Mathematical Evaluation of Entrance Surface Dose (ESD) for Patients Examined by Diagnostic X-Rays

Abstract
Exposures from diagnostic medical X-rays are the most important synthetic source of exposure to ionizing radiation in several countries. However information on medical exposure of diagnostic X-rays is integrated into international legislative repertories. In Sebha city, there is a lack of data on the assessment of patient’s entrance surface dose (ESD) and the health risk from conventional radiography in daily routine of diagnostic medical examinations. In this research, the Entrance Surface Dose (ESD) was estimated for adult patients underwent diagnosis X-ray examinations in one of radiographic center in Sebha city. The ESD has been estimated indirectly using exposure factors for patients. The results showed that the mean patient entrance surface doses (ESD) were 41.73±5.84 mGy, 7.43±2.58 mGy, 103.7±125.53 mGy, 7.25±4.32 mGy and 11.24±16.18 mGy respectively for Pelvis (AP), Chest (AP), Lumbar Spine (AP), Cervical Spine (AP) and Skull (AP). The mean ESD values are found to be higher than mean ESD reference values. This indicates that the necessity for reducing the patient doses to the acceptable levels recommended by the international radiation protection commissions to protect patients from risk of higher exposures to diagnostic X-rays.

Keywords: Entrance surface dose (ESD); Diagnostic X-rays; Lumbar spine; Cervical spine

Abbreviations: ESD: Entrance Surface Dose; ICRP: International Committee of Radiation Protection; TLD: Thermoluminescent Dosimeters; FSD: Focus To Surface Distance

Introduction
X-ray examinations are an established tool of medical diagnosis. Patients undeniably benefit from these examinations; even though the ionizing nature of X-rays means that there are unavoidable effects which may definitely occur. For example the deleterious effects for patients happed while patients overexposure to X-rays. For this reason, it is necessary to apply radiation protection principles in medical diagnosis using X-rays procedures. In addition, all exposures from X-rays must be justified and optimized in terms of benefit and risk [1-3]. It also well-known that the X-rays transfer a certain amount of energy to biological system as it is penetrating; however this energy may be risky of cells those building up biological entities [4]. There is increased concern about exposing patients from higher levels of diagnostic X-rays. This concern noticed in recommendations of the International Committee of Radiation Protection (ICRP) [5-7].

The recommendations directed to put together all countries to provide restricted radiation dose for patients undergoing the X-ray examinations in the almost all radiographic centers and radiology departments at hospitals. One of the major important factors in radiation protection is patient dose. The patient dose is usually specified by means of determining entrance surface dose (ESD) for patient being exposed to diagnostic X-rays. The entrance surface dose (ESD) is defined as the absorbed dose to air at the point of intersection of the X-ray beam axis with the entrance surface of the patient, including backscatter [8]. The entrance surface dose is one of the basic quantities for measuring the patient dose and as well for optimizing the patient dose. This quantity is basic criterion for comparing to the other international reference dose levels which is very important from the point of view for radiation protection [9]. There are many different methods for determination of the ESD. In common, the ESD can be determined mainly by two methods: either by direct measurements using Thermoluminescent dosimeters (TLD) stacked on the patient’s skin or indirectly via mathematical model calculations based on the X-ray machine output. The ESD can be determined from the measurements performed on a phantom and data from the patient’s exploration [10-12].

Generally, applying the TLD in measuring the ESD for patients involves time consuming and using special equipments which may not be available at the most radiographic centers. On the other hand, using ionization chambers to measure the ESD for patients require using of conversion factors to convert the ionization chamber (IC) reading to absorbed dose which to some extent is complicated method [13]. Although due to the hard accessibility of TLD or IC instruments, the mathematical method was employed in this study to estimate the ESDs. The aim of this research was to estimate the ESD for patients exposed to diagnostic X-Rays at medical radiographic centers in Sebha city. To fulfill this objective The ESD was estimated applying Chuan and Tsai formula for many patients exposed to diagnostic X-rays for six examinations. The values obtained of the ESD from this research were compared with the international ESD values reported in the literature.
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Materials and Methods

The X-ray diagnostic equipment was used to expose patients with total number of 45 patients. The specification of this machine complies with the DHHS requirements, minimum inherent filtration Aluminum equivalent 2 m m Al/75, X-ray rating up to 150 $k_{vp}$. At the beginning, the patient’s data such as Age and Gender were recorded and then the patient was centered by technician to be ready for radiographic. The parameters such as peak tube voltage ($k_{vp}$), exposure current and time product (mAs) and focus to surface distance (FSD) were recorded at the time of the examination. This information was recorded for each patient undergoing the particular diagnostic procedure. In present work the Chuan and Tsai formula [14] is applied to calculate the ESD for patients coming to the X-ray radiographic center. The entire selected sample was mainly from adults: men, women and including few cases of children. This formula is given as follows:

$$\text{ESD (mGy)} = c \left( \frac{k_{vp}}{\text{FSD}} \right)^2 \left( \frac{\text{mAs}}{\text{mm.Al}} \right)$$

Where $k_{vp}$ represents X-ray peak tube voltage and mAs represents the exposure value which means that tube’s current times exposure time. While FSD (Focus to Skin Distance) represents the measured distance between X-ray tube and patient part being exposed to X-rays, mm. Al gives minimum inherent filtration Aluminum equivalent and $c$ is constant which equals to 0.2775. The obtained data was analyzed using Excel.

Results

This work was carried out in one of radiographic center in Sebha city. One X-ray unit was included in this study. The results obtained were recorded in tables shown below. The results included gender, patient’s age, $k_{vp}$, mAs, FSD and entrance surface dose (ESD) for all different cases being exposed to diagnostic X-rays. The results also included medical procedures involving different positioning of patients such as Anterior-Posterior (AP) and Lateral (LAT). The other medical procedures including Posterior-Anterior (PA) are not considered in this study owning to the little cases being examined. Tables listed underneath (1-6) indicate the estimated values of the ESD in every examination. Table 1 indicates exposure factors and estimated ESDs for patients undergone to Pelvis (AP) examination. Table 2 indicates exposure factors and the estimated ESDs for patients undergone to Chest (AP) examination. Table 3 shows the exposure factors and estimated ESDs for patients undergone to Lumbar Spine (AP) examination. Table 4 shows also the exposure factors and estimated ESDs for patients undergone to Cervical Spine examination. Tables 5-6 present the exposure factors and estimated ESDs for patients undergone to Skull (AP & LAT) examinations. Table 7 indicates the mean values of the patient exposure factors, such as $k_{vp}$, mAs, FSD and ESD. The last Table 8 shows the compression between the results obtained during this study, previous studies and the established international reference levels of ESDs.

Table 1: The Estimated Esds for Pelvis.

| Number | Gender | Age | Diagnostic Type | $k_{vp}$ | mAs | FSD (Cm) |
|--------|--------|-----|----------------|--------|-----|---------|
| 1      | F      | 41  | Pelvis AP      | 88     | 79  | 43      |
| 2      | F      | 44  | Pelvis AP      | 88     | 79  | 43      |
| 3      | F      | 63  | Pelvis AP      | 80     | 66  | 43      |
| 4      | F      | 38  | Pelvis AP      | 84     | 79  | 43      |
| 5      | F      | 24  | Pelvis AP      | 85     | 79  | 43      |
| 6      | M      | 39  | Pelvis AP      | 89     | 79  | 43      |
| 7      | F      | 30  | Pelvis AP      | 80     | 66  | 43      |
| 8      | F      | 31  | Pelvis AP      | 86     | 79  | 43      |
| 9      | F      | 29  | Pelvis AP      | 86     | 79  | 43      |
| 10     | F      | 24  | Pelvis AP      | 85     | 79  | 43      |

Table 2: The Estimated Esds for Chest.

| Number | Gender | Age | Diagnostic Type | $k_{vp}$ | mAs | FSD (Cm) | ESD (Mgy) |
|--------|--------|-----|----------------|--------|-----|---------|-----------|
| 1      | F      | 24  | Chest AP       | 80     | 66  | 100     | 5.86      |
| 2      | F      | 80  | Chest AP       | 121    | 12  | 53      | 8.68      |
| 3      | F      | 70  | Chest AP       | 123    | 10  | 53      | 7.47      |
| 4      | F      | 52  | Chest AP       | 120    | 12  | 45      | 11.84     |
| 5      | F      | 58  | Chest AP       | 85     | 79  | 100     | 7.92      |
| 6      | F      | 64  | Chest AP       | 75     | 66  | 100     | 5.15      |
| 7      | F      | 60  | Chest AP       | 80     | 79  | 100     | 7.01      |
| 8      | F      | 46  | Chest AP       | 85     | 79  | 100     | 7.92      |
| 9      | F      | 60  | Chest AP       | 85     | 79  | 100     | 7.92      |
| 10     | M      | 24  | Chest AP       | 70     | 66  | 100     | 4.49      |
| 11     | F      | 24  | Chest AP       | 90     | 79  | 100     | 8.88      |
| 12     | M      | 4   | Chest AP       | 50     | 45  | 100     | 1.56      |
### Table 3: The Estimated Esds For Lumbar Spine.

| Number | Gender | Age | Diagnostic Type | Kvp | Mas | FSD(Cm) | ESD (Mgy) |
|--------|--------|-----|------------------|-----|-----|---------|----------|
| 1      | F      | 40  | Lumbar Spine AP  | 90  | 450 | 43      | 273.52   |
| 2      | F      | 38  |                  | 110 | 245 | 43      | 222.46   |
| 3      | F      | 43  |                  | 90  | 132 | 43      | 80.23    |
| 4      | F      | 42  |                  | 104 | 197 | 53      | 105.25   |
| 5      | F      | 63  |                  | 125 | 590 | 53      | 455.36   |
| 6      | F      | 26  |                  | 106 | 284 | 53      | 157.62   |
| 7      | F      | 63  |                  | 90  | 123 | 43      | 74.76    |
| 8      | M      | 19  |                  | 90  | 123 | 43      | 74.76    |
| 9      | M      | 55  |                  | 122 | 284 | 43      | 317.2    |
| 10     | M      | 39  |                  | 110 | 245 | 43      | 222.46   |

### Table 4: The Estimated Esds for Cervical Spine.

| Number | Gender | Age | Diagnostic Type  | Kvp | Mas | FSD(Cm) | ESD (Mgy) |
|--------|--------|-----|------------------|-----|-----|---------|----------|
| 1      | F      | 35  | Cervical Spine LAT | 85  | 79  | 118     | 5.69     |
| 2      | F      | 40  |                  | 70  | 66  | 117     | 3.28     |
| 3      | F      | 26  |                  | 71  | 66  | 117     | 16.43    |
| 4      | F      | 32  |                  | 88  | 79  | 100     | 8.49     |
| 5      | F      | 33  |                  | 80  | 66  | 100     | 5.86     |
| 6      | F      | 36  |                  | 80  | 66  | 100     | 5.86     |
| 7      | F      | 28  |                  | 75  | 66  | 100     | 5.15     |

### Table 5: The Estimated Esds for Skull.

| Number | Gender | Age | Diagnostic Type | Kvp | Mas | FSD(Cm) | ESD (Mgy) |
|--------|--------|-----|-----------------|-----|-----|---------|----------|
| 1      | M      | 4   | Skull AP        | 66  | 45  | 86      | 3.68     |
| 2      | F      | 43  |                 | 81  | 79  | 45      | 35.51    |
| 3      | F      | 5   |                 | 65  | 55  | 100     | 3.22     |
| 4      | M      | 1   |                 | 58  | 55  | 100     | 2.57     |

### Table 6: The Estimated Esds for Skull.

| Number | Gender | Age | Diagnostic Type | Kvp | Mas | FSD(Cm) | ESD (Mgy) |
|--------|--------|-----|-----------------|-----|-----|---------|----------|
| 1      | F      | 8   | Skull LAT       | 70  | 66  | 100     | 1.84     |
| 2      | F      | 4   |                 | 70  | 66  | 100     | 4.49     |
| 3      | M      | 5   |                 | 70  | 66  | 100     | 4.49     |

### Table 7: Mean Values of the Estimated Esds.

| Diag. Type          | This Study | [15] | [16] | [17] | [18] | [19] |
|---------------------|-----------|------|------|------|------|------|
| Pelvis (AP)         | 41.73     | *    | 0.62 | 1.25 | 10   | 4    |
| Chest (AP)          | 7.43      | *    | 0.18 | *    | *    | *    |
| Lumbar Spine (AP)   | 10.37     | 22.61| 2.25 | 10   | 6    | 10   |
| Cervical Spin(LAT)  | 7.25      | 2.4  | *    | *    | *    | *    |
| Skull (AP)          | 11.24     | *    | *    | *    | *    | *    |
Table 8: Comparison between the Present Study and the Literature.

| Diag. Type | $k_v$ | mAs | FSD | ESD (mGy) |
|------------|-------|-----|-----|-----------|
| Pelvis (AP)| 50-123 | 123-590 | 43 | 31.70-46.96 |
| Lumbar (AP)| 70-88 | 66-79 | 53-118 | 3.28-16.43 |
| Spine (LAT)| 87-43 | 57-99 | 99-28 | 7.25-4.32 |
| Skull (AP)| 58-81 | 123-590 | 43-53 | 74.76-455.36 |
| Cervical Spine (AP)| 70-88 | 66-79 | 103.7±125.53 | 3.28-16.43 |

Discussion

This study was directed to the estimate entrance surface dose (ESD) for patients undergoing diagnostic X-ray examinations at the radiology department. The selected sample in this investigation included 45 patients. The data collected from one center in Sebha city. The protocol used to image patients in this center was the highest $k_v$, and the lowest mAs for Pelvis (AP), Chest (AP), Cervical Spine (AP) and Skull (AP). Although the lowest $k_v$, the highest mAs were used to image Lumbar Spine (AP). The estimated ESDs varied from 31.70-46.96 mGy for Pelvis (AP), 1.56-11.84 mGy for Chest (AP), 74.76-455.36 mGy for Lumbar Spine (AP), 3.28-16.43 mGy for Lumbar Cervical (AP) and 3.22-35.51 mGy for Skull (AP). When comparing the values obtained of ESDs from this study to previous studies and international reference levels (IRLS), (Table 8), the mean ESDs evaluated by this work were found to be higher than both the previous studies and the IRLs. The minimum dose value (7.25 mGy) in this study was with case of Cervical Spine (LAT). While the maximum dose value (103.7 mGy) in this study was with case of Lumbar Spine (AP). In all cases of examinations, higher values of the ESDs are obtained. Judging from Table 8, the mean ESDs evaluated by this work were found to be higher than both the previous studies and the IRLs.

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