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The Need of Head and Pelvis Radiation Protective Devices in Performing CT Chest Scan

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Abstract

Objectives: Radiation protective patient devices for CT examinations should be provided but not overly done to increase radiographers' workload, running cost and patient's stress. This study aims to investigate using lead cap, half lead aprons and lead drape would reduce absorbed doses in CT chest scan. These devices are stipulated by law in China that should be equipped in each CT room.

Materials and methods: Absorbed doses in the head and neck, as well as in the pelvic regions, were measured using a female adult anthropomorphic phantom and thermoluminescence dosimeters (TLD). CT scans using the same chest protocol, were performed on the phantom with no radiation protective devices and different combinations of radiation protective devices. Paired sample t-test and repeated measures ANOVA were used to compare the differences between with and without the use of radiation protective devices.

Results: There was no significant difference in the absorbed doses in the brain and the eyes with and without using a lead cap for CT chest scan. The insignificant difference in absorbed dose was replicated in the pelvic organs. In terms of the type of radiation protective devices used, i.e. applying shielding at the front or applying at the front and back or wrapping the pelvis up, no significant difference was found as well.

Conclusion: Using lead cap, half lead apron and lead drape did not reduce doses received in the head and pelvic regions during CT chest scan.

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Introduction

The number of CT examinations increases in a rapid pace in many countries, including People Republic of China. To reduce the burden of population radiation dose from medical exposures, China has renewed the national guidelines of Requirement for radiological protection in medical x-ray diagnosis (GBZ130) [1] and Radiological protection requirements for X-ray computed tomography (GBZ165) [2] in 2013. These guidelines specify personal lead protective devices and shielding devices that should be provided to patients and accompany personnel in performing CT scans. As part of compliance monitoring, government officials also perform annual onsite inspection on these devices to ensure they are equipped in each CT room and they are worn during examinations.

According to the guidelines, it is mandatory to equip not less than two half lead skirts, a lead collar and a lead cap for out-of-plane radiation protection in each CT examination room for patients and accompany personnel in China. Xi et al. [3] reported patients wearing lead apron and lead collar in performing CT chest scans by a dual-source CT scanner (Somatom Definition, Siemens) had significantly reduced entry doses to the eyes, the thyroid, the chest, the small bowel and the gonad. The researchers reported the eyes received the highest entry doses, which were 14.3 times and 533 times more than the entry doses to the thyroid with and without using a lead collar, respectively. From their data, we suspect the lead cap may offer some degree of protection to the eyes in CT chest scans. In addiction, in our last annual inspection in 2018, we were advised by inspector to equip one more lead protective device, a lead drape. To the best of our knowledge, dose reduction by using the lead drape as part of the out-of-plane shielding is yet to be reported in China. However, local professionals advocated wrapping lead around patients during CT scans was a good practice [4].

There is lack of evidence to support the effectiveness of out-of-plane shielding to patients' brain and the eye lens by wearing a lead cap in performing CT scan in international studies. Previous studies have investigated occupational radiation protection to intervention radiology operators [5] offering by the lead cap, but no study has been performed on patients. Eye lens are radiation sensitive and superficial organs so they are intended to be protected in performing CT head scans using bismuth eye shield together with scan plane angulation to reduce scatter radiation [6]. Iball and colleagues [7] developed and commercialized a light and two-pieces abdominal and pelvis shielding device for targeting pregnant patients to wear in CT scans. They reported significant reductions in organ doses and effective doses were achieved by the shielding during CT chest.

This study aims to present absorbed doses in the head, abdominal and pelvic regions of an anthropomorphic phantom during CT chest scan with and without out-of-plane shielding devices required in the People Republic of China.

Material and methods

This phantom study did not require an approval by our hospital review board.

Material

A commercially available dosimetry verification phantom, representing a 55kg and 160cm tall adult female torso (702D CIRS ATOM, Norfolk, VA) was used in this study. The phantom is made by tissue-equivalent epoxy resins comprising soft tissue, cartilage, spinal cord, spinal disks, lung, brain, sinus and homogeneous bone to represent an average female adult with average bone composition. The phantom is composed of thirty-eight sections, each section 25mm thick, from the vertex to the upper thigh with numbered predrilled holes. Predrilled holes, each 5mm in diameter, can fit a wide variety of detectors, including Thermoluminescence dosimeter (TLD) chip. The predrill holes are readily located by the manufacturer for organ specific dosimetry. For the purpose of this study, TLD were placed in 119 holes to measure doses in twelve organs that are in concerning of using shielding for CT chest. The twelve organs are the eyes, the brain, the thyroid, the liver, the spleen, the stomach, the pancreas, the kidneys, the intestine, the ovaries, the uterus and the urinary bladder. The phantom was borrowed from the radiotherapy department of the hospital.

Three hundred and sixty-five square (3.2x3.2x0.89mm) solid TLD chips (LiF: Mg, Ti TLD-100, Thermo Scientific) with measurement ranges 10pGy to 10Gy were used for this study. The chips were initiated according to manufacturer guideline before collection. At collection, pre-readout annealing was performed by a hot-gas TLD reader (Harshaw 5500, Thermo Scientific Corporation, Ohio, USA) using a cycle consisting of a preheat segment at 45^{o}C for 10s, an acquiring phase for with a linear ramp rate of 17.5^{o}C/s to 350^{o}C, following by anneal and cooling. The glow curve of each TLD was observed to ensure it is free of low-temperature peak. Three hundred fifty-seven TLD chips were inserted in phantom holes for dose measurement while the rest were used for recording background radiation. TLD preparation and subsequent readouts were performed at the radiodosimetry laboratory of a local university.

Phantom preparation

Hole identification of each organ were looked up from the map book provided by the phantom manufacturer. One hundred and nineteen tissue equivalent solid plugs were removed from the holes and cut into three segments. Three TLD chips were sandwiched between two segments. The phantom was held by a holder provided by the manufacturer and positioned supine and head first on the CT table for scanning. The phantom was carefully adjusted so its mid sagittal plane and bilateral mid-axillary lines were overlapped by the CT alignment laser lights. The scan reference point was set at the level of the neck and shoulder junction.

Scan protocol and shielding

Table 1 gives the imaging parameters of our standard clinical CT chest protocol used in this study by a single source 64-row CT scanner (Somatom Definition AS, Siemens AG, Erlangen, Germany). Sixty-four slices, yielding a 32 cm scan length, was used to cover from the last cervical spine to 2.5cm below the last pairs of ribs. The first scan was performed on the phantom without shielding in place. After each scan, TLD chips were removed from the phantom, readout, annealed and inserted into the same holes for the next scan. The second to fourth scans were performed on the phantom by wearing different shielding devices: (a) a lead cap and a half lead skirt at the front of the pelvis, (b) a lead cap and half lead skirts at the front and at the back of the pelvis, (c) a lead drape wrapping around the pelvis. Scans with shielding devices on were repeated, so all together 8 scans were performed for this study. All shielding devices were made by conventional 0.35mm Pb equivalent lead rubber. These devices were standard local products that were purchased by hospital procurement.

Absorbed dose calculation

TLDs were read by a hot-gas TLD reader (Harshaw 5500, Thermo Scientific Corporation, Ohio, USA) using a cycle consisting of a preheat segment at 45°C for 10s, an acquiring phase for with a linear ramp rate of 17.5°C/s to 350°C, following by anneal and cooling. The glow curve of each TLD gave the number of counts. Conversion constant of number of courts to dose was found by exposing a PM tube. Individual absorbed dose was calculated by averaging the dose received by the TLDs placed in the organ minus the background dose. Absorbed doses of thirteen organs were calculated from each scan.

Statistical analysis

Paired sample t-test was used to compare absorbed doses with and without using protective devices. Repeated measures ANOVA was used to identify differences of absorbed doses in the pelvic region by using a front apron, a front and back apron and a lead drape. Statistical significance is considered at *p* value lesser than 0.05.

Results

Eight chest scans were performed using automatic tube current modulation, the mean effective mAs, CTDIvol and DLP were 65.8±0.9, 2.6±0.03 mGy and 91.4±1.1 mGycm, respectively. Our scan length was 32 cm long, covered from section 11 to section 23 of the phantom. The lead cap covered sections 1 to 5 from the vertex down to the eyes of the phantom while half lead skirt and lead drape covered the pelvis from section 27 to the end of the phantom.

Table 2 gives the absorbed doses of 8 organs in the neck and abdominal regions. Among the organs, the spleen received the highest absorbed dose (3.82±0.65 mGy) followed by the thyroid (3.63±0.45 mGy). The organ received the least absorbed dose was the intestine (0.15±0.15 mGy). ANOVA and post hoc test with Bonferroni correction did not show statistical significant difference of absorbed dose ($p>0.05$) of each of these organ between having and not having shielding being placed on the phantom. Figure 1 shows the absorbed doses of all thirteen organs. The spleen, the liver, the adrenals and the kidneys were the abdominal organs that fell within the Field Of View (FOV) of chest CT in this study. The spleen and the liver where closest to the thorax but because the whole spleen fell inside the FOV, hence it had higher absorbed dose than the liver. On the other hand, the thyroid which is the organ right superior to the FOV also received a similar amount of absorbed dose to the spleen. Thyroid was located on section 10 while the eyes were located on section 5 of the phantom. The eyes were about 7.5cm further away from the superior border of the FOV. In result, the eyes absorbed dose was 22% of the thyroid dose.

Table 3 shows absorbed doses received by the brain, the eyes, the ovaries, the uterus and the bladder with and without shielding over them. Independent sample t-test did not show significant dose reduction in the brain and the eyes by wearing a lead cap for CT chest. ANOVA and post hoc test with Bonferroni correction was used to test for significant dose reduction of the ovaries, the uterus and the bladder with shielding applied on the pelvis by three different ways, i.e. half lead skirt at the front only, half lead skirt at the front and back and wrapped up by a lead drape. The bladder was the only organ showed significant dose reduction by using protective devices at the front and at the back (26.6±31.8 μGy), comparing to no shielding over the pelvis (51.6±24.5 μGy), shielding at the front of the pelvis (45.1±24.7 μGy), and using lead drape to wrap the pelvis (34.3±28.3 μGy).

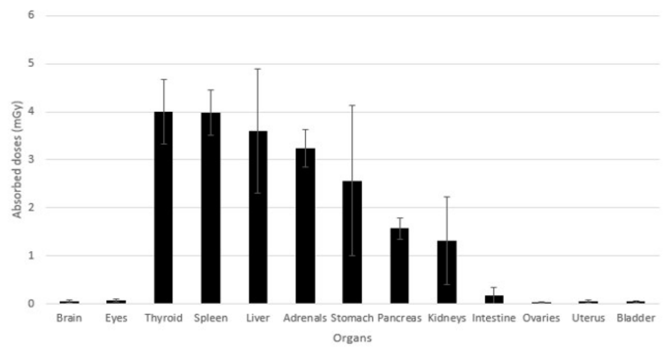

Figure 1: Absorbed doses in chest CT scan without using lead protective devices.

Table 1: CT chest protocol

Parameters	Setting
kV	100
Slice thickness (mm)	5
No. of slice	64
FOV (cm)	27.8
Rotation time (s)	0.5
Pitch	1.2
Iterative reconstruction	Not available
Mean effective mAs	65.8±0.9
Mean CTDIvol (mGy)	2.6±0.0
Mean DLP (mGy.cm)	91.4±1.1

Table 2: Absorbed doses (mGy) of the thyroid and abdominal organs in different shielding device applications

	No shielding	Lead cap and half lead skirt (front)	Lead cap and half lead skirt (back)	Lead drape
Thyroid	3.63±0.45	3.79±0.75	3.82±0.50	4.20±0.73
Spleen	3.82±0.65	4.09±0.42	4.12±0.44	4.03±0.38
Liver	3.43±1.35	3.99±0.94	3.69±1.34	3.55±1.39
Adrenals	3.27±0.08	3.16±0.43	3.15±0.54	3.52±0.19

Stomach	2.19±1.54	2.77±1.67	2.61±1.66	2.81±1.37
Pancreas	1.48±0.15	1.55±0.15	1.59±0.19	1.74±0.28
Kidneys	1.10±1.07	1.41±0.85	1.35±0.93	1.43±0.83
Intestine	0.15±0.15	0.21±0.17	0.18±0.18	0.19±0.19

Table 3: Absorbed doses (μGy) comparison of the use of lead protective devices in the head and pelvic regions. *#Repeated measures ANOVA and Bonferroni post hoc test $p<0.05$

	Brain	Eyes	Ovaries	Uterus	Bladder
No device	60.1±33.29	80.8±27.20	36.0±12.21	58.8±26.23	51.6±26.46*
Lead cap	50.1±32.81	63.4±22.85	NA	NA	NA
Front half lead skirt	NA	NA	47.1±9.85	56.2±20.69	45.1±24.73#
Front and back half lead skirt	NA	NA	36.5±14.20	41.1±27.19	26.6±31.88*#
Lead drape	NA	NA	40.1±17.75	51.4±26.70	34.3±28.32

NA: not applicable

Discussion

This phantom study has presented absorbed doses in the head, abdominal and pelvic regions during CT chest scan with and without using out-of-plane shielding devices. Our data shows there is no significant dose reduction by using out-of-plane shielding devices. Absorbed doses of the abdominal organs showed reduction with increase distance of the organs to the FOV, as the head and pelvis locate further away, absorbed doses received by those organs were very low already. Wearing a lead cap did not further reduced absorbed dose to the brain and the eyes while putting on half lead skirt on the pelvis or using lead devices to wrap around the pelvis also did not achieve further dose reduction to the ovaries, the uterus and the bladder.

The protective devices tested in this study are mandatory were the devices in each CT examination room for out-of-plane protection which is required in China. In our literature review, Ott et al., (2010) [8] also reported the necessary protective equipment in Switzerland. In their study, organ doses of the ovaries and the bladder was reduced 18% to 41% in chest CT by using wrap-around demi apron. Iball and Brettle (2011) [7] also reported dose 35% of dose reduction in the uterus by a wrap-around demi apron. We suggest the discrepancy in dose reduction of the ovaries and uterus found between our results to these studies could due to the difference in imaging parameters of the chest CT protocols. By using low kV and automatic tube current modulation, our CTDIvol and DLP were much lower than these two studies. Secondly, Ott et al. (2010) and Iball and Brettle (2011) both used a male phantom to calculate doses received by the ovaries and uterus, the variation of their estimated locations of the organs in a male pelvis to those in our female phantom is unknown.

Our results show the thyroid receives a high absorbed dose in chest CT scan. Thyroid is a superficial organ which is radiosensitive as well. In the phantom, the thyroid was just above the upper border of the scan field of view of the chest scan, it would receive a significant amount of scatter and in-plane radiation from the primary beam. Our department has followed the national guideline by equipping thyroid lead rubber collar in our CT room, however it is not our routine practice to apply the collar to patients during CT scan. Our collar is a bib-style collar with a large portion extending to the upper chest and sternum, which would generate artefacts. Nowadays, band-shape lead rubber collar is available in the local market, which can be placed on patient's neck without interfering the clavicles and below. Due to the lack of information in local studies on the composition of lead rubber of the collar, as well as radiological assessment of image quality and efficiency with the collar in place for CT scans [6,9], further study is required before applying the collar routinely in clinical practice.

In chest CT scan, breast is another organ of concerns in term of radiation protection. Among the International Commission on Radiological Protection (ICRP) tissue weighting factors, breast tissue weighs 0.12 in calculations of the effective dose while the thyroid weighs 0.04. Studies [9,11], literature review [12] and meta-analysis [13] have been performed to assess the effect of in-plane breast shielding in dose reduction and image quality. Future study to identify suitable material or design of shielding devices in breast dose reduction could increase the awareness of in-plane shielding in performing CT in local practice.

To the best of our knowledge, it is not a clinical practice to use in-plane thyroid and breast in-plane shielding in China. Our hospital procurement team did not find these shielding devices in the local market as well. In terms of the utilization of out-of-plane shielding, local researchers have reported low utilization rate. However, they did not go into utilization of individual protective device, as well as the underlying reasons for low utilization. Iball and Brettle (2011) [14] performed an international survey on fetal shielding on pregnant patients undergoing CT scans. They reported only half of the respondents from Europe used lead shielding while the use was 95% in respondents in United States of America (USA). Furthermore, Iball and Brettle found the weight and the maneuverability of the device were affecting its utilization. However, in the study conducted by Safiullah et al. (2017) [15] on the prevalence of shielding utilization in head, chest and abdominopelvic CT scans in USA, they reported the utilization was about 60%. Eye and thyroid shielding was rarely used in performing chest CT but gonad shielding was given to about 73% of chest CT examinations. We propose local study is needed in China to reveal the utilization rate of each protective device and underlying reason of their high and low utilizations.

American Association of Physicists in Medicine released a position statement in 2019 on the discontinuation of using patient gonadal and fetal shielding during X-ray based diagnostic imaging [16]. Recently, The British Institute of Radiology also published a guidance to general public to give evidence and explain the notion of the discontinuation. Patient shielding has been a long practice in medical imaging, nonetheless evidence from previous studies showed shielding provides negligible benefit. Its potential benefit is reduced even more with the new CT technology such as dual source energy, iterative reconstruction, etc. that can achieve dramatic dose reduction to the scan region. In our departments, we perform CT audit regularly to ensure our radiographers choose the correct scanning protocols, define FOV and scan length accurately and position patient correctly for the scan. Since the first national Diagnostic Reference Level (DRL) for adults in X-ray computed tomography (WS/T 637-2018) was implemented in 2019 in China, many medical imaging departments have begun to set their local DRL. This evidence-based practice may help radiographers to make more awareness of the dose that they deliver in each scan and allow them to build confidence and adapt to not using out-of-plane shielding in the future. The results of our study concur out-of-plane shielding has insignificant dose reduction to the head and pelvic regions in performing CT chest.

Conclusions

Results of this anthropomorphic phantom dosimetry study do not support the use of out-of-plane radiation protection devices for CT chest scan.

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