Radiation dose measurements at radiosensitive organs in overcouch barium enema examination

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Abstract: The objectives of this study were to measure the radiation dose on the skin surface at the selective radiosensitive organs and to compare its distributions on an anthropomorphic phantom during an overcouch barium enema examination. This study was also designed to suggest the suitable exposure parameters for the projections in overcouch barium enema examination. The eye lens, thyroid, breast, and gonad were selected in this study and the dose was measured using thermoluminesence dosimeters (TLD) with computed radiography system. Five radiographic projections were carried out including supine, prone, right lateral decubitus, left lateral decubitus, and prone-angled view (Hampton's view) to demonstrate the entire lower gastrointestinal tract. The highest skin surface dose (SSD) was received at the gonad followed by breasts, lens, and thyroid, corresponding to 2.49 ± 1.32 mGy, 0.14 ± 0.08 mGy, 0.057 ± 0.032 mGy, and 0.044 ± 0.04 mGy, respectively. The exposure parameters for tube voltage in a range of 75 kVp to 80 kVp, and tube current between 36 mAs and 40 mAs can provide proper image quality for abdominal region for an individual with average body weight.

Keywords*: barium enema, radiosensitive organs, overcouch, skin surface dose*

1. Introduction

Barium enema examination is one of the important procedures in radiological investigation with the aim to demonstrate anatomical structures of the lower gastrointestinal tract (GIT). Barium enema examination has been proven to provide significant findings with high diagnostic accuracy in the detection of several bowel pathologies such as colorectal cancer and large polyps.[1] The examination requires the use of barium sulphate as positive contrast to demonstrate the structure of large intestine clearly on radiography films inclusive of mucosal lining of rectum wall, sigmoid colon, descending colon, transverse colon, and ascending colon. In addition, air is generally introduced in barium enema study as negative contrast to provide better visualization of mucosal lining of the GIT. Combination of both negative and positive contrast enhancements is also known as double contrast barium enema. The contrast administered into the large intestine will first be observed under the fluoroscopic guidance which is also known as undercouch barium enema. Then, the entire gastrointestinal tract will be acquired into several 2D radiographic images in multiple projections using general radiography system, which also known as overcouch barium enema examination.

The advances in medical technology such as development of computed tomography (CT) system had refined the variation and availability of gastrointestinal studies. For instance, virtual CT colonoscopy, contrast enhanced abdominal CT and dual-contrast abdominal-pelvic CT are among common protocols requested in many health institutions for GIT study. However, barium enema still remained as a preferable method in radiological examination since it produces low radiation dose to the patient compared to other CT procedures.[2,3] In addition, the added time between fluoroscopic spot radiographs and overcouch films allow colonic absorption of intraluminal water which results in better barium coating at the intestinal wall. In fact, the additional overcouch images such as Hampton's view, right lateral decubitus, and left lateral decubitus provide better visualization of large bowel which could be missed in spot radiographs during undercouch barium enema examination. Thus, it plays an important role in improving the accuracy of the diagnosis.[4]

The other concern is the significant radiation dose to the superficial radiosensitive organs such as eye lens, thyroid glands, breasts, and gonad during overcouch barium enema examination. The distribution of scattered radiation during x-ray exposure may deliver unnecessary dose to these organs. The most prominent radiation effect to the eye is the development of lens opacities and cataracts.[5] Due to uncertainty concerning the risk, the International Commission on Radiological Protection (ICRP) had issued a statement stated that the threshold in absorbed dose for the lens is now considered to be 0.5 Gy.[5] Risk of breast cancer may correlate with doses less than 0.1 Gy.[6] High doses of radiation dose leave permanent damage to thyroid which may lead to hypothyroidism. Moreover, reproductive organs also experienced the similar impact as the radiation sensitivity of a tissue is directly proportional to the rate of proliferation of its cells.[6]

Further development in CT technology had improved the CT protocols especially in lowering the radiation dose to patients. Introduction of tube current modulation technique in abdominal-pelvic CT showed a significant reduction in radiation dose to the patient. Organ-based tube-current modulation (OB-TCM) is a new technique to reduce superficial dose to the eyes, thyroid, and breast. Previous studies show that OB-TCM could reduce by 22% the dose to the eyes and 10% dose to the breast.[7, 8] Automatic tube current modulation can reduce effective dose by 43% in CT coronary angiography.[9] Thus, CT produces higher radiation dose than barium enema examination could be misleading. Furthermore, with combination of fluoroscopic spot images and overcouch radiography of different projections can lead to a high total radiation dose for the entire GIT study. In fact, several studies also reported that the procedure of double contrast barium enema using analogue radiography produces relatively high effective dose with 10.7 mSv.[10, 11] In pediatric radiology it has been recognized that children have two to three times higher risk of developing cancer from the irradiation than adults.[12] It is found out that barium enema gives higher mean effective dose to infants and children compared to other radiological examination such as barium swallow and micturating cystourethrography.[13]

Therefore, the objectives of this study were to measure the skin surface dose at the lens, thyroid, breasts, and gonad on an anthropomorphic phantom in an overcouch barium enema examination other than to suggest the suitable exposure parameters for the projections in overcouch barium enema examination. The phantom used in this study was design similarly to human tissue whereby all the organ dose measurements presented from this study can be clinically reliable for clinical settings.

2. Materials and methods

This is an experimental study of radiation dose measurements on adult anthropomorphic phantom (Pixy whole body phantom, USA) mimicking adult human of 160 cm, 70 kg. The study was conducted at the x-ray laboratory, Diagnostic Imaging and Radiotherapy programme, Universiti Kebangsaan Malaysia using ceiling suspension radiography system (GE Healthcare, USA) with focal spot size of 50 cm to 180 cm, maximum tube loading power of 150 kV, 4320 mAs/hour and computed radiography system (Konika Minolta, Japan).

The procedure was performed on an anthropomorphic phantom with gastrointestinal tract implanted inside the torso which similar to a procedure conducted on patient. The phantom was equipped with filling port for contrast injection into certain organs. The diluted contrast agent was inserted into the stomach, sigmoid colon, and rectum using a 5 c.c. syringe. The contrast used was gastrografin with dilution ratio of 1:2 (gastrografin:water). Approximately 18 ml diluted contrast was introduced into the stomach and 5 ml contrast was introduced into the sigmoid colon and rectum. In this study, oral gastrografin was chosen over barium sulphate for care maintenance of the phantom as the barium solution is difficult to clean up and may remain in the phantom after usage. In barium enema examination, gastrografin can be indicated in cases in which the use of barium sulphate is unsatisfactory, undesirable, or contraindicated. The mean transit and emptying time of gastrografin is faster than barium sulphate. However, dilution of gastrografin occurred as it progressed through the intestines, resulting in decreased opacity in the colon.[14]

In barium enema study, there are two methods of image acquisition required for the procedure namely undercouch and overcouch imaging. Undercouch imaging uses image intensifier in fluoroscopic system to capture all images during the procedure (fluoroscopic screening) while overcouch imaging uses general radiography system to obtain images right after fluoroscopic screening is completed.

Five overcouch projections were performed in this study consisted of supine anterior-posterior (AP), prone posterior-anterior (PA), left lateral decubitus, right lateral decubitus and Hampton's view projections. Measurement of radiation dose in several selected organs is highly important during barium enema examination. The radiation dose may include exposure from the primary beam and the secondary radiation beams during both undercouch and overcouch processes, depending on the location of these organs. The entrance surface dose (ESD) was measured and recorded in milligray (mGy) after undergoing a series of procedures including annealing, calibration, radiation dose exposure, and read-out process. The annealing and dose read-out was performed with a Harshaw-5500 reader (Thermo Electron Corp., USA) while calibration was performed with a radiography system. Thermoluminescence dosimeters (TLDs) calibration was designed to create a graph pattern for radiation dose conversion from nanoculomb (nC) to miligray (mGy) by exposing it to a known dose, which was measured with a digital radiation survey meter (model 660) having an ion-chamber model 660-3 beam measurement probe and a readout/logic unit (model 451P). These TLDs were interpreted 24 hours after the exposure to allow the shallow TL peak to fade out. The TLD used in this study was micro-square shaped and sealed in specific plastic wrap with numbers.

A total of seven TLD chips (3.2 mm × 3.2 mm × 0.15 mm) were securely taped on the phantom skin surface over the radiosensitive organs for each set of procedure. Two TLD were placed at right and left eyes, one TLD at thyroid gland, two TLD at right and left breast, and another two TLD on gonadal area (Figure 1a-1d).

Constant position of the TLDs was maintained throughout the experiment. The phantom was then subjected to x-ray exposures ranging from 65 kVp to 80 kVp and 25 mAs to 40 mAs for all five projections (supine, right lateral decubitus, left lateral decubitus, prone and Hampton's view). The entire process was repeated for 3 times to increase the confidence level in terms of statistical data other than reduce uncertainties in radiation dose reading with constant equipment and positioning setup.

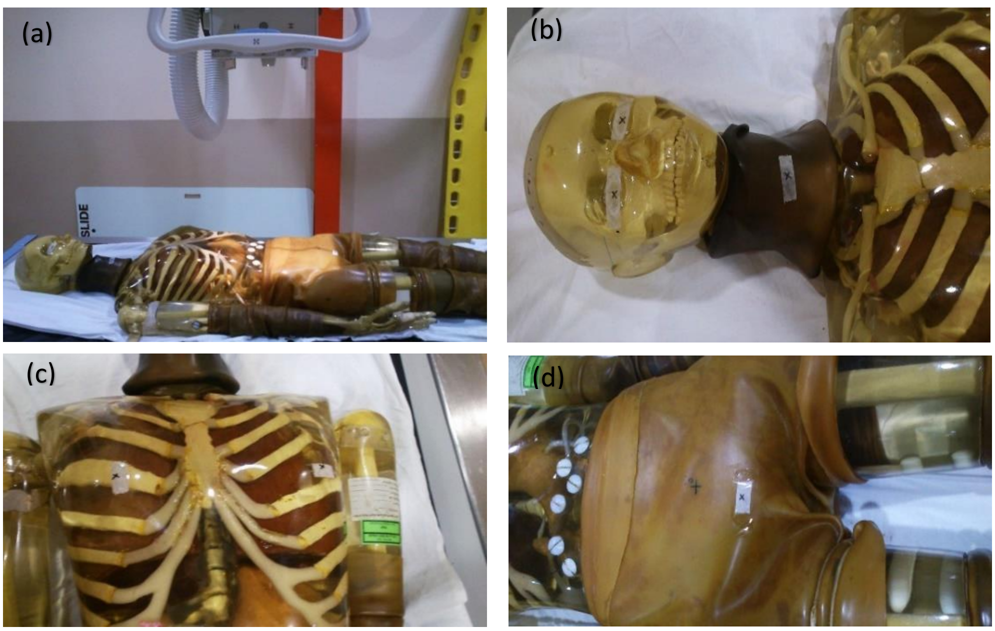

Figure 1. (a) Pixy whole body phantom, (b) TLD chips placement on the lens and thyroid of Pixy whole body phantom, (c) TLD chips placement on right and left breast of Pixy whole body phantom, and (d) TLD chips placement on the gonad of Pixy whole body phantom.

Table 1. Exposure parameters tested on five different projections during overcouch barium enema examination.

Exposure Parameters		Projections				
kV	**mAs**	**Supine**	**Right lateral decubitus**	**Left lateral decubitus**	**Prone**	**Hampton's**
65	25	–	–	–	–	–
65	32	–	–	–	–	–
75	32	–	–	–	–	–
75	40	√	√	√	√	–
80	32	+	+	+	+	–
80	40	+	+	+	+	√

– Underexposure, + Overexposure, √ Proper exposure
Proper exposure is indicated by an adequate contrast and density of the radiographic images obtained.

3. Results and discussion

In this study, we used an anthropomorphic phantom to estimate the radiation dose delivered to the radiosensitive organs during overcouch barium enema examination. We used the same digital radiography system in all experiments to ensure the reproducibility of the exposure parameters and phantom positioning. The surface absorbed radiation dose was measured for the most radiosensitive organs that are either within the primary radiation beam (gonad) or exposed to scattered radiation (breast, thyroid, and lens). All overcouch radiographic exposures were made based SSD of 100 cm with the optimum field size of 35 cm × 43 cm.

3.1. Exposure Factors

Table 1 shows the exposure parameters used for supine, right lateral decubitus, left lateral decubitus, prone, and Hampton's view along with the results of the image obtained using the parameters. The most suitable exposure parameters were equal for supine, right lateral decubitus, left lateral decubitus, and prone position which were 75 kVp and 40 mAs. The suitable exposure parameters for Hampton's view were 80 kVp and 40 mAs..

Each images obtained were evaluated to obtain an optimal image that demonstrates the region of interest with contrast administration. Assessing the density and contrast of a radiograph is the main key in determining the quality of the image obtained. Two independent certified radiologists with minimum of 10 years of working experience were involved in the assessment of image quality for all radiography projections. The assessment was based on 5-likert score (1 = unsatisfactory; 2 = poor; 3 = fair; 4 = good; 5 = excellent) evaluation on the bony trabecular pattern and corticle outlines. The trabecular bone pattern of the iliac should be demonstrated well to indicate that the exposure parameters provide adequate density to the image. Trabecular bone pattern is useful in detection of bone pathologies such as osteoporosis. Bony cortical outlines must be well seen to ensure adequate contrast of the radiograph. Aside from assessing the density and contrast of the radiograph, the size, shape, position, and overall architecture of the colon must be well demonstrated in overcouch radiographs of barium enema examination.

The kilovoltage for prone-angled view was slightly higher compared to the other projections because the angulation was applied. In Hampton's view, the phantom is in prone position while the x-ray tube is angled 45º caudally. The area of radiation only includes the sigmoid colon region instead of the whole abdomen. The angulation causes more scatter radiation to the irradiated area. Hence, higher kVp energy is required to produce more penetrating beams with a higher percentage of radiation reaching the image receptor.

3.2. Dose Distribution in Different Projections

Maximum surface dose was delivered to the gonad followed by breasts, lens, and thyroid. The median surface dose for each organs were as follows: gonad, 2.49 ± 1.32 mGy; breasts, 0.14 ± 0.08 mGy; lens, 0.057 ± 0.032 mGy; thyroid, 0.044 ± 0.04 mGy.

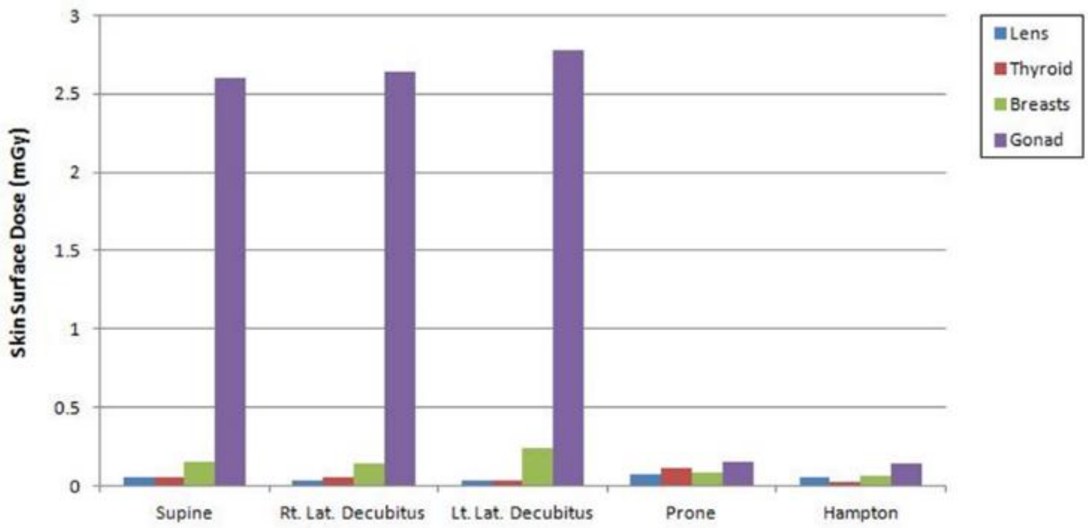

Figure 2. Skin surface dose on lens, thyroid, breasts, and gonad in five different projections during overcouch barium enema examination.

Figure 2 shows the skin surface dose distribution on lens, thyroid, breasts, and gonad in five different projections during overcouch barium enema examination. Gonad received the highest dose recorded among the radiosensitive organs, higher than 2.5 mGy, and the dose was the highest in left lateral decubitus, followed by right lateral decubitus, and supine position. However, there was no significant difference between the dose to gonad in these three projections (α>0.05). The other entire organs received dose lower than 0.5 mGy. In prone and lateral decubitus position, all organs received dose lower than 0.5 mGy, with the highest dose to gonad.

The reason of measuring the surface skin dose is that because the skin entrance is exposed to the greatest amount of radiation compared to other organs. Lens, thyroid, and glandular breast are all located near the surface, therefore the radiation dose to these organs can be well estimated with the value of surface absorbed dose. This study focuses solely on the radiation dose given in the overcouch barium enema procedure which consists of 5 basic projections. The amount of radiation to which patients are exposed to are higher if the fluoroscopy spot films are included because the radiation dose from fluoroscopy is not uniformly distributed.

The surface absorbed dose to gonad in supine and lateral decubitus positions, which was included in the irradiated abdominal region was significantly higher than the scattered radiation dose to the lens, thyroid, and breasts (α<0.05). Breasts received the second highest surface absorbed dose after gonad because of their position on the chest, near the abdomen. However, the surface absorbed dose to all four organs were lower in prone and Hampton's view as the radiation beam is scattered by other organs before reaching the lens, thyroid, breasts, and gonad. Radiation dose to the lens was recorded highest in Hampton's view. The energy used for this projection is 80 kVp, which is higher than the other projections, and the x-ray tube was closer to the eyes because the angulation is applied caudally. Radiation intensity is higher as the distance decreases. Previous study also reported that extreme angulations are associated with high air kerma values.[15]

The specific settings used in imaging procedures as well as the patient's size affect the radiation dose given to the patient. In comparison to previous studies, the effective dose in a study by Suleiman et al. (2014) was 0.3 mSv for all barium study procedures.[16] Livingstone et al. (2008) reported mean effective dose of 1.06 mSv during barium enema procedure.[13] In a study done by Ruffles et al. (2009), the mean dose area product (DAP) for the overcouch barium enema done by radiographers and radiologists were 291.9 cGy·cm2 and 264.7 cGy·cm2 respectively.[11] The difference in readings were caused by patient's size and the operator's technique.

There are several limitations in this study. The exposure parameters used are the standard parameters for an adult with average body weight, therefore the results are not applicable to estimate the radiation dose given for patients who require different exposure parameters such as pediatrics, underweight, or overweight patients. Besides that, it is difficult to compare our results with previous studies, as the radiation dose values were often recorded for both undercouch and overcouch projections.

4. Conclusion

The radiation dose to the radiosensitive organs in overcouch barium enema examination is well within established safety limits, in the light of the current practice. The exposure parameters in the range of 75 kVp to 80 kVp, and 32 mAs to 40 mAs can provide proper image quality of abdominal region for an individual with average body weight. Gonad receives the highest surface skin dose compared to lens, thyroid, and breasts in overcouch barium enema examination because it is included in the primary beam area. Additional studies are needed in order to establish reference dose levels to patients during a whole barium enema examination.

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