Radiation Dose Reduction at a Price: the Effectiveness of a Pediatric Male Gonadal Shield During Helical CT Scans

Lawrence T. Dauer¹; Kevin A. Casciotta¹; Lawrence N. Rothenberg¹

¹Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, 1275 York Ave. New York, NY 10021, USA

§Corresponding author

Email addresses:
  LTD:  dauerl@mskcc.org
  KAC:  casciotk@mskcc.org
  LNR:  rothenbl@mskcc.org
Abstract

Background

The purpose of our study was to quantify the radiation dose reduction to the gonads and its effect on image quality when a male pediatric gonad shield was used during computed tomography (CT) scanning.

Methods

The dose reduction to the gonads was measured for both direct radiation and for indirect scattered radiation from the abdomen. A 6 cm$^3$ ion chamber (Model 10X5-6, Radcal Corporation) was placed on a Humanoid real bone pelvic phantom at a position of the male gonads. When exposure measurements with shielding were made, a 1 mm lead wrap-around gonadal shield was placed around the ion chamber sensitive volume.

Results

The use of the shields reduced scatter dose to the gonads by a factor of about 2 with no appreciable loss of image quality. The shields reduced the direct beam dose by a factor of about 35 at the expense of extremely poor CT image quality due to severe streak artifacts.

Conclusion

When evaluating shielding effectiveness it is important to consider the exposure levels, the specific technique factors, as well as image quality to determine when the use of such shielding is appropriate.
Introduction

The use of computed tomography (CT) scanning has increased rapidly since its introduction in the early 1970s. During the 1990s CT usage almost doubled, representing about 11% of radiology procedures in 1999 [1]. These values are consistent with a United States estimated rate for CT of 91 per 1000 population through the year 2000 [2]. In 1999, about 11% of all CT scans were performed on children age 0-15 years [1]. It is expected that the use of the modality will increase as the number of detectors and the clinical utility of CTs are increased. It has been estimated that the number of CT scans performed annually has steadily increased in the U.S. from 2.8 million in 1981 [3] to 20 million in 1995 [2] and 60 million in 2006 [4], a number that seems destined to grow substantially. For a typical 120 kVp x-ray beam, CT doses to the adult body range from 15-35 mGy while doses to the pediatric body are double at 29-68 mGy using adult technique factors (milliampere-seconds)[5]. CT doses to the adult head range from 60-115 mGy while doses to the pediatric head are about 30% higher at 78-152 mGy using adult technique factors [5]. Also, when you have similar techniques, the effective doses are substantially higher in children by a factor of about 2 to 4 [6].

Simple dose reduction methods that do not impair diagnostic image quality should be considered for clinical use [7] in an effort to reduce risks of induced cancers and other effects [8]. Various authors have suggested that pediatric CT doses could be reduced by 30-50% or, more relative to adult doses,
primarily by reducing the milliampere-seconds utilized, with no loss of diagnostic accuracy [9-14]. In a further attempt at reducing exposures to specific areas of the pediatric body, physicians are increasingly considering the use of shielding devices, including specially designed gonadal shielding for male testes. CT represents a shielding challenge because of the confounding dose from both the primary x-ray beam and the significant scatter component in the body during the multidirectional scanning.

The International Commission on Radiological Protection suggests that the weighting factor for the gonads is 0.20 based on the radiation sensitivity of the gonads due to the risk of mutagenesis [15], with the dose to the gonads therefore contributing 20% of the effective whole-body dose. Various shielding designs have been developed over the years to reduce gonadal doses including lead blankets, bismuth shielding, clam-shell style male testicular shields, and flexible shields attached using Velcro.

The goal of our phantom study was to measure the effect of a 1 mm lead equivalent, flexible, wrap-around pediatric male gonad shield (Flexible gonad protector, Dr. Goos-Suprema) on the testicular radiation exposure from both the primary beam and the scatter component during abdominal and pelvic helical CT scans. In addition, the effect of the presence of the shield on the radiographic image will be discussed.
Methods

The study was performed using a sectional pelvic phantom (pelvic real-bone sectional phantom, Humanoid Systems - currently Radiology Support Devices, Inc., Long Beach CA, USA) (Fig 1). This phantom consists of a human skeleton embedded in tissue simulating plastic [16, 17]. It is designed to simulate an average large pediatric or adult patient’s interaction with x-rays over the diagnostic energy range. No simulated organs exist within the phantom itself. A 6 cm$^3$ ion chamber (Model 10X5-6, Radcal Corporation) was placed on the phantom at the position of the male gonads to measure the exposure at this location (Fig 2). When shielded exposure measurements were made, a 1 mm lead wrap-around gonadal shield (Fig 3) was placed around the ion chamber sensitive volume. This geometry mimics the expected use of the shield during clinical applications.

Two trials were evaluated. In the first trial the abdomen of the phantom was scanned using a routine abdominal examination protocol (Table 1, CT technique factors) on a 16 slice CT scanner (Lightspeed 16H, General Electric) in a craniocaudal direction starting at a location just above the diaphragm and ending just above the bottom edge of the symphysis. The resulting scatter exposure was measured both with and without the gonadal shield in place. Because of limited access to the CT scanner, measurements were able to be repeated only five times. For this abdominal scan trial, the ion chamber representing the testes, and the
gonad shield were specifically placed outside of the scanning range so that the measured exposure represented only the scatter component.

In the second trial, the pelvis of the phantom was scanned using the same routine abdominopelvic examination protocol (Table 1) in a craniocaudal direction from the area just above the bottom edge of the symphysis to the upper thigh. The resulting exposure was measured both with and without the gonadal shield in place. For this trial, measurements were also repeated five times.

For both trials, the radiation exposures to the testicular region with and without the wrap-around gonadal shielding were compared using the Student’s *t* test. Statistical significance was set at a *p* value of less than 0.05.

During both trials, representative CT images were obtained in order to evaluate image quality with and without the gonadal shield in place.

**Results**

Tables 2 and 3 summarize the results of the phantom measurements, listing the gonad exposures without shields and with the large, medium, or small gonad shield in place. For the first technique, employing an abdominal scan with scatter dose to the gonads, the average measured gonad exposure was 69.2 mR without the gonad shield and was reduced to 30.2, 33.5, and 40.0 mR when the large, medium, or small shields were used, respectively. The shields appear to reduce scatter exposure to the gonads from an abdominal CT scan by about a factor of 2 (Table 2), a value shown to be statistically significant (*t*=29.97,
p<0.001). For the second technique, employing a pelvic scan with direct exposure to the gonads, the average measured gonad exposure was 4820 mR (~48.2 mGy) without the gonad shield and was reduced to 137.5, 172.9, and 268.0 mR when the large, medium, or small shields were used, respectively. The shields appear to reduce the direct exposure to the gonads by about a factor of 35 (Table 3), a value shown to be statistically significant (t=732, p<0.001).

Images of an abdominal region were evaluated both with (Fig 4(A)) and without (Fig 4(B)) the gonad shield in place to measure noise within the same region. Noise was identical for each image, with a standard deviation of 6.6 Hounsfield Units in the region of interest (i.e. with or without the shield). When images of the pelvic region were evaluated with the gonad shield in place, severe streaking and image degradation was noted, as shown in Figure 5.

**Discussion**

For the abdominal scans without gonadal shielding, the scatter exposure component to the gonads represented about 1.5% of the exposure to the gonads during a direct pelvic scan without gonadal shielding. For the abdominal scan, the large wrap-around shields appear to reduce the scatter exposure to the gonads by about 56%. For the direct pelvis scan, the exposure to the gonads was much higher, at 4820+/-14 mR, and the large wrap-around shields provided a more substantial shielding effect, reducing the direct beam exposure to the gonads by about 97%.
Price, et al [18] have performed a similar study that utilized a male Alderson therapy phantom, a 1 mm lead rubber wrap-around gonad shield, and lithium borate TLDs to measure doses to a testes phantom modeled from a single-slice CT scan. They found that doses to the gonads could be reduced by about 77% for indirect scans outside of the gonadal area. They also reported severely degraded images for direct pelvic scans. Hidajat et al. [19] used a male Alderson radiation therapy phantom and protected the testes with a 1 mm lead testicular capsule to obtain a 95% reduction in dose. Hohl et al. [7] measured the dose to the gonads for 66 men (34 with 1 mm lead capsule shields and 32 without shields) that underwent routine abdominopelvic multi-detector CT with a 16 slice machine by using lithium fluoride thermoluminescent dosimeters. They report an 87% reduction in dose to gonads during abdominal scans. Table 4 compares the results of these literature reports including type of study, scanning protocol, testicular dose and percent reduction. While the doses to the shielded gonads are consistent within the literature values, there are differences in overall percent reduction that are most likely related to setup, CT parameters, and measurement techniques.

Image quality does not appear to be significantly affected when the scanned area is well outside of the gonadal shield location as was the case of the abdominal scan (Fig 4). Image quality is significantly reduced when the shield is located within the scan volume itself as was the case of the pelvic scan (Fig 5). The severe streak artifacts, caused by the presence of lead in the shield, render the
image diagnostically unusable for most CT studies [20]. Therefore, an understanding of patient positioning and shielding usage is necessary. In addition, a number of studies have shown that useful dose reduction tools such as simple shields are not always used correctly, resulting in inadequate coverage of reproductive organs because the shield was not positioned correctly, or inappropriately shaped or sized devices were utilized [21-23].

It is important to note that while gonadal shields may help reduce the scattered exposure component, there are other simple techniques that can be explored to reduce overall radiation exposure to pediatric patients. In a jointly issued guideline, the National Cancer Institute and the Society for Pediatric Radiology suggest the following reduction techniques for pediatric patients [24]: (1) perform only necessary CT examinations; (2) adjust exposure parameters for pediatric CT based on child size, region scanned, organ systems scanned, and scan resolution; and (3) to minimize the CT examinations that use multiple scans obtained during different phases of contrast enhancement (multiphase examinations) especially for body (chest and abdomen) imaging. The US Food and Drug Administration has also released recommendations for reducing pediatric CT doses that include[25]: (1) optimizing CT settings; (2) reducing the number of multiple scans with contrast material; and (3) eliminating inappropriate referrals for CT.
Conclusion

A Humanoid phantom and a 6 cm$^3$ ion chamber can be very useful when performing shielding evaluation studies for CT scanning. The 1 mm wrap-around lead design for the gonadal shields reduced scatter exposure to the testes by a factor of about 2 with no appreciable loss of image quality. The shields reduced the direct beam exposure by a factor of about 35 at the expense of extremely poor image quality due to severe streak artifacts. Important considerations for determining when it is most appropriate and effective to utilize such shielding include the exposure levels, the specific technique factors, as well as the potential effects on image quality.

Competing interests

The authors declare that they have no competing interests.
Authors' contributions

LD and LR conceived of the study, collected the bulk of the data, and drafted the manuscript. KC participated in the design and coordination of the study and assisted in the collection of the data. All authors read and approved the final manuscript.

Acknowledgements

The authors wish to thank the MSKCC Radiology Department for giving us research time on the CT scanner.

References


Figures

Figure 1 - Humanoid abdominal/pelvic phantom.

Figure 2 - CT image of Humanoid phantom showing the location of the ion chamber at the level of the pelvis. Ion chamber was located to approximate male gonad geometry (window level set at maximum to enhance the view through the chamber wall).

Figure 3 – 1 mm lead wrap-around gonad shields in three sizes (flexible gonad protector, Dr. Goos-Suprema).

Figure 4 – Comparison of abdominal CT images of Humanoid phantom both (A) with and (B) without the gonad shield in place. Identical region of interest was selected to measure noise as indicated by the circle.

Figure 5 – Pelvic CT image of Humanoid phantom with gonad shield in place and directly situated in the beam. Note the severe streaking artifacts and general image degradation.
Tables

...
Table 1 - CT technique factors utilized in this study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td>Adult – Helical</td>
</tr>
<tr>
<td>kVp</td>
<td>120</td>
</tr>
<tr>
<td>Average mA</td>
<td>260</td>
</tr>
<tr>
<td>Time per rotation (s)</td>
<td>0.7</td>
</tr>
<tr>
<td>Scan Field of View</td>
<td>Large</td>
</tr>
<tr>
<td>Z-axis collimation (mm)</td>
<td>1.25</td>
</tr>
<tr>
<td>Table speed (mm/rot)</td>
<td>18.75</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.938</td>
</tr>
<tr>
<td>Reconstructed Scan Width (mm)</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 2 - Measured ion chamber readings (mR) representing gonadal exposure from an abdominal CT scan.

<table>
<thead>
<tr>
<th>Scan #</th>
<th>No Shield</th>
<th>Large Shield</th>
<th>Medium Shield</th>
<th>Small Shield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68.6</td>
<td>28.3</td>
<td>33.5</td>
<td>40.0</td>
</tr>
<tr>
<td>2</td>
<td>69.2</td>
<td>29.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>69.5</td>
<td>28.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>69.1</td>
<td>29.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>69.4</td>
<td>35.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average +/- std.dev.</td>
<td>69.2 +/- 0.4</td>
<td>30.25 +/- 30.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Reduction</td>
<td>56%</td>
<td>52%</td>
<td>42%</td>
<td></td>
</tr>
</tbody>
</table>

- 17 -
Table 3 - Measured ion chamber readings (mR) representing gonadal exposure from a pelvic CT scan.

<table>
<thead>
<tr>
<th>Scan #</th>
<th>No Shield</th>
<th>Large Shield</th>
<th>Medium Shield</th>
<th>Small Shield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4820</td>
<td>138.9</td>
<td>172.9</td>
<td>268.0</td>
</tr>
<tr>
<td>2</td>
<td>4840</td>
<td>138.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4820</td>
<td>136.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4820</td>
<td>139.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4800</td>
<td>134.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average +/- std.dev. 4820 +/- 14 137.5 +/- 2.2

% Reduction 97% 96% 94%
Table 4 - Comparison of literature reports and present study for scattered dose reduction with the use of gonadal shields during abdominal CT scans (with the testes not in the direct beam).

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Type</th>
<th>Scanning Protocol</th>
<th>Testicular Dose (mGy)</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hidajat et al. 1996 [19]</td>
<td>Phantom, 1 mm capsule</td>
<td>Single-slice sequential, 10mm slice, 250 mAs/slice, 120 kV</td>
<td>1.46</td>
<td>0.07</td>
</tr>
<tr>
<td>Price et al. 1995 [18]</td>
<td>Phantom, 1 mm wrap-around lead rubber</td>
<td>Single-slice spiral, 10mm slice, 220 mA, 120 kV</td>
<td>0.82</td>
<td>0.19</td>
</tr>
<tr>
<td>Hohl et al. 2005 [7]</td>
<td>Patient, 1 mm capsule</td>
<td>16-slice spiral, 16 x 1.5 mm collimation, 150 mAs$_{eff}$, 120 kV</td>
<td>2.40</td>
<td>0.32</td>
</tr>
<tr>
<td>Present study</td>
<td>Phantom, 1 mm wrap-around canvas</td>
<td>16-slice spiral, 16 x 1.25 mm collimation, 260 mA, 120 kV</td>
<td>0.69</td>
<td>0.30</td>
</tr>
</tbody>
</table>