International Journal of Research in Education Humanities and Commerce

Volume 07, Issue 06 "November - December 2026"

ISSN 2583-0333

ORGAN VOLUME AND EFFECTIVE DOSE ASSESSMENT IN AP CHEST X-RAY EXAMINATION

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https://doi.org/10.37602/IJREHC.2026.7602

ABSTRACT

The present work aims to describe a new method for calculating the effective dose to the heart, lungs, breasts, and thyroid for patients undergoing AP chest–ray examination. This model of calculation takes into account variation of dose due to depth, relative risk factor (organ sensitivity to radiation), and % organ volume exposed in the irradiation. The entrance skin dose is 0.212 mGy which is in good agreement with previously recorded values. The effective dose for the heart is 0.0008 mSv, 0.0125 mSv for lungs, 0.0019 mSv for breast, and 0.00004 mSv for thyroid. Lungs appear to be subjected to more organ and effective dose than other organs. This is attributed to the greater % volume exposed to radiation. The % organ volume becomes a good indicator for the organ radiation risk since smooth straight-line relationships were recorded. The calculated effective dose is in agreement with Monte Carlo method 2025 in case of Lungs and Breast. For Thyroid Monte Carlo method is over estimating the present value. Similar calculations can be applied for other x-ray examinations.

Keywords: Skin dose, Organ dose, effective dose, x-ray exposure.

1.0 INTRODUCTION

Diagnostic X-ray imaging has become a cornerstone of modern medical diagnostics, with increase in the number of examinations performed in recent years. This rise, however, comes alongside growing concerns regarding the risks associated with ionizing radiation exposure to patients. Notably, radiation exposure from medical imaging accounts for the largest collective absorbed dose among patients when compared to other sources of ionizing radiation.

To mitigate these risks, the principle of (ALARA), "As Low As Reasonably Achievable" is highly recommended [1]. This principal concern on maintaining radiation exposure at levels sufficient to produce high-quality images with minimum radiation dose to the patients. Thus, it is crucial to continually review and optimize existing imaging protocols to ensure that they yield images of adequate quality for reliable diagnoses, while also minimizing the radiation exposure associated with these techniques.

In evaluating radiation exposure during x-ray examinations, the Entrance Skin Dose, ESD, serves as a critical parameter. Monitoring ESD is essential for optimizing patient doses and ensuring safety during imaging procedures. Furthermore, the Effective Dose, ED, to specific organs is critical for assessing the potential biological damage, evaluating long-term cancer risks, optimizing imaging protocols, and prioritizing patient safety.

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Radiation intensities (or doses) absorbed by organs during X-ray examinations vary significantly depending on the organ's proximity to the radiation beam, tissue sensitivity, anatomical thickness or volume, and machine settings. This variation can result in uneven radiation exposure across the body, affect image quality and potentially compromise diagnostic accuracy. Since not all body tissues are equally sensitive to radiation, the "effective dose" (in mSv) calculates the overall risk to the organs. Consequently, the precise evaluation and optimization of patient radiation entrance dose, ESD, is an essential component of radiological protection which refers to the radiation absorbed by the skin at the point where the beam enters the body.

The present work aims to establish a relationship between organ volume and organ effective dose, received in AP chest x-ray examination.

2.0 MATERIALS AND METHODS

In this model the x-ray output, entrance skin dose and organ dose is calculated taking into account the inverse square law and the % volume occupied by the organ in the exposed cavity, finally the effective dose is calculated considering the tissue weighting factor for the organ. Organ dose is calculated by multiplying the % volume occupied and the organ dose at the organ position.

$$\boldsymbol{Organ\ Dose} = \%\ \boldsymbol{organ\ volume\ occupied} \times \boldsymbol{dose\ at\ organ\ position} \qquad (1)$$

2.1 X-ray Output, Entrance Skin Dose, Organ Dose.

The x-ray output, OP, the entrance skin dose, ESD, and effective dose, ED, is estimated for a three-phase power supply x-ray machine as follows [2].

The x-ray output, OP (in mGy/mAs) is given by:

$$\boldsymbol{OP\ (mGy/mAs)} = \boldsymbol{0.8 \times 6.54 \times 10^{-4} \times (kvP)^2\ \times 0.00876} \qquad (2)$$

The factor 0.00876 is added to convert the output from mR to mGy.

The entrance skin dose ESD (in mGy) as follows [2]:

$$\boldsymbol{ESD(mGy)} = \boldsymbol{OP(mGy/mAs)} \times \boldsymbol{mAs} \times \left(\frac{\boldsymbol{100}}{\boldsymbol{FSD}}\right)^{\boldsymbol{2}} \times \boldsymbol{BSF}$$

Where, BSF=1.3, is the back scattered factor.

Figure (1) shows the irradiation geometry and dimensions for a patient in supine AP chest x-ray examination. According to the Figure the focus skin distance (FSD) is derived as follows:

$$\boldsymbol{FSD} = (\boldsymbol{SID} - \boldsymbol{OID}) - \boldsymbol{T} \qquad (4)$$

Where; T is the body thickness or organ depth in (cm).

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Volume 07, Issue 06 "November - December 2026"

ISSN 2583-0333

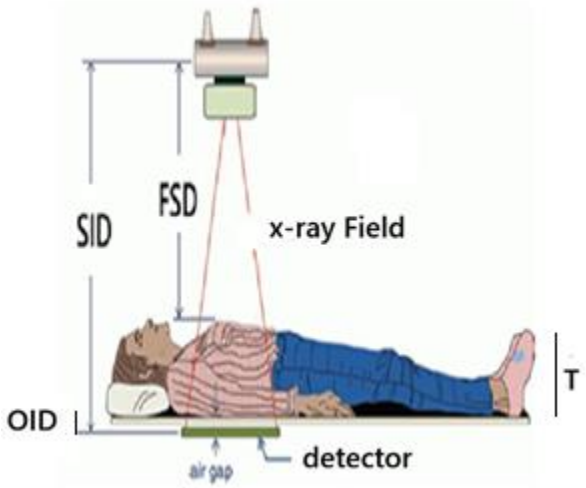


Figure: 1 Ap supine chest x-ray irradiation geometry

The effective dose, ED, for the organs (in mSv) is calculated using the following formula [3].

$$\boldsymbol{ED(mSv) = ESD(mGy) \times Q_R \times w_T} \qquad (5)$$

Where; Q_R is the radiation quality factor, for x-ray; $Q_R = 1.0$, $\boldsymbol{w_T}$ is the tissue weighting factor for individual organ under exposure. The weighting factor $\boldsymbol{w_T}$ accounts for how sensitive the organ is for radiation-induced cancer and how much it contributes to the total health detriment. Values for weighting factors for organs under risk for chest x-ray examination is shown in table 2, ICRP 103 [4].

Table (2): Weighting factors, wT for main organs at risk during chest X-ray examination

Examination	Organs At high Risk	W_T
AP- chest x-ray	lungs	0.12
	Breast	0.12
	Thyroid gland	0.04
	Heart	0.04

2.2 Determination the Organ Dose (P_{Organ})

In X-ray examinations the distribution of radiation intensities (dose) through organs is not uniform, therefore the absorbed dose by the organs varies significantly depending on the organ's proximity to the beam entrance and organ volume, tissue weighting factor, anatomical thickness, and x-ray machine settings. Organ doses represent how much the organ is subjected to radiation in the exposed cavity considering the depth of the organ from the skin according to the inverse square law and % volume occupied by the organ relative to the cavity under exposure. For chest x-ray (AP view), the entrance surface dose, ESD, is the maximum radiation

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intensity (dose) measured right at the patient's skin. While different organs sit at different depths will receive little lower doses according to the inverse square law.

Assume position A in figure 2 is the skin position and the entrance dose at skin (ESD) is $\boldsymbol{P_A}$, then the dose at organ position B is P_B. All organs sitting at the arc of the x-ray sphere are assumed to receive same radiation intensities.

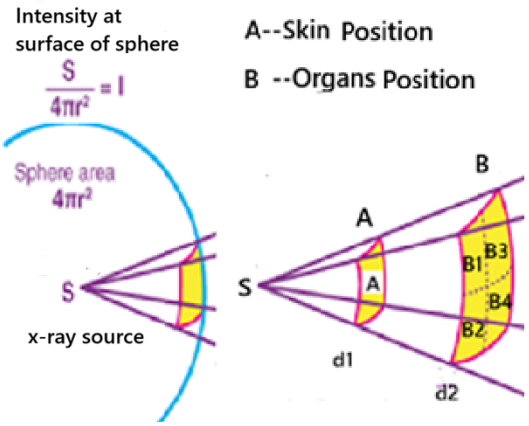


Figure 2: The distribution of the x-ray in air as an arc of sphere.

The dose at the organs position below the skin is reduced according to the inverse square law using figure 1, and is given as:

$$\boldsymbol{P_B = Dose\ at\ organ\ position = P_A \times (\frac{FSD}{FSD+d_2})^2} \qquad (6)$$

The % of volume occupied by the organ relative to cavity volume is calculated as:

$$\%\ \boldsymbol{volume\ ccupied\ by\ the\ organ = \frac{Organ\ volume}{Cavity\ volume}} \qquad (7)$$

A standard anatomical “chest cavity volume during AP chest x-ray in supine position is 6500 – 7000 cm3 for adult male and 4700 – 5200 cm3 for adult woman, average value of 6750\ cm^{3} for male patients is considered in this work [5].

The organ dose is then calculated as:

$$\boldsymbol{Dose_{organ} = P_B \times \%\ volume\ occupied\ by\ the\ organ} \qquad (8)$$

The above equation takes into account the variation of dose with respect to the depth and organ volume.

2.2.1 Heart Dose:

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Volume 07, Issue 06 "November - December 2026"

ISSN 2583-0333

The heart roughly measures about 12 cm in length, 8.5 cm in width, and 6 cm in thickness, and the heart volume is between 700 to 800 cm3 for male and 550 – 650 cm3 for woman [6], an average value of 750 for male is considered in this work. The heart sits about 3.5-5 cm under the skin [7], average value of 4.25 cm is considered in this work. The dose is reduced at heart position according to the inverse square law as follows:

$$\therefore \ \boldsymbol{Dose_{at\ heart\ position} = P_{A-skin} \times \left(\frac{151}{151+4.25}\right)^2 = 0.9459\ P_{A-skin}}$$

$$\%\ \boldsymbol{volume\ occupied\ by\ the\ heart} = \frac{750}{6750} = \mathbf{0.1111}$$

Organ dose to the heart is given by:

$$\therefore \ \boldsymbol{Dose_{\ heart} = Dose_{at\ heart\ position} \times 0.1111 = 0.105\ P_{A-skin}} \quad \boldsymbol{mGy}$$

2.2.2 Lungs Dose:

The lungs sit about 1.5 cm to 4.5 cm below the skin (average value of 3 cm is considered in this work). On average, each lung measures about 30 cm in length and 15 cm in width with an area of about 450 cm2 and an average lung volume of about 5800 – 6000 cm3 for male and 4200 cm3 for woman, keeping in mind that lying supine decreases maximum inspiratory lung volume by approximately 10% to 15% [5], average value of 5300 for male is considered in this work. The dose is reduced at lung position according to the inverse square law as follows:

$$\therefore \ \boldsymbol{Dose_{at\ lung\ position} = P_{A-skin} \times \left(\frac{151}{151+3}\right)^2 = 0.9614\ P_{A-skin}}$$

$$\mathbf{\%\ volume\ occupied\ by\ the\ two\ lungs} = \frac{5300}{6750} = \mathbf{0.7866}$$

The dose to lungs is given by:

$$\boldsymbol{Dose_{lungs} = 0.9614 \times P_{A-skin} \times 0.5142 = 0.7562 \times P_{A-skin}} \quad \boldsymbol{mGy}$$

2.2.3 Breast Dose:

Breast tissue (uncompressed) sits about 0.25 cm to 1.2 cm (average value of 0.725 cm is considered) deep from the skin. The breast base width (the horizontal distance across the chest where the breast tissue begins and ends) typically ranges from 10 cm to 15 cm (average value of 12.5 cm is considered in this work). The length across the breast tissue running over the nipple usually ranges from 18 cm to 23 cm. Accordingly, each Breast area is about 250 cm2 and a volume of 250 – 650 cm3 [8, 9]. Average volume value of 450 cm3 for each side is considered in this work. The dose is reduced at position of the breast according to the inverse square law as follows:

$$\therefore \ \boldsymbol{Dose_{at\ Breast\ position} = P_{A-skin} \times \left(\frac{151}{151+0.725}\right)^2 = 0.9904\ P_{A-skin}}$$

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% volume occupied by the two Breasts is given by:

$$\%\ \boldsymbol{volume\ occupied\ by\ the\ breasts} = \frac{2 \times 450}{6750} = 0.1333$$

The breasts dose is given by:

$$\boldsymbol{Dose_{Breasts}} = 0.9904 \times \boldsymbol{P_{A-skin}} \times 0.1333 = 0.1320 \times \boldsymbol{P_{A-skin}} \quad \boldsymbol{mGy}$$

2.2.4-Thyroid Dose

Thyroid accounts for a negligible fraction of the total chest cavity area, generally less than 0.5%, with standard anatomical dimensions of 4 to 6 cm length per lobe, 1 to 1.8 cm width per lobe, 0.8 to 1.6 cm depth per lobe. Thyroid tissue sits about 1.3 cm to 2 cm deep from the skin surface with an average area of 7 cm2 and an average volume of 12-18 cm3 for male for each loop [10]. Average value 15 cm3 is considered in this work. The dose is reduced at position of the organ according to the inverse square law as follows:

$$\therefore\ \boldsymbol{Dose_{at\ thyroid\ position}} = \boldsymbol{P_{A-skin}} \times \left(\frac{151}{151 + 1.65}\right)^2 = 0.9784\ \boldsymbol{P_{A-skin}}$$

$$\%\ \boldsymbol{volume\ occupied\ by\ combined\ thyroid} = \frac{2 \times 15}{6750} = 0.0044\ \ \boldsymbol{squares}$$

The Thyroid dose is given by:

$$\boldsymbol{Dose_{Thyroid}} = 0.9784 \times \boldsymbol{P_{A-skin}} \times 0.0044 = 0.00434 \times \boldsymbol{P_{A-skin}}$$

3.0 RESULTS AND DISCUSSION

Entrance skin dose and effective dose for major organs exposed to radiation during AP chest x-ray are estimated for 54 chest x-ray examinations carried out at Erbil International Hospital-Erbil City. Patient's age was between 20-81 y, average patient's weight was about 70 kg, and average machine technical factors for the 54 cases were;

$$\boldsymbol{Average\ KVp\ is}\ \ 81.97,\ \ \boldsymbol{Average\ mAs\ is}\ 12.77,\ \ \ \boldsymbol{Average\ SID\ is}\ 180\ \boldsymbol{cm},$$

$$\boldsymbol{Average\ chest\ thickness}\ (\boldsymbol{T})\ \boldsymbol{is}\ 22\ \boldsymbol{cm}.$$

The x-ray output (mGy), focal skin distance (cm), and the entrance skin dose (mGy) are calculated as follows:

The x-ray output (mGy), focal skin distance (cm), and the entrance skin dose (mGy) are calculated as follows:

$$\boldsymbol{X-ray\ output}\ (\boldsymbol{OP}) = 0.0307\ \boldsymbol{mGy/mAs}, \boldsymbol{Focal\ Skin\ Distance}\ (\boldsymbol{FSD}) = 158\ \boldsymbol{cm}.$$

$$\therefore\ \ \boldsymbol{Entrance\ Skin\ Dose}\ (\boldsymbol{ESD}) = 0.212\ \ \ \boldsymbol{mGy}.$$

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The effective dose (ED) in mSv for the organs is calculated as follows:

$$\therefore \ \boldsymbol{Effective\ Dos\ (ED) = Organ\ Dose \times w_T} \qquad \boldsymbol{mSv} \qquad (9)$$

The entrance skin dose, % volume occupied by the organ, organ dose (mGy), and the effective dose (mSv) for organs under exposure in supine AP chest examination are shown in table 3.

Table 3: Calculated Organs Doses and Effective Doses

Organs	Average depth (cm)	Weighting factor (w_t)	Average Organs Volume (cm^3)	Entrance Skin Dose ESD (mGy)	Organs Dose (mGy)	$Effective\ Dose$ ED (mSv)
Heart	**4**	**0.04**	**750**	**0.212**	**0.0222**	**0.0008**
Lungs	**3**	**0.12**	**5300**		**0.1603**	**0.0192**
Breasts	**0.725**	**0.12**	**900**		**0.0279**	**0.0033**
Thyroids	**1.65**	**0.04**	**30**		**0.0009**	**0.00003**

According to table 3, lungs receive the highest organ and effective doses, followed by breasts, heart, and then thyroid. This is attributed to the greatest volume occupied by the lungs. Table 4 shows the entrance skin dose compared with the dose reference level set by the previous work and international bodies [9], good agreement is observed.

Table 4: Comparing the ESD value with other previous work

Reference Study	ESD (mGy)
Present Study	**0.212**
Margaret. I. Ike-Ogbonna1 2020 [12]	0.195 – 0.66
Obed et al, 2007 [13]	0.35
Osman et al., 2010 [14]	0.23 ± 0.4
Dlama et al., 2014 [15]	0.5 – 0.54
Nijiti et al, 2014 [16]	$1.08 \pm 0.43 - 0.76 \pm 0.2$
Taha et al., 2016 [17]	0.12 ± 0.27
IAEA., 1996 [18]	0.4
NRPB, 1999 [19]	0.3

Table 5 shows the present effective dose values for AP chest x-ray compared with Monte Carlo calculation [11].

Table 5: The Effective Dose (mSv) compared with Monte Carlo calculations

Organs	Present Work	Monte Carlo 2025
Heart	0.0008	----------
Lungs	0.0192	0.01248
Breast	0.0033	0.003574
Thyroid	0.00009	0.001399

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Values calculated in the present work is lower than that recorded by Monte Carlo calculation for thyroid and in agreement with that for breast and lungs. No result is given to the heart by Monte Carlo calculation 2025. Monte Carlo effective dose for thyroid is over estimating the real value since volume occupied by thyroid is about 6% of that for breast and thyroid sits deeper than breast under the skin by about 43%, those two factors may significantly reduce the dose. Accordingly, it is expected a much lower effective dose received by thyroid compared to that for breast. Figure 3 shows the variation of organ dose with organ volume. Organ dose affected by three variables, depth, volume, and tissue weighting factor. The only clear relationship can be seen between organ dose and organ volume; linear relationship is clearly set, see figure 3. Variations of the effective dose (mSv) with organ volume is also a linear function as shown in figure 4. The result in the present work indicate that organ volume is a good indicator for the organ dose and effective dose receives in practice.

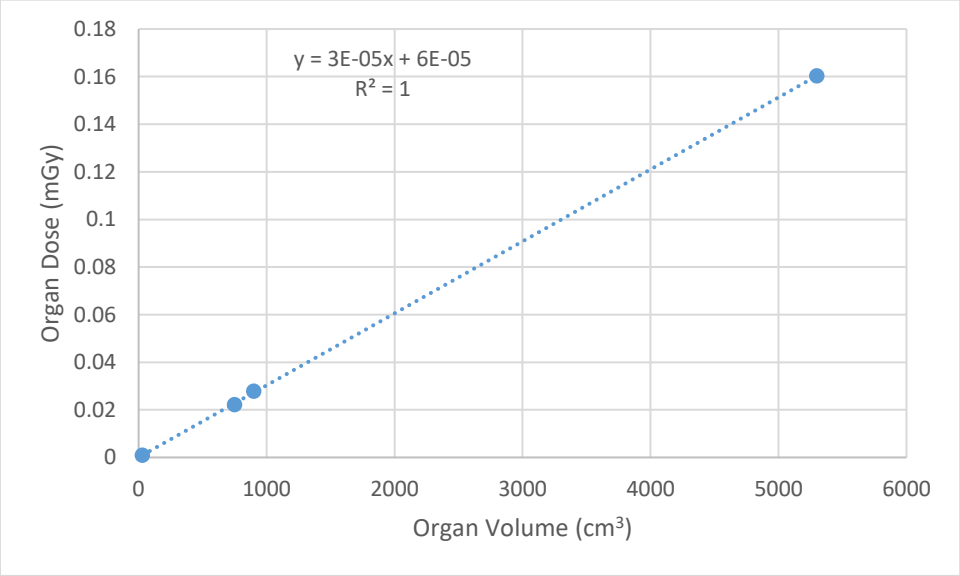
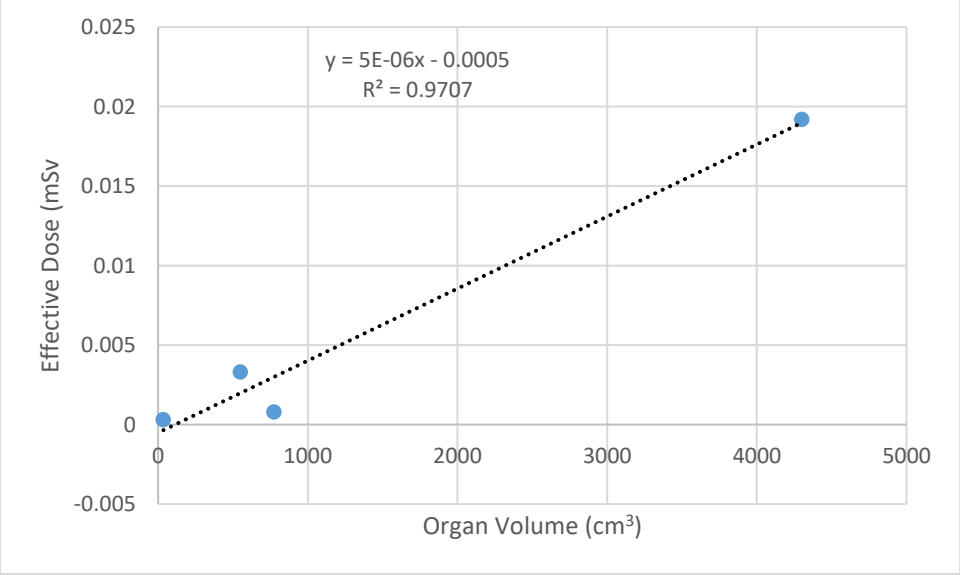


Fig. 3: Variation of organ dose (in mGy) with organ volume (in cm3)



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Fig. 4: Variation of the effective dose with organ volume

4.0 CONCLUSION

The present calculation takes into account three important variable that may affect the organ and effective doses; organ depth, % organ volume occupied, and tissue weighting factor. Organ dose is in good agreement with previous work. The effective dose is also in acceptable agreement with Monte Carlo calculations [10] for Lungs and Breast. A smooth linear relationship was observed between organ dose, effective doses and organ volume. This indicates that organ volume is a good indicator for radiation organ and effective doses. Similar calculation can be used to estimate the organ and effective doses for other x-ray examinations. This work contributes to the ongoing efforts to optimize radiation safety protocols in medical imaging practices.

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