oct 2010
- Martin CJ, Farquhar B, Stockdale E, MacDonald S (1994) A study of the relationship between patient dose and size in paediatric radiology. *Br J Radiol* 67:864–871
- Kyriou JC, Fitzgerald M, Pettett A, Cook JV, Pablot SM (1996) A comparison of doses and techniques between specialist and non-specialist centres in the diagnostic X-ray imaging of children. *Br J Radiol* 69:437–450
- McDonald S, Martin CJ, Darragh CL, Graham DT (1998) Dose-area product measurements in paediatric radiography. *Br J Radiol* 69:318–325
- Mooney R, Thomas PS (1998) Dose reduction in a paediatric X-ray department following optimization of radiographic technique. *Br J Radiol* 71:852–860
- Hufton AP, Doyle SM, Carty HM (1998) Digital radiography in paediatrics: radiation dose considerations and magnitude of possible dose reduction. *Br J Radiol* 71:186–199
- Gogos KA, Yakoumakis EN, Tsalafoutas IA, Makri TK (2003) Radiation dose considerations in common paediatric X-ray examinations. *Pediatr Radiol* 33:236–240
- Yakoumakis EN, Tsalafoutas IA, Aliberti M, Pantos GI, Yakoumakis NE, Karaiskos P, Georgiou EK (2007) Radiation doses in common X-ray examinations carried out in two dedicated paediatric hospitals. *Radiat Prot Dosimetry* 124:348–352
- Kiljunen T, Tietäväinen A, Parviainen T, Viitala A, Kortensniemi M (2009) Organ doses and effective doses in pediatric radiography: patient-dose survey in Finland. *Acta Radiol* 50:114–124
- Suliman II, Elshiekh EH (2008) Radiation doses from some common paediatric X-ray examinations in Sudan. *Radiat Prot Dosimetry* 132:64–72
- Smans K, Vaño E, Sanchez R, Schultz FW, Zoetelief J, Kiljunen T, Maccia C, Järvinen H, Bly R, Kosunen A, Faulkner K, Bosmans H (2008) Results of a European survey on patient doses in paediatric radiology. *Radiat Prot Dosimetry* 129:204–210
- International Commission on Radiological Protection (2007) The 2007 recommendations of the International Commission on Radiological Protection (ICRP publication 103). *Ann ICRP* 37 (2–4), Pergamon, Oxford
- Ruiz MJ, González L, Vaño E, Martínez A (1991) Measurement of radiation doses in the most frequent simple examinations in paediatric radiology and its dependence on patient age. *Br J Radiol* 64:929–933
- Azevedo AC, Osibote OA, Boechat MC (2006) Paediatric x-ray examinations in Rio de Janeiro. *Phys Med Biol* 51:3723–3732
- Commission for European Communities (1996) European Guidelines on quality criteria for diagnostic images in paediatrics (EUR-16261)
- Hart D, Jones DG, Wall BF (1996) Coefficients for estimating effective doses from paediatric x-ray examinations. Chilton, NRPB-R279. HMSO, London
- International Commission on Radiological Protection (1991) 1990 recommendations of the International Commission on Radiological Protection (ICRP publication 60). *Ann ICRP* 21(1–3). Pergamon, Oxford
- International Commission on Radiological Protection (2007) Radiological protection in medicine (ICRP publication 105). *Ann ICRP* 37(6), Pergamon, Oxford
- International Commission on Radiological Protection (2006) ICRP supporting guidance 5. *Ann. ICRP* 35(4), Pergamon, Oxford
- National Council on Radiation Protection and Measurements (NCRP) (1993) Limitation of Exposure to Ionizing Radiation. Report No. 116, NCRP Publications, Bethesda
- Traffic collision. Wikipedia. http://en.wikipedia.org/wiki/Traffic_collision. Accessed 18 July 2011.
- Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (2000) UNSCEAR 2000 Report to the General

- Assembly, with scientific annexes. Vol. I, Annex B, Exposures from natural radiation sources. United Nations, New York
43. Fact Sheet on U.S. Nuclear Powered Warship (NPW) Safety. Available via <http://www.mofa.go.jp/region/n-america/us/security/fact0604.pdf> Note the dose given in this Fact Sheet is equal to that due to cosmic radiation at sea level. Accessed 30 Oct 2010
 44. Federal Aviation Administration Office of Aerospace Medicine, Civil Aerospace Medical Institute (2010) Available via <http://jag.cami.jccbi.gov/cariresults.asp>. Accessed 28 Oct 2010
 45. Lario J, Sánchez-Moral S, Cañaveras JC, Cuezva S, Soler V (2005) Radon continuous monitoring in Altamira Cave (northern Spain) to assess user's annual effective dose. *J Environ Radioact* 80:161–174
 46. Watson SJ, Jones AL, Oatway WB, Hughes JS (2005) Ionising radiation exposure of the UK population: 2005 Review. HPA-RPD-001. Available via <http://www.hpa.org.uk/Publications/Radiation/HPARPDSeriesReports/HpaRpd001/>. Accessed 28 Oct 2010