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The use of gonadal shielding in singular common diagnostic radiographic procedures

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Abstract The aim of this study was to make recommendations regarding when the use of gonadal shielding is significant in reducing gonad dose for common diagnostic procedures. Two separate literature reviews were conducted and the data compared. The first review proposed to determine average entrance surface doses (ESD) for common diagnostic procedures and the second to determine a threshold for exposure to the gonads below which risk of genetic effects was negligible. By comparing accepted ESD and associated gonad doses with the threshold dose, recommendations for each procedure could be made. This recommendation would be that either gonadal shielding is significant in reducing risk of genetic effects for this examination, or that gonadal shielding would make no difference because the doses involved are negligible. Common procedures were selected as well as common series, based on the fact that these procedures contribute relatively high dose to the gonads. A threshold dose to the gonads was established to be 10 mGy. Below this level of exposure, genetic risk to the gonads is considered negligible. It was found that none of the series or individual exams contributed significant dose to the gonads (dose levels above the 10 mGy threshold). It should be noted, however, that this recommendation applies only to individual patients receiving individual exposures. The effect of repeat examinations or the risk to a population of patients was not considered. It was also found that gonadal shielding may alleviate fears of radiation exposure in patients. It was recommended that for all individual examinations/series included in this study that gonadal shielding was unnecessary because the doses involved present negligible genetic risk to the patient. However, best practice in radiography includes upholding the 'As low as reasonably achievable' principle (ALARA) and considering the fears of patients, and it is for this reason that gonadal shielding should be used.

Keywords: diagnostic radiography, fears, gonads, lead shielding, radiation protection

Introduction

The primary duty of radiographers is to produce images of high diagnostic quality with the minimal amount of dose being given to each patient. This duty of care is primarily upheld by using the 'As low as reasonably achievable' principle (ALARA), which incorporates the use of time, distance and shielding in order to minimise patient dose.

Along with this, there is a public perception of the hazards of radiation, fed largely by incidents such as Chernobyl and nuclear fallout. Many patients present with an inflated sense of risk associated with x-ray and expect a radiographer to protect them from this perceived danger.[1] This expected protection is almost always in terms of gonadal lead shielding.

Observations made by the authors on clinical experience indicate that decisions about the application of gonad shielding are usually made on a subjective basis. Measures to protect patients are given sporadically, at best. There exists a need, therefore, for factually based recommendations so that decisions regarding gonad shielding can be made objectively and consistently. This study will address the question: 'When and under what circumstances should I consider gonad radiation protection?'

There are three possibilities that can happen to the primary beam as it travels through the body. The first is that some of the x-rays will pass through the body without any interaction, this is known as 'transmission'. The second is that some of the x-rays can interact with atoms and transfer all of their energy to the atom, this is known as 'absorption'. Finally, some of the x-rays can interact with an atom, lose some of their energy and in the process change trajectory, this is known as 'scattering'. Due to this scattering, the gonads can still receive a radiation dose even though they are not in the direct x-ray beam.[2]

Much research has been undertaken previously in the area of entrance surface dose (ESD) measurement for a range of examinations, by reputable bodies such as the National Council on Radiation Protection and Measurements (NCRP), International Commission on Radiological Protection (ICRP) and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). A number of studies provide ESD levels and recommend maximum acceptable dose levels for standard radiographic procedures.[3–6] However, to our knowledge, there is no study which brings these two bodies of knowledge together to make sound recommendations on which procedures require gonadal radiation protection to minimise risk and which do not.

The present study looks at the research of the recognised authorities published data to: first, find well-accepted average ESD and associated gonadal dose for a range of examinations, and second, to propose a dose to the gonads which is not acceptable to exceed for a single exam. For the purposes of this study this dose level will be referred to as the threshold dose to the gonads.

By comparing these levels, recommendations as to when gonadal radiation protection will be of significance and when it may only contribute to little other than a patient's peace of mind, can be made.

Methods

The initial step of this study was to investigate internal scatter and how this affects the gonad dose. To have a clear understanding of this, research needs to be undertaken to look at what happens to the primary beam as it passes through a medium and how this results in internal scatter. A variety of texts and journal articles were reviewed to determine this phenomenon. Afterwards, a selection of radiographic examinations for inclusion in the study had to be investigated. Criteria for selection were established for this purpose and the ranges of radiographic examinations for inclusion were determined.

The research took the form of two separate literature reviews. The first review was purposed to locate all available sources that recorded ESD for the range of examinations previously selected for inclusion in the study. An average ESD for each examination was determined using ESDs recorded from all sources.

The percentage of the maximum ESD for each examination that should be attributed to the testes and ovaries was calculated via use of the Monte Carlo technique. Approximate gonadal dose was thus determined for each examination.[7]

Some examinations were then grouped into common radiographic series. By adding together gonad doses for a group of examinations, total gonadal dose for a number of entire radiographic series was also determined.

The second literature review was focused on locating sources, such as ICRP, NRPB and UNSCEAR publications, medical physics texts and various journal articles, to try to ascertain a standard threshold dose to the gonads for both males and females. By taking these recommended thresholds into account, a maximum permissible dose level to the gonads was determined. This maximum dose level was applied equally to all examinations.

As a result of these literature reviews, recommendations as to whether gonadal radiation protection need be a consideration for each examination could be made. This was done by comparing the approximate gonadal doses for singular examinations to the threshold dose to the gonads. Recommendations were made based on the premise that examinations which contributed dose levels to the gonads that were less than the threshold dose, were negligible. These examinations did not require any extra measures of radiation protection for the gonads, although as radiographers it is our duty of care to patients to always minimise dose by upholding the ALARA principle. For examinations that produced dose levels that were above the dose threshold, it was recommended that additional gonadal shielding measures are vital in order to reduce patient dose.

Further recommendations were also made concerning a number of common radiographic series. In these cases, gonadal radiation protection was recommended when total gonad dose for the entire series equalled more than the recommended threshold dose to the gonads. If the combined gonadal dose was found to be less than the recommended threshold dose, then additional gonadal shielding measures for all examinations in the series were deemed unnecessary.

When a recommendation was made that radiation protection for the gonads was not necessary, it should be noted that this recommendation only takes into account singular examinations for singular patients. Patients undergoing many repeat examinations would accumulate much higher doses over time, in which case reductions to dose deemed negligible in this study may add up over many examinations to become significant. Also, judgements made on what risk was significant to an individual did not take into account the population to which the individual belongs. A 'negligible' risk to an individual may translate into a number of induced malignancies in a large population. Judgement as to what was an acceptable threshold did not consider this. Recommendations contained within this study should only apply to 'one off' patients, useful only when considering examinations and patients in isolation. Considering a threshold dose that took into account repeat examinations and epidemiological studies was decided to be beyond the scope of this study.

Results

The projections selected for this study were chosen on the basis of the following: they are common examinations in diagnostic radiography; they are relatively high dose examinations to radiosensitive organs in which gonadal shielding may provide some benefit; and a number of valid sources for the ESD for these projections could be located. Thus allowing the dose to the gonads to be calculated.

Based on the above criteria, the projections selected for this study were:

Chest – PA and lateral
Skull – PA and lateral
Pelvis – AP
Thoracic spine – AP and lateral
Abdomen – AP
Lumbar spine – AP, Lateral and L5/S1 joint

To establish a dose level to the gonads for the x-ray projections selected, we required the entrance surface dose (ESD) and the organ dose to the gonads.

The IRCP, NRPB, and UNSCEAR have established measured ESD for diagnostic radiography examinations to which we have referred to for guidance.[8–10] A further four separate studies were selected to compare the data obtained across the board. These studies were chosen based on the following: publication in a reputable journal within the last 10 years; studies that had obtained ESD doses for the chosen examinations; and studies that contained the selected radiographic projections.[3–6]

The organ dose to the gonads was obtained from publication NRPB-R186. This was expressed as absorbed dose in the organ relative to the ESD. The gonad doses were calculated through experiments using anthropomorphic phantoms. Monte Carlo techniques were used to covert ESD to gonad dose. Any gonad dose that registered below 1.E-04 (0.0001) mGy was ignored, as it was deemed insignificant.[7]

The ESD levels from all seven sources[3–6, 8–10] were tallied and an average ESD (mGy) was calculated.

The organ dose for the ovaries and testes was obtained for each projection, this required selecting a kVp level and filtration level for a given examination.

The radiographic texts, Bontrager (2005) and Ballinger (1999) were reviewed and we selected the kVp that most closely reflected their indication and that of our combined clinical experience observations. The filtration was taken as the standard 2.5 mm Al.[11,12]

Once the organ dose for the gonads was selected, this enabled simple calculations against the average ESD for each projection and the results for the estimated dose to the gonads and ovaries were obtained. The results of the estimated dose to the gonads

Table 1 Estimated gonad dose for specific x-ray projections.

Projection	Ovary dose	mGy	Testes dose	mGy
Chest – PA	5.84E-04	0.000584	*	*
Chest – lateral	1.20E-03	0.0012	*	*
Skull – PA	*	*	*	*
Skull – lateral	*	*	*	*
Pelvis – AP	7.45E-01	0.745	2.72E+00	2.72
Thoracic spine – AP	1.24E-03	0.00124	*	*
Thoracic spine – lateral	1.92E-03	0.00192	*	*
Abdomen – AP	8.85E-01	0.885	1.70E-01	0.17
Lumbar spine – AP	8.78E-01	0.878	2.03E-02	0.0203
Lumbar spine – lateral	6.11E-01	0.611	6.83E-03	0.00683
Lumbar spine – spot	9.45E-01	0.945	7.35E-03	0.00735

All measurements in mGy
* = normalised doses under 1.E-04

Table 2 Accumulated dose for acute abdomen series.

Series	Ovary dose	mGy	Testes dose	mGy
Chest – PA	5.84E-04	0.000584	0	0
Abdomen supine	8.85E-01	0.885	1.70E-01	0.17
Abdomen erect	8.85E-01	0.885	1.70E-01	0.17
Total dose	1.77E+00	1.770584	3.40E-01	0.34

All measurements in mGy

Table 3 Accumulated dose for a lumbar spine series.

Series	Ovary dose	mGy	Testes dose	mGy
Lumbar spine – AP	8.78E-01	0.878	2.03E-02	0.0203
Lumbar spine – lateral	6.11E-01	0.611	6.83E-03	0.00683
Lumbar spine – spot	9.45E-01	0.945	7.35E-03	0.00735
Total dose	2.43E+00	2.434	3.45E-02	0.03448

All measurements in mGy

Table 4 Accumulated dose for a sinus examination.

Series	Ovary dose	mGy	Testes dose	mGy
Chest – PA	5.84E-04	0.000584	0	0
Skull – PA x 2	0	0	0	0
Skull lateral	0	0	0	0
Total dose	5.84E-04	0.000584	0	0

All measurements in mGy

were tabulated against the reference dose as shown in Table 1.

Accumulated dose for common radiographic series (e.g. lumbar spine series) were tabulated, which allowed for measurement of the overall dose to the gonads after several exposures to be identified. These results are shown in Tables 2, 3, and 4.

After conducting the literature search, it was discovered that there is no definitive threshold that states at what dose levels gonadal shielding should be used to reduce the risk of inducing a cancer. NRPB Volume 6 No 1 states that doses below 10 mGy are not associated with an increased cancer risk.[13] Calculations, as shown in Tables1 to 4 demonstrate that the dose received by the gonads in the chosen radiographic examinations were significantly lower than the 10 mGy threshold dose level.

Discussion

There are five processes of attenuation that affects the primary beam.

Coherent scattering occurs when the incoming photon's energy of the primary beam is small (less than 10 KeV)14 when compared to the ionisation energy of the atoms of the attenuating medium.[15] The incoming photon does not have enough energy to eject an electron from an atom. Thus, there is no energy lost by the photon with the only change being the direction of the photon. Bushong states that at '70kVp, approximately 5% of x-rays undergo coherent scattering' and therefore coherent scattering is not a significant cause of attenuation in diagnostic radiography.[16]

The photoelectric effect occurs when all of the incoming photon's energy is equal to or just greater than the ionisation energy of the attenuating medium. The photon transfers all of its energy to an electron (therefore is absorbed) and the electron is ejected from the atom (and known as a photoelectron). The electron has kinetic energy that is equal to the difference between the energy of the incident photon and the binding energy of the electron.[16] Due to this process, there is an electron vacancy that is filled by electron transition from a higher energy level. When an electron from an outer shell is transferred to this vacancy, a characteristic x-ray is emitted with an energy that is equal to the difference in the binding energy of the two shells in which the transition occurred.[14] The photoelectric effect is a predominant form of attenuation of the primary beam in diagnostic radiography.

Compton scattering occurs when a relatively high-energy incoming photon strikes an outer electron, ejecting it from its orbit.[17] This ejected electron is now known as a 'Compton or recoil electron'. The incident photon is deflected and travels in a new direction as scatter radiation. Its energy is equal to the difference between the incident x-ray photon and the energy of the outer electron. Compton scattering is a predominant form of attenuation of the primary beam in diagnostic radiography and will contribute the most to internal scatter and therefore any gonadal dose.[15]

Pair production and photodisintegration will only arise in x-ray energies that exceed 1.02 MeV and 7 MeV respectively, therefore these processes do not occur in diagnostic radiography.[15,16]

All parts of the body are sensitive to radiation, some more so than others. The main use of lead shielding is to protect the radiosensitive gonads. The latest ICRP report has shown that the tissue weighting factors for the gonads are not as radiosensitive as first thought. The value has been reduced from 0.2 W_T to 0.08 W_T. Despite this large reduction in weighting factor sensitivity, lead protection is still considered important for the gonads to reduce any unnecessary dose.[18]

Once a radiographer has declared that she is pregnant the annual dose limit that she is allowed to receive is reduced from 20 mSv to 5 mSv.[19] This dose corresponds to the acceptable limit that a fetus can receive. This dose level adds further justification to the idea that the dose received by the gonads from most radiographic examinations is so low that there is a negligible risk of inducing cancer.

The threshold for permissible dose to the gonads implemented in this study was 10 mGy. Below this level, the risk of genetic effects is so small as to be considered negligible. It was found that all examinations included in the study had dose levels far below the threshold. The closest singular examination to the threshold was the testicular dose on the AP pelvis at 2.72 mGy, with the majority of procedures being under 1 mGy. It can be said, then, that for all examinations included in this study, measures of gonadal radiation protection are unnecessary, when looking at the risk of the gonadal genetic effect of radiation, and thus an increased cancer risk to the patient, or genetic effects to their offspring. The same result was noted for all of the radiographic series included in the study. The series included all contributed dose to the gonads and yet were still below the 10 mGy threshold and hence required no additional measures of gonadal protection. The series that contributed the dose closest to the threshold was the lumbar spine series with 2.434 mGy. Most of the series were under 10% of the threshold dose. It should be remembered, however. that this applies only for a singular patient having a single examination. Accumulative dose and the significance for a population of patients have not been taken into account. Radiation protection does reduce dose to the gonads but radiation levels involved are so small that they are trivial for singular examinations.

Even though there is little basis for arguing that radiation doses below the chosen level would have no associated cancer or genetic risk to the patient or their offspring, it is still believed that any increase in dose would cause an increase in risk. Also there is a patient's perception that gonadal shielding is used for their protection and if this isn't used during the examination they are being placed at an increased risk. So to alleviate these fears and anxieties it is good radiographic practice to use lead protection.

As identified by Hendee, the radiation exposure that accompanies medical imaging procedures is a topic of great concern to patients. This fear is present without a proper understanding of the statistical risks and misinterpretation of the possible consequences. Some of these consequences include cancer, genetic changes and developmental abnormalities.[20]

Misconceptions about x-ray radiation have existed ever since they were first discovered, by Roentgen in 1895, as an invisible and largely mysterious force. The misunderstanding surrounding radiation has been amplified by the false representation given in various forms of the media such as comics, cartoons and movie productions along with historical events such as the Hiroshima/Nagasaki bombings in 1945 and the Chernobyl incident in 1986.[20] This has led to patients presenting to imaging departments with an idea that the exposure to x-ray radiation that they are to receive is much more dangerous than it actually is and it is not uncommon for patients to request lead protection. These requests are made on the assumption that a piece of lead shielding will protect them from the harmful effects that radiation can induce, in themselves, or as is the focus of this study the possibility of genetic effects in their offspring. To overcome these fears, it is essential that the radiographer addresses any concerns that patients may have and advise them that having the examination would be more beneficial than any risks associated from the radiation exposure. For this reason, radiation protection should be used in all cases where the patient demonstrates concern – as long as the lead shielding does not obscure the required anatomy.

Conclusion

For singular examinations on a single patient, gonadal radiation protection should not be considered effective at reducing the risk of genetic effects since the doses received from these examinations are considered negligible. It is good practice, however, to use gonadal radiation protection in order to address the psychological fears of the patient and to uphold the ALARA principle.

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