Evaluation of the Effectiveness of Gonad Shielding in Digital Radiography

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Abstract. This study evaluated the effectiveness of a custom-made gonads shield made from recycled lead gowns, in terms of dose reduction factors. It established how much reduction was achieved when gonad shields were in place and how it was affected by varying the radiographic parameters, including tube potential, current-time product (mAs), and automatic exposure control (AEC). An adult anthropomorphic phantom was exposed in an anteroposterior pelvic (AP) projection examination. Gonad doses were measured using nanoDot^{TM} optically stimulated luminescent dosimeter (OSLD). For the male examination, when the AEC was switched on, the gonad shield reduced the absorbed dose to the testes by 67% while dose reduction of 58% was achieved in the female pelvic X-ray examination. With manual control of mAs and standard voltage (70kVp), a dose reduction of 89% and 59% was observed for male and female phantom, respectively. Various tube potential values with constant mAs achieved a dose reduction of 88% for males, and for the female phantom, a dose reduction of 63% was obtained. The effectiveness of gonad shielding was affected by the location of gonads. Male gonads located externally were easily identified and shielded, thus benefited from a larger dose of reduction. In contrast, the actual positions of the female ovaries were not visible and often estimated. The dose reduction achieved were also lower.

Keywords: Contact shields, Dose reduction factor, mAs, tube voltage, AEC

INTRODUCTION

Gonad shielding was introduced in the 1950s as part of the radiation protection measures for patients. The intent was to minimise the potential for heritable genetic effects from medical exposures. It was expected to reduce radiation dose to gonads by 95% and for female adults by 50% [1].

Since the introduction of gonadal shielding, the practice has varied depending on the individual centre and radiographers' practices. Shielding of the gonads requires that gonads be placed within 5 cm of the X-ray field during exposure; the only exceptions are if the shielding degrades diagnostic information [2]. This practice is useful for both diagnostic and therapeutic procedures. Usually, a protective shield of either lead or aluminium is placed outside the body to cover the pelvis region. This region is defined below the pelvis girdle, being the sensitive region around the testicular region for males. For females, the part of interest is the pelvis region with sensitive organs such as the uterus and the ovaries. Pelvic shielding was aimed at preventing infertility due to sterility [1].

There is a long-standing debate on the practice of gonadal shielding [1, 3-7]. Those who are for the practice argued that gonads are radiosensitive organs. The use of gonad shielding in the paediatric population may be beneficial due to the longer lifetime of the patient and increased lifetime risk of developing radiation-induced effects. Those against the practice argued that the use of gonad shields could block important anatomic/radiographic information, leading to unnecessary repeats of X-rays and radiation dose to patients. It is challenging to locate the female organs (ovaries and uterus) just from external anatomical landmarks. Due to the normal variation of human anatomy, the odds of missing the organ locations is very high. Furthermore, with automatic exposure control (AEC) in modern digital radiography units, there is a risk of the gonadal shields blocking the AEC detectors, thereby obstructing the proper functioning of the AEC, leading to higher radiation doses to patients [8]. The National Council on Radiation Protection and Measurements (NCRP), Statement No. 13, also stated that gonad doses to the ovaries were contributed mainly by scattered X-rays; gonadal shielding was therefore not recommended for a routine abdominal and pelvic examination [9].

The effectiveness of gonad shielding was questioned, especially in the female examination. Subsequently, recommendations have been put forward to halt the practice. This recommendation was based on image quality issues; that the gonad shield obstructs radiological information obstruction. These studies did not include dosimetry assessment. With a likelihood of dose increase to organs due to scattering, absorbed dose analysis would be particularly important. A previous study based on air KERMA measurements had shown an increase in absorbed to the gonads when shields are placed [8]. However, air KERMA does not represent the actual radiation dose to the gonads. On the other hand, studies conducted in the male examination had shown that gonad shielding resulted in up to 42% of dose reduction for the lumbar spine [4].

The International Commission on Radiological Protection (ICRP), Report 103, reduced radiation risk values to the gonads to 0.086 [2]. This means that the irradiation of gonads contributes to only 8% risk of stochastic effect due to radiation. Whilst it may seem that radiation risk from diagnostic imaging is too low due to a combination of low radiation doses and risk, there is still justification that protection is always a better policy.

With X-ray imaging being widely available and a standard modality of examination, there is an increase in population exposure. Dracham et al. reported that with each Gray (Gy) of radiation exposure, there is an increased rate of solid cancer by about 35% in males and 58% in females [10]. Pelvic and lower abdomen radiography are near reproductive organs, thus is important to consider shielding efficacy. While many studies had been carried out to investigate the effectiveness of commercial gonad shields, to the best of the authors' knowledge, none had investigated the effectiveness of gonad shields made from recycled lead (Pb) gowns.

In this study, we attempted to do a comprehensive quantitative efficacy analysis of gonad shielding. In particular, the gonad shields examined were custom made in-house using recycled lead (Pb) gowns. We examined several physical adjustable parameters disposable to the radiographers to ensure quality pelvic examinations. These parameters are tube voltage, tube current-time product, and AEC control.

MATERIAL AND METHODS

An anthropomorphic phantom (model no: ART-702G, CIRS Radiology Support Devices, Inc., Norfolk, Virginia, USA) composed of tissue and bone equivalent epoxy resin was irradiated using a Carestream DRX-Evolution system (CARESTREAM HEALTH, USA, New York Inc) digital X-ray system.

For organ dose measurements, the Al_2O_3:C based nanoDot^{TM} dosimeter (Landauer Inc., Glenwood, US) were used (Figure 1). The InLight® microStar reader (Lindauer Inc., Glenwood, IL, USA) was used to read the dosimeters.

The OSL dosimeters were optically bleached using a high luminescence LED light for 12-24 hours to erase residual doses. Initial readings were then recorded for individual dosimeters before being used for dose measurement [11].

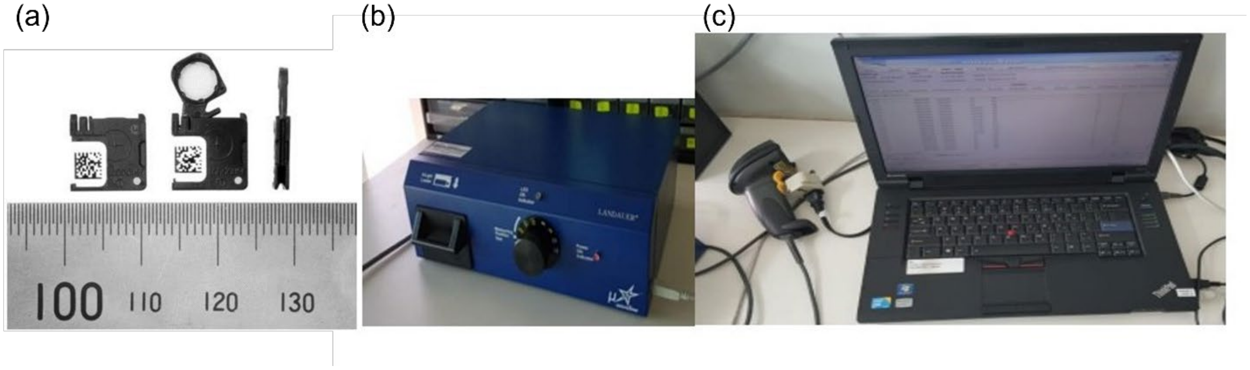

FIGURE 1. The OSLD dosimetry system comprising of (a) nanoDot^{TM}, (b) microStar reader, and (c) barcode reader with a processing unit

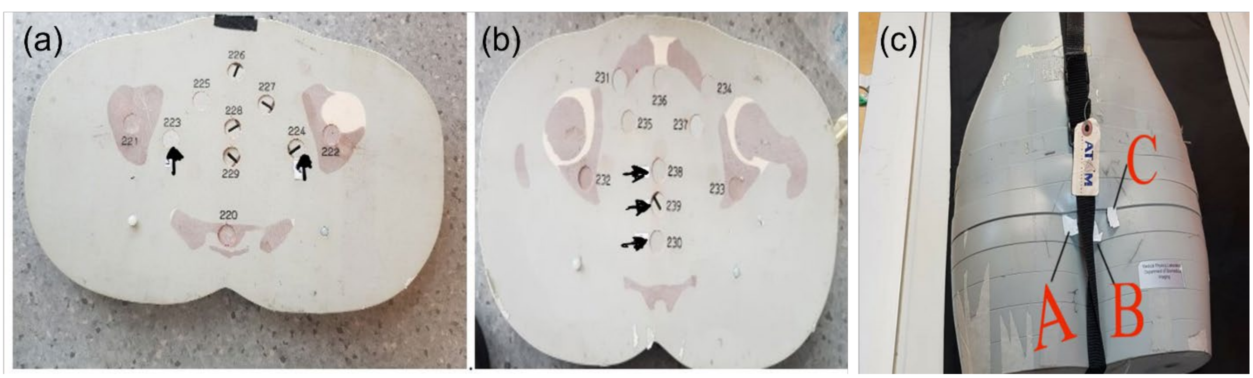

FIGURE 2: A cross-section of the female phantom at the (a) ovary position (b) uterus positions and for male phantom, the the position representing testes at the surface of the phantom. The nanoDot™ units were placed inside the phantom at the ovary and uterus positions (indicated by the black arrows) and on the testis, indicated by the orange labels (A,B, and C).

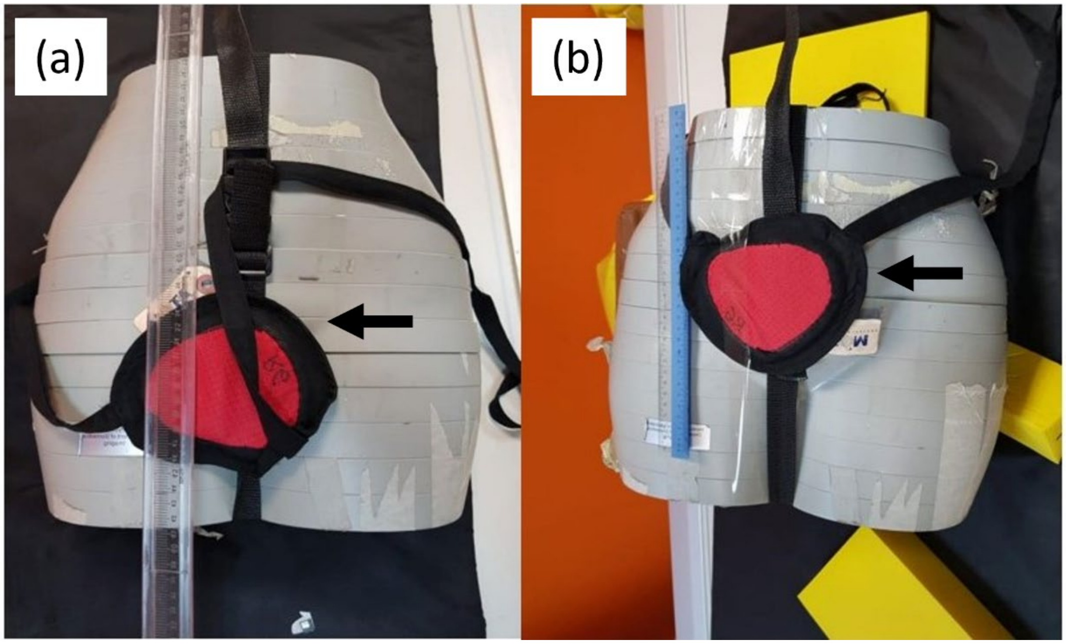

FIGURE 3: Position of the gonad shield for (a) male and for (b) female phantom (indicated by the black arrow). The same phantom was used but the placement of the gonad shields represented male and female positioning the gonad shields.

The same anthropomorphic phantom was used for the male and female pelvic examination. For the female phantom, three units of nanoDots™ dosimeters were inserted in the phantom at the uterus position and on each ovary (Figure 2 a, b). For the male examination, three units of nanoDots™ dosimeters were placed on the surface of the pelvis at the position representing testes (Figure 2 c). Figure 3 shows the positioning of the gonad shields. The gonad shields used were custom-made in-house by the medical physicists and radiographers, using recycled lead gowns. It comprised 40 sheets of a mixture of 0.25 and 0.5 mm Pb equivalent sheets, stacked together and sewn within two sheets of fabrics.

The pelvic part of the phantom was placed in a supine position with the median sagittal plane of the body at right angles to and in the mid-line of the table, and AP pelvic examinations were performed. The X-ray tube was adjusted to a focus-surface distance (FSD) of 100 cm (Figure 4). The collimator was open wide to 35 x 43 cm^2 to include the pelvic region and the lower abdomen.

We evaluated the percentage of dose reduction with and without using gonad shield in various clinical settings as listed in Table 1. An explanation on the clinical scenario simulated by these setups were also explained. The AEC of the Carestream DRX system was checked and calibrated during the quality control test conducted annually and was deem to be suitable to be used for clinical X-ray examinations. The dosimeters were read three times; the mean and 1 standard deviation (SD) of the mean was computed.

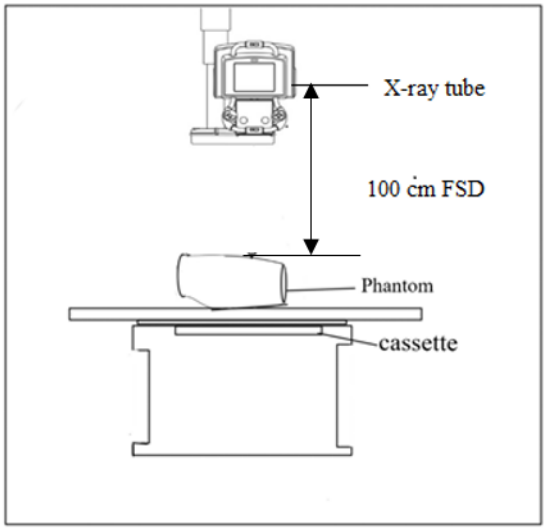

FIGURE 4: Setup position of the phantom on the X-ray table.

TABLE 1. Measurement settings and the clinical scenarios simulated.

Settings	Measurement settings	Clinical scenario simulated
Without AEC (manual)	Fixed tube potential (70 kVp), varied tube current-time product (16, 20 25 mAs)	Older X-ray units without AEC functions or X-ray examinations performed on patient's bed. Higher mAs is applied for patients with larger body habitus to increase radiation signals to the detector.
	Fixed tube current-time product (25 mAs), varied tube potential (70, 80, 90, 100 kVp)	Older X-ray units without AEC functions or X-ray examinations performed on patients beds. Higher kVp is applied for patients with larger body habitus to increase radiation penetration and thus radiation signals to the detector.
With AEC	Varied tube potential, AEC controlled tube current-time product	Modern X-ray systems are often equipped with AEC functions. The AEC will cut off the radiation once a sufficient radiation dose was received by the AEC detectors located underneath the patient in the patient couch.

Note: AEC is automatic exposure control, kVp is the tube potential, and mAs is the tube current-time product.

RESULTS

Samples of the radiographic images are shown in Figure 5. The image in Figure 5 (a to c) were deemed clinically acceptable. Figure 5 (d) represents a clinically unacceptable image for a female pelvic examination but is useful for a lower abdomen examination. This is because the presence of the gonad shield obstructed the important anatomical structure in the pelvic region. It would still be helpful for gonad shielding if the radiograph had been intended for the X-ray examination of the lower abdomen region.

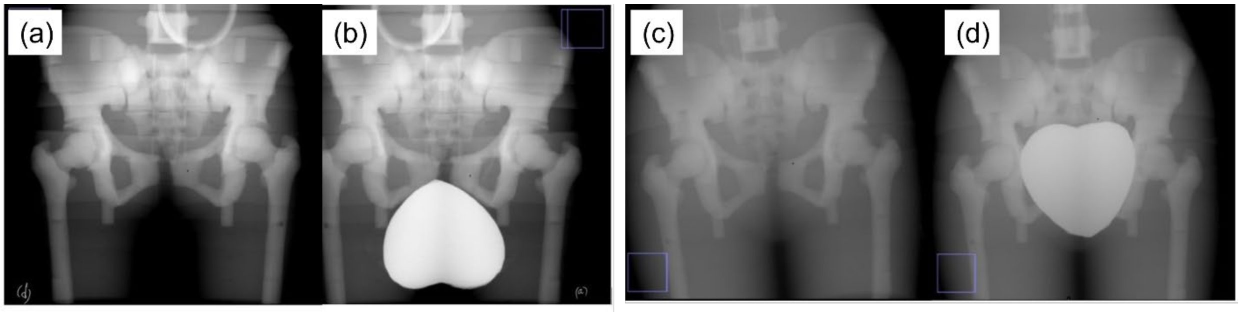

FIGURE 5: Radiographs showing phantoms (a, c) without and (b,d) with gonad shields and the representative gonad shield placements on phantom for (a,b) male and (c,d) female patients.

The gonad doses from a supine pelvic radiographic examination over a range of clinical tube voltages and tube current-time product settings were obtained. The measured gonad doses with the AEC switched off (manual) settings, at tube potential fixed at 70 kVp, but varied mAs values are shown in Table 2.

The values represent the mean and 1 SD of the absorbed doses of all the nanoDot™ units for male (n=3) and female (n=5) phantom setup. The values represent the uncertainty of a single measurement, but with at least three dosimeters for each setting. For the male gonads, a dose reduction of 89% was observed (from 1.90 ± 0.41 mGy reduced to 0.20 ± 0.05 mGy). For the female gonads, a dose reduction of 59% was observed (0.33 ± 0.06 mGy reduced to 0.13 ± 0.02 mGy).

TABLE 2. Absorbed doses with AEC control switched off (manual setting), fixed tube potential of 70 kVp and variable tube current-time product (mAs).

Tube current-time product (mAs)	**Absorbed dose (mGy)**			
	Male		**Female**	
	Unshielded	**Shielded**	**Unshielded**	**Shielded**
16	1.48±0.10	0.17±0.05	0.27±0.05	0.13±0.06
20	1.93±0.10	0.22±0.07	0.33±0.07	0.15±0.06
25	2.29±0.05	0.26±0.08	0.38±0.09	0.11±0.05

TABLE 3. Absorbed doses with AEC control switched off (manual setting), fixed tube current-time product of 25 mAs and variable tube potentials (kVp).

Tube potential (kVp)	**Absorbed dose (mGy)**			
	Male		**Female**	
	Unshielded	**Shielded**	**Unshielded**	**Shielded**
70	2.29 ±0.11	0.26±0.06	0.39±0.09	0.12±0.05
80	3.23±0.09	0.29±0.04	0.54±0.12	0.19±0.04
90	4.02±0.12	0.57±0.05	0.86±0.05	0.37±0.08
100	4.88±0.23	0.74±0.14	1.26±0.17	0.47±0.05

TABLE 4. Absorbed doses for various kVp with AEC control switched on.

Tube potential (kVp)	**Absorbed dose (mGy)**			
	Male		**Female**	
	Unshielded	**Shielded**	**Unshielded**	**Shielded**
70	2.34±0.10	0.22±0.08	0.38±0.16	0.10±0.05
80	1.26±0.10	0.14±0.03	0.24±0.03	0.10±0.03
90	1.14±0.04	0.10±0.04	0.19±0.14	0.11±0.05
100	0.81±0.07	0.10±0.03	0.24±0.15	0.10±0.05

Table 3 shows the results of the gonad doses with the tube current-time product fixed at 25 mAs, variable tube potentials and the AEC switched off. For this setting, increasing the tube potential increased the patient doses. The mean gonad dose for unshielded gonads was 3.6 ± 1.1 mGy and 0.8 ± 0.4 mGy, for male and female phantom, respectively. The gonad doses with gonadal shields applied were reduced to 0.8 ± 0.4 mGy (88% dose reduction) and 0.3 ± 0.2 mGy (63% dose reduction) for male and female gonads, respectively.

Most modern digital radiography systems are equipped with AEC functions, and typically, AP pelvic examinations would be performed with the AEC switched on. Table 4 shows the mean absorbed doses for the gonads measured with the AEC switched on for various tube potential settings. For the male gonads, an overall dose reduction of 67% was observed (from 1.39 ± 0.66 mGy reduced to 0.14 ± 0.06 mGy). For the female gonads, an overall dose reduction of 58% was observed (0.26 ± 0.08 mGy reduced to 0.10 ± 0.01 mGy).

The gonad doses for unshielded gonads were notably lower when this setting was used. Increasing tube potentials also demonstrated lower gonad doses. This is because using the AEC setting, the exposure time was automatically reduced when sufficient signals reached the AEC detectors.

For all three settings, the lower gonad dose for the female phantom was because the organs were located internally; thus, radiation doses were attenuated. The dose reduction achieved was lesser than the male gonads.

Figure 6 shows the overview of the dose reduction achieved with and without the AEC switched on, shown as the fraction of the gonad dose. On average, using AEC reduced the gonad dose by approximately one half; 53% and 46% for male and female phantom, respectively. Using the gonad shields plus AEC, the gonad doses were reduced to 5% and 16% of the radiation dose received for unshielded gonads and a manual exposure setting. The dose reduction was more at lower tube potentials and lesser at higher tube potentials.

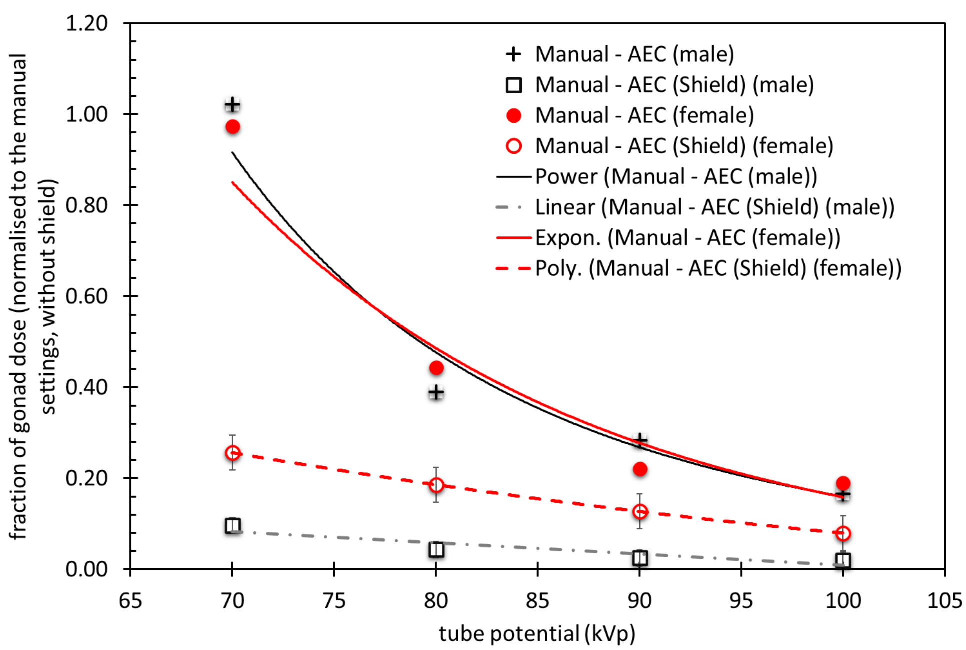

FIGURE 6. Overview of the dose reduction achieve with and without the AEC switched on, shown as the fraction of the gonad dose. The gonad doses were normalised to 1 for the manual settings without the shield application.

DISCUSSION

The images obtained for all shielded examinations of the male's bony landmarks showed that the whole pelvis, sacrum, and pubic symphysis were visible. For the female examination, the obscured pubic symphysis would be of great concern for patients with pubic symphysis diastasis, prevalent in pregnant women. Generally, an acceptable female radiograph for patients who have incurred trauma injuries must have all threshold landmarks to assess fractured bones; it is therefore not a useful image for this type of scan.

To effectively shield the female gonads, a customised design for each patient may be needed because of the anatomic variation of the pelvic cavity. Furthermore, it is difficult to establish the exact geometry of the pubic cavity because of its internal location, unlike male patients where the gonads are visible externally.

The use of gonad shields results in > 50% dose reduction when used under tube potentials ranging from 70 to 100 kVp. The protection value to the gonads outweighs the risk of positioning errors, statistically would give room for a second radiograph, if needed.

The tube voltage of 70kVp and 25mAs were the current standard practice of our department. This setting was primarily based on experience and standard settings by the manufacturer. The main emphasis was to ensure that the gonad shield does not obstruct anatomy of interest and a relatively lower dose. The so-called optimised settings were not based on an extensive evaluation of image contrast and resolution. One of the reasons is, as long as there is sufficient exposure to the digital receptor, sub-optimal image quality can be post-process digitally to adjust the image on the digital display.

A similarity in the trend of higher dose reduction achieved in the male compared to the female was not surprising, given that male gonads are located on the surface and received a higher amount of radiation dose when no gonadal shielding was applied.

This difference in dose reduction was clinically significant for males and indicates a greater benefit with no impact on image quality when correctly placed.

For comparison on the sufficiency of AEC without the need for gonadal shielding, the following was established; gonad doses at higher tube voltages was significantly reduced, indicating AEC was even more effective than manual optimisation of mAs values at higher voltages. It is likely that the effect of AEC in radiation protection at higher tube voltage is more conspicuous and can replace optimised parameters with shields in place.

Table 5 shows the summary of selected literature on the effectiveness of gonad shielding. The findings of this study concur with those of the works of Clancy et al.[4], Fauber [6] and Kaplan et al. [8]. However, compared to Clancy et al., we reported a more considerable dose reduction in the gonads due to the custom-made gonad shields comprising multiple layers of the recycled lead gowns.

Kaplan et al. (2018) reported that the presence of gonad shields with AEC increased the X-ray output by 147% in adult phantom, leading to increased absorbed dose at unshielded locations such as colon, stomach and ovaries up to 100% [8]. However, the gonad shields were still effective in reducing the gonad doses by 67% for paediatrics and 16% for adult female phantom [8]. We also believe that absorbed dose is a better representation of the gonad dose than KERMA, which is the radiation exposure reaching the detector.

Daniels and Furey (2008) reported that gonad shields offer little protection for organs outside the primary region as the main contribution were only scattered radiation [3]. We agree with their findings as dose contribution from the primary beam is vastly different from scattered radiation dose from internal organs or external scatter.

TABLE 5. Summary of previous literature on gonad shielding

Author, year	Modality	Phantom/Study design	Methods & dosimeter	Results
Daniels & Furey, 2008 [3]	Siemens Tridoris 712 MP, GE Advantx, Phillips Optimus	Rando anthropomorphic phantom (male and female 3 mm surface lead shields Out of field irradiation (scattered radiation) 60 – 120 kVp, 100 mAs	Radcal ion chamber, model 9095	15 ± 13.1% for males and 5 ± 5.6% for females Contribution from scattered radiation
Clancy et al., 2010 [4]	GE MAXIRay 100	Rando anthropomorphic phantom (male and female) 0.25 mm Pb equivalent lead apron Gonad shields	AP and lateral lumbar spine TLD	No dose reduction for female. Males had 42% dose reduction.
Fauber, 2016 [6]	-	Anthropomorphic phantom 10 exposures Flat contact shields	Pelvic imaging TLD	36.4% increase in gonad dose when no gonad shields was used.
Kaplan et al., 2018 [8]		Anthropomorphic phantom (adult & 5-yo equivalent) Female gonad shields	Pelvis imaging Dose-area product (DAP),	DAP increased 63% -- 147% due to the presence of gonad shields for paediatric and adult Absorbed doses under shielded area reduced by 16 – 67% for adult and paediatric phantom.
This work	Carestream DRX	70 – 100 kVp, 16 – 25 mAs Atom anthropomorphic phantom Custom made gonad shields	AP pelvis OSLD	Reduction of gonad dose No AEC, 70 kVp: Male (89%), Female (59%) No AEC, 25 mAs: Male (88%), Female (63%) AEC: Male (67%), Female (58%)

Note: TLD = thermoluminescent dosimeter, DAP = dose-area product, OSLD = optically stimulated luminescent dosimeter, AP = antero-posterior, yo= year-old, The limitation of this study included that the one-size phantom may not adequately simulate the radiation dose attenuation due to additional fat and muscle mass for patients with larger body habitus. The uncertainty due to normal positional variation due to normal anatomy variation in female patients could not be simulated.

CONCLUSION

We investigated the impact of various exposure parameters in the effective use of a custom made gonadal shielding made from recycled lead gowns for AP pelvic examination. Male shielding is recommended due to its effectiveness in easy to identify gonads and has a higher shielding factor. However, for females, shielding is likely non-effective due to a higher risk of error in positioning and finding the proper shield and a slightly lower shielding factor. The findings of this study could be useful to guide centres that wish to consider the practice of gonadal shielding.

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