Exposure levels of CT and conventional X-ray procedures for radiosensitive pelvic organ in Saudi Arabia

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ABSTRACT
Radiosensitive organs in the pelvic cavity of 313 patients were exposed to low-dose diagnostic radiation to assess the entrance surface air dose (ESD) and effective doses (ED), and also to compare the X-ray and computed tomography (CT) dose levels. The patients were examined at King Abdul Aziz Specialist Hospital and King Faisal Medical Complex in Taif City, Saudi Arabia for 4 months in 2020. In conventional pelvic imaging, the DOSCAL software was used to assess the ESD. To estimate the CT radiation dose to the pelvis, the CT dose index (CTDIw, usually CTDIvol) and dose length product (DLP) were utilized. For routine pelvic X-ray imaging, the mean ESD and ED were found to be 7.2 mGy and 0.38 mSv, respectively. For CT imaging, the mean values of CTDIw, DLP, and ED were found to be 10.9 mGy, 593 mGy-cm, and 8.9 mSv, respectively. The obtained values of ESD and ED were found in agreement with the reported data available in the literature. However, a significant variation has been observed for conventional X-ray and CT doses among the selected hospitals. In comparison to conventional radiography, the CT induces 20 times higher doses to pelvic organs. The obtained results may help to establish the local diagnostic reference levels (DRLs).

1. Introduction
In recent decades, radiological studies have received great attention from the scientific community due to the applications of radiation in diagnosis, monitoring/ follow-up, and therapy. Conventional X-ray imaging and computed tomography (CT) are the two most frequently used imaging modalities for the identification of numerous pathologic disorders (Osman et al., 2013). The most serious issue with conventional imaging and CT is exposure to ionizing radiation. There is still a lack of clear guidelines for patients’ exposure to ionizing radiation during radiological examinations. Radiation exposure ranges from 10 to 100 mGy on average, which could increase the risk of cancer, particularly during pelvic examinations (Davies et al., 1997). The patient’s health could be jeopardized due to the given radiation dose. As a result, the issue of radiation dose must be taken seriously in order to reduce the given dose to patients and minimize the unexpected health risk (ICRP, 1991; Vaňo et al., 2015).

Computed tomography is a type of imaging that generates a sequence of slice data of the body, and facilitates a three-dimensional scenario of the investigated organs. This is accomplished by irradiating thin slices of the patient with a constantly rotating beam, known as the fan beam (Sadri et al., 2013). In comparison with the planar radiography, CT images have higher contrast resolution, thus offers a strong ability to distinguish subtle differences in tissue attenuation (contrast). Today, CT allows the imaging of the whole body within 5–20 s with a sub-millimeter resolution. Therefore, the progress of CT imaging may continue sequentially by focusing on technology, image quality, and clinical applications. Dual-source CT and C-arm detector CT are also used for this purpose. CT is likely to have a higher innovation rate compared to the previous time. As a result, the most modern development is receiving the greatest attention (Alkadhi & Euler, 2020; Hausleiter et al., 2009). However, the CT scanning process also considered the deposition of a non-negligible amount of radiation dose to the patients. Accurate quantification of CT dose to the patients and also the calibration of the CT scanners are still a great challenge to the scientific community. A review of the literature revealed the importance of determining the radiation dose during
CT (Einstein et al., 2007; Sulieman et al., 2018). Doses reported by the CT console during the scanning procedure are based on the CTDI paradigm. This index is a standardized measure of the CT system’s dose output and is expected to be equal to the estimated doses when the scan is performed (Hasford et al., 2015). The recent increases in radiation exposure during CT and the large differences in radiation dose due to protocols and scanner-dependent factors make this fact more clear.

The improvement of patient dose monitoring (in both an axiom and a postulate) is important to ensure that the radiation dose is at an acceptable level. This validates the ALARA principle while achieving the required diagnostic information, which yields the optimization concept (Berrington de González et al., 2009). To achieve optimization, direct assessment of radiation dose during exposure or diagnostic procedures must be performed using a novel concept, diagnostic reference levels (DRLs). As recommended by the International Commission on Radiological Protection (ICRP, 1991) and numerous other studies, DRLs serve as an important guideline that adds value to radiation dose management (Osman Hamid, 2020; Sulieman et al., 2021).

Many classical methods are available to estimate the entrance skin dose (ESD) receiving by patients through conventional radiography. The widely used techniques are thermoluminescent dosimeters (TLDs), optically stimulated luminescence (OSL), ionization chamber (Tsapaki et al., 2007). In this study, the latter one was the technique of choice for estimation of ESD from conventional pelvis radiography.

Patients are at risk during pelvic examinations because the pelvis contains radiosensitive organs such as the ovaries, bone marrow, and testes. Standardized measurement methods that comply with the international patient protection regulations have not been enacted in Saudi Arabia. Moreover, there exist only a few earlier studies and only scarce data on radiation exposure to the pelvis from the Saudi community (Osman Hamid, 2020; Sulieman et al., 2018). In addition, recent years have shown an increasing number of relevant specialists in the health sector in Saudi Arabia including the city of Taif; nevertheless, there is a lack of a unified protocol for radiation exposure during CT and conventional X-rays imaging of the pelvis. For these reasons, the current study was undertaken to evaluate the CT and conventional X-ray doses during routine pelvic examinations, as well as to compare the practice of the aforementioned hospitals.

2. Materials and methods

From May to August 2020, data were collected from two major hospitals in Taif city, Kingdom of Saudi Arabia. There were 313 patients in total, 200 patients from the King Abdul Aziz Hospital [hospital A] and 113 patients from the King Faisal Medical complex [hospital B]. Before the data collection, ethical approval was obtained from the respective bodies. On a specially designed sheet, exposure factors such as tube potential (kV) and tube current (mA) multiplied by the time were recorded. Table 1 shows the number of participating patients and their gender distribution in this study. The imaging machines were subjected to an extensive quality control program following the established policies and guidelines provided by each hospital to eliminate any discrepancies in machine performance.

The CT tube current was varied according to the patient size based on anteroposterior and lateral pilot scans, resulting in a range of 120–280 mA, a tube potential of 120 kV, a rotation time of 0.8 s. and a noise index of 35.72. A specially designed sheet was used to record the pitch, the number of slices, and scan length.

All patients under the age of 18 and those who had more than one helical CT were excluded from the data collection phase. All other remaining patients referred for pelvic examinations, during the data collection period, were included in this study. A simple and user-friendly Microsoft Excel (version 2010) program was used to analyze the data and estimate the mean and standard deviation, as well as the graphical representation. Tables 2 and 3 summarize the specifications of X-ray and CT devices that are utilized in imaging procedures.

| Table 1. Distribution of gender among the study sample. |
|-----------------------------------------------|
| Gender | Frequency | Percentage (%) |
|--------|-----------|----------------|
| Male   | 196       | 62.6           |
| Female | 117       | 37.4           |
| Total  | 313       | 100            |

| Table 2. Specification of conventional machines used in the investigated hospitals. |
|-----------------------------------------------|
| Hospital | Manufacturer   | Maximum tube voltage (kV) | Filtration, Al and Al equivalent (mm) | Last QC check | Installation year |
| A        | GE Health Care | 150                       | 2.3                                      | July 2019     | 2015             |
| B        | Siemens       | 150                       | 2.4                                      | Sept 2019     | 2014             |
Table 3. CT machine specifications used in the investigated hospitals.

| Hospital | Manufacturer | Slice class | Latest QC check | Installation year |
|----------|--------------|-------------|-----------------|-------------------|
| A        | Siemens      | 64          | Dec 2019        | 2016              |
| B        | GE           | Helical 64  | Sept 2019       | 2015              |

2.1. Dose assessment for conventional X-ray machines

The entrance surface dose or entrance skin dose (ESD) is a key factor that is used to describe the radiation dose (in mGy) absorbed by the skin as it reaches the patient, and it has been extensively discussed in many studies (Alghoul et al., 2017; Alisagharzadeh et al., 2015; Yousif Jumaa, 2014). In the current study, ESDs were primarily assessed using an appropriate DOSCALC software and equation (1) (Osman Hamid, 2020; Ofori et al., 2012; Osman Hamid, 2021).

\[
ESD = OP \times \left(\frac{kVp}{80}\right)^2 \times mAs \times \left(\frac{100}{FSD}\right)^2 \times BSF
\]  

where \(OP\) expresses the output of the X-ray tube (mGy/\(mAs\)) measured at a distance of 100 cm from the tube focal spot along the beam axis at 80 kVp, kV is tube voltage recorded at a given examination (Suliman & Habbani, 2007). Generally, it is from 50 kV (least value) to the highest value of 80 kV, and this is the saturation point of the X-ray tube where the output takes a steady-state shape. The \(mAs\) is the tube current-time product, \(FSD\) is the focus-to-skin distance, \(BSF\) describes the backscatter factor assumed for a 15 × 15 cm\(^2\) field size, which is matched with the field size used in most pelvic examinations. The beam energy (keV) and field size are the key factors for determining the BSF, which was estimated to be 1.32. The appropriate value for \(BSF\) was extracted from the given table in the appendix of the report NRPB-R186 (Jones & Wall, 1985).

The \(OP\) is the output parameter that has numerous uncertainties. This is because, it is not linear with \(mAs\) that were used in each examination, and also it depends on the potential difference of the tube as well as patient size. \(OP\) was assessed at the classical distance for pelvic examinations and field size, utilizing a calibrated dose rate meter (UNFORS Inco Billdal, city, Sweden). \(OP\) was estimated from a curve, which was normalized to each kV value. As shown in Figure 1, the kV values are plotted against the tube output (OP) for each hospital, and then the values of the tube output can be easily obtained for any particular kV value.

The effective dose for conventional radiography was estimated using the Monte Carlo method, and then the ESD was multiplied by the conversion coefficients relating the ESD-to-organ equivalent doses (Vijayam et al., 2000). In this study, to link the ESD with ED, the amount of ESD obtained from equation (1) was multiplied by the conversion coefficients derived from the Monte Carlo methods. To accurately utilize these factors, it is critical to clarify the tube potential, field size, and total filtration of radiographic equipment used in clinical practice (International Atomic Energy Agency [IAEA], 2007; International Commission Radiation Units [ICRU], 2005).

2.2. Dose assessment for CT

The machines were multi-slice CT systems (GE, USA, and Siemens Somatom; Germany), based on standard protocols for the pelvis. The parameters for each scan included the following: distance from the center, an interval of slice space (t), the thickness of the slice (T), average tube current (mA), peak potential difference (kVp), slice number (N), beam pitch (table movement per rotation over beam width, P), scan length (L), and time required for the acquisition of all slices (t). All previous parameters were implemented on the system under the clinical situation for 72 patients (average height = 168 ± 10 cm; weight 70 ± 5 cm). Then, by setting the system based on the parameters, the dose was estimated and the average values of CTDIw and DLP were calculated.

For the helical scan, equation (2) was used to calculate the dose length product (DLP) (Suliman et al., 2018),

\[
DLP (mGy - cm) = \sum nCTD I \times T \times A \times t
\]  

where \(nCTD I\) represents the ratio of CTDIw to mAs, \(T\) is the thickness of slice (cm), \(A\) is the X-ray average tube current (mA), and \(t\) is the total time of data collection during a specific protocol (s).

To provide the amount of radiation dose received by the patients, the DLP can be converted into an effective dose (Abuelhia & Alghamdi, 2020). The effective dose (ED) was then estimated by using the simple relation (3) (Hausleiter et al., 2009)

\[
ED/DLP = K
\]

In this study, the used DLP conversion factors \((K)\) were extracted from the latest ICRP publication 102 (Valentin, 2007), and also estimated from the study of
Huda and Mettler (2011). Conversion factors were based on the tests performed at 120 kV in 32-cm acrylic phantoms for all body tests (including the neck) and 16-cm acrylic phantoms for all head tests. The K value was estimated to be 0.015 and 0.019 mSv/mGy cm for the abdomen and pelvis, respectively, according to ICRP 102 (Valentijn, 2007), and this factor depends mainly on the region or organ under examination.

3. Results and discussion

Table 4 shows the average values of weighted computed tomography dose index (CTDIw) and dose length product (DLP). Table 5 shows the mean and standard deviation of the age for the male and female participants, body mass index (BMI), as well as the entrance skin dose (ESD), and pelvis effective dose (ED).

4. Discussion

The purpose of this study was to evaluate the ESDs during pelvic examinations via conventional radiography and CT, estimate the effective doses, and compare the practices for the aforementioned examinations.

Table 1 depicts the sample size (n = 313) and gender distribution (males, 62.6%, and females, 37.4%), indicating that there was no gender semi-distribution. In this study, the measured mean values of CTDIw and DLP for CT pelvic examinations are 10.78 mGy and 593 mGy-cm (Table 4). According to Sadri et al. (2013), the average values of CTDIw and DLP for helical scans were 12.9 mGy and 482 mGy-cm, respectively. The current findings revealed a lower value for CTDIw and a much higher value for DLP, which could be attributed to the incorporation of modern technology with current machines, such as mA modulation, beam geometry, shaping filters, and radiation quality for various scanners. Furthermore, the Sadri et al. (2013) study included a larger sample size from more than six hospitals, and this value could be interpreted as a source of statistical variation.

Table 5 displays the mean BMI, age, ESD, and effective dose for both imaging modalities. The average ages for males and females were 47.8 and 41.3 years, respectively, indicating that all samples were adults with acceptable BMIs.

The ESD for conventional radiographic pelvic examinations was found to be 7.2 mGy, which is consistent with the previous data of 6.9 mGy reported by Tsapaki et al. (2007). Sadri et al. (2013) reported a value of 12.7 mGy for CT ESD. However, the CT ESD was not calculated in the current study because it may vary throughout the scan projection due to variations in beam intensity from one projection to the next caused by the use of mA modulation technology, AEC, or auto-mA (an abbreviation for automatic exposure control). In CT, AEC serves as a radiation dose management tool, preserving diagnostic information and preventing photon starvation in dense areas.

Effective doses (ED), which is an important radiation protection quantity, were estimated using Monte Carlo calculation (ICRP-102, 2007). This estimates the K factor for conversion from DLP to ED. Figure 2 shows a comparison of ED in the two hospitals. Of note, the hospitals had different practices; thus, irradiation levels for both modalities (conventional radiography and CT) were different. The average effective dose obtained in this study was consistent with the previous study available in the literature (Aliasgharzadeh et al., 2015). Despite these findings, there was a small fractional variation; however, these are not very significant. The uncertainty in estimating the effective dose is particularly high for diagnostic examinations involving low-energy radiation.

When comparing practices for performing pelvic examinations in hospitals A and B, our findings revealed that hospital A irradiated patients with lower radiation doses during CT pelvic examinations than hospital B. This finding could be attributed to that hospital A activating and implementing an extensive quality management program as well as highly skilled technologists and medical physicists in this hospital ensure proper monitoring throughout all phases of various CT examinations.

When compared to hospital A, the pelvic examinations in hospital B delivered lower radiation doses for conventional radiography (Figure 2). This finding could be attributed to the fact that hospital B is using thick tube filtration (2.4 mm aluminum and aluminum equivalent), whereas hospital A is using a less thick filtration (2.3 mm aluminum and aluminum equivalent) system. An absence of appropriate filtration contributes to ESD by more than 90% (Osman et al., 2013), thereby increasing effective doses. These results validate the fact that the introduction of DRL in Saudi Arabia could lead to a reduction in conventional radiation dose, as in the UK by 50% from 1985 to 2000 (Acero et al., 2020). In addition, the DRL can be used in CT pelvic examinations to

Table 4. Mean values of weighted computed tomography dose index (CTDIw) and dose length product (DLP).

| Pelvis protocol | CTDIw (mGy) | DLP (mGy-cm) |
|-----------------|-------------|--------------|
| Axial           | 9.65        | 523          |
| Helical         | 10.78       | 593          |

Table 5. Mean (± SD) values of participants’ age, body mass index (BMI), ESD, and pelvis effective dose (ED).

| Parameter       | Age (Years) | BMI (kg/m²) | ESD (mGy) | ED (mSv) |
|-----------------|-------------|-------------|-----------|----------|
| Female          | 47.8 ± 22.3 | 24.7 ± 1.7  | 10.4 ± 1.82 | NC       |
| Male            | 41.3 ± 19.8 | 25.8 ± 0.9  | 11.2 ± 1.24 | NC       |
| CT patients     | 39.4 ± 18.7 | 24.5 ± 1.2  | N/A       | 8.89 ± 0.25 |
| X-ray Patients  | 48.6 ± 17.6 | 25.4 ± 0.7  | 7.2 ± 0.61 | 0.38 ± 0.09 |

NC = Not calculated, N/A = Not available.
limit the wide variation in radiation dose received by patients during pelvic examinations. Furthermore, the radiation dose can be reduced to a reasonable level that is compatible with the required diagnostic information.

Since the general CT irradiates pelvic organs with higher radiation doses than conventional radiography; specifically, the average ED for conventional radiography and CT examinations were found to be 0.38 and 8.9 mSv, respectively. This shows a 23.5-fold increase of radiation dose for CT compared to the conventional X-ray examination.

To obtain a relative scenario, this study also compiles the ED for CT pelvic examinations available in the literature (Tsapaki et al., 2001; Brix et al., 2003; Shrimpton et al., 2003; Papadimitriou et al., 2003; Tsai et al., 2007; Treier et al., 2010; Pantos et al., 2011; Héliou et al., 2012). The effective dose from the current study was estimated to be 8.9 mSv, which is shown to be higher than the findings of 7.1, 8.2, and 8.01 mSv by Shrimpton et al. (2003), Papadimitriou et al. (2003), and Huda and Mettler (2011), respectively. Similarly, the present data show a lower value compared to the reported values of 15.4, 14.4, 15, 9.3, and 10.5 mSv by Brix et al. (2003), Tsapaki et al. (2001), Tsai et al. (2007), Pantos et al. (2011) and Treier et al. (2010), respectively. Such a difference among the literature data may be attributed to different imaging protocols applied in each study as well as variation of the dosimetric techniques to estimate the effective doses.

5. Conclusion

Since X-ray imaging and CT scanning procedures have become a very common diagnostic technique these days, the study of machine integrity concerning the deposited dose compared to the reference dose shows a great significance. In this study, we measured conventional X-ray and CT doses for radiosensitive organs in the pelvic cavity for 313 patients in KSA. It has been found that the ESD and ED were at acceptable levels compared to the previous studies in both imaging modalities (conventional X-ray and CT). However, there was a noticeable variation in radiation levels between the hospitals under study. Furthermore, a non-negligible deviation was also observed while compared with the available literature data. It is thus expected that the obtained results may serve as guidelines for obtaining reference doses for radiological examinations in two hospitals under investigation. Additional studies with large sample sizes from different departments and facilities are required to establish the local diagnostic reference levels.

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Disclosure statement

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