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Estimation of effective dose in common radiographic examinations using dose area product (DAP) meter of North Indian population

Nirmal Kumar Panda[1*], Ravindra Kumar[2], Joginder Singh[2], Sudipta Mohakud[3], Debasis Padhi[4]
[1] Radiographic Technician Grade I, Department of Radiodiagnosis and Imaging, AIIMS Bhubaneswar, Odisha, India
[2] Medical Technologist, Department of Radiodiagnosis and Imaging, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, India
[3] Additional Professor, Department of Radiodiagnosis and Imaging, AIIMS Bhubaneswar, Odisha, India
[4] Managing Partner & Senior Consultant Radiologist, Nidan Diagnostic and Research Center, Berhampur, Ganjam, Odisha, India
Corresponding Author: Nirmal Kumar Panda

Abstract

Background

Diagnostic radiology is a major contributor to radiation exposure from man-made sources. Dose Area Product (DAP) is widely used to estimate patient radiation dose and assess associated risks. Establishing effective dose values and comparing them with international reference levels is essential for dose optimization.

Objective

To estimate effective dose (ED) in common digital radiographic examinations using DAP measurements and to compare the results with international dose reference levels.

Materials and Methods

This prospective study was conducted on 350 adult patients undergoing 27 routine radiographic examinations at UCMS and GTB Hospital, New Delhi. DAP values were recorded using a KermaX® DAP meter attached to a digital radiography system (Definium-8000, GE). Patient demographic parameters and exposure factors (kVp, mAs, FFD) were documented. Effective dose was calculated using standard conversion coefficients. Statistical analysis was performed using mean ± standard deviation and one-sample t-test.

Results

The mean DAP values (Gy·cm²) were 0.13 ± 0.09 for Chest-PA, 0.43 ± 0.22 for Abdomen-AP, 0.47 ± 0.39 for Pelvis-AP, 0.50 ± 0.30 for Lumbar-AP, and 0.88 ± 0.44 for Lumbar-Lateral examinations. Corresponding mean effective doses (mSv) were 0.02 ± 0.01, 0.07 ± 0.04, 0.066 ± 0.05, 0.11 ± 0.06, and 0.29 ± 0.041 respectively. The estimated effective doses were significantly lower than international reference levels reported by Hart *et al*. (2005) and comparable with other published studies. Statistical analysis showed significant differences ($p < 0.002$).

Conclusion

Effective doses estimated using DAP in digital radiography were generally lower than established international reference levels. The study highlights the role of modern digital systems in dose reduction and provides baseline data for establishing Diagnostic Reference Levels (DRLs) in the Indian population.

Keywords: Dose area product, effective dose, digital radiography, radiation dose, diagnostic reference levels, x-ray imaging

Introduction

Use of X-ray facilities and equipments has increased rapidly in medical practices. Diagnostic radiology has an enormous share of public dose from man-made sources. In fact diagnostic radiology is, so far, the largest source of man-made radiation. For example, diagnostic radiology and nuclear medicine procedures are the cause of about 88% of collective effective dose from man-made sources in the US [1, 2].

Dose Area Product (DAP) is a quantity used in assessing the radiation risk from diagnostic x-ray examination and interventional procedures. It is defined as the absorbed dose to air averaged over the area of the x-ray beam in a plane perpendicular to the beam axis multiplied by the area of the beam in the same plane. It is usually measured in unit of Gy.cm^2 and radiation backscattered from the patient is excluded, provided that the cross sectional area of the beam lies completely within the detector, it may be shown by simple application of the inverse square law that the reading will not vary with the distance from the tube focus. Thus the DAP can be measured at any point between the diaphragm housing on the x-ray tube and the patient, but not so close to the patient that there is significant backscattered radiation [3, 4].

DAP meter consist of flat large area parallel plate ionization chamber connected to suitable electrometers which respond to total charge collected over the whole area of the chamber. The meter is mounted close to the tube focus where the area of the X-ray beam is relatively small and dose rates are high. It is normally mounted on the diaphragm housing where it does not interfere with the examination and is usually transparent so that when fitted to an over couch x ray tube the light beam diaphragm device can still be used. The advantage of DAP is that it is the most easily measured parameter for quantification of radiation doses. It can be used for both radiography and fluoroscopy. Additionally, DAP is more directly related to effective dose because it includes the beam area and it can be assessed for examinations with multiple projections. As mentioned earlier, we need to calculate the effective dose (ED) for estimating radiation risks. It is calculated by following equation given below [5].

Effective dose (mSv) = DAP (Gy.cm^2) X Conversion Coefficient (mSv/Gy.cm^2)

ED can be of value for comparing the relative doses from different diagnostic procedures and for comparing the use of similar technologies and procedures in different hospitals and countries as well as the use of different technologies for the same medical examination, provide the reference patient or patient populations are similar with regard to age and sex (ICRP 2007) [6, 7]. Essentially there are two main variables that influence the effective dose to a patient from any X-ray examination. These are the volume of patient (multiplication of the area exposed and depth) and the absorbed dose to the irradiated volume. Factors such as tube potential, filtration and mAs govern the dose itself [8, 9, 10].

In our study, the ED was estimated using DAP which is received by patient during common digital radiographic examination and compare the ED and DAP with international dose reference levels.

Materials and Methods

The study was performed in Department of Radiology and Imaging, University College of Medical Sciences (UCMS) and Guru Tegh Bahadur (GTB) Hospital, New Delhi, India between 01.12.2017 to 24.05.2018. Digital X-ray machine (Definium-8000, GE) and KermaX® DAP meter was used for the study.

Study Design

We collected data from total 350 adult patients undergoing digital radiographic examination for 27 commonly done views. Minimum 10 patients were included for each specific radiographic view done in routine digital radiographic room. Critically ill patients, Patient age less than 14 year, pregnant patient, were excluded from study. This study consist of 32 patients for Chest Postero-anterior (PA), 19 for Chest Antero-posterior (AP), 10 for Abdomen-AP, 10 for Pelvis-AP, 10 for Lumbar spine-AP, 10 for Shoulder, 10 for Elbow-AP, 10 for Elbow-Lateral (Lat), 13 for Forearm-AP, 12 for Forearm-Lat, 10 for Wrist-PA, 10 for Wrist-Lat, 16 for Hand-PA, 16 for Hand-Oblique, 10 for Knee-AP, 10 for Knee-Lat, 20 for Leg-AP, 20 for Leg-Lat, 10 for Ankle-AP, 10 for Ankle-Lat, 15 for Foot-AP, 15 for Foot-Oblique, 10 for C-Spine-AP, 10 for C-Spine-Lat, 10 for L-S Spine-AP, 10 for L-S Spine-lat, 10 for D-Spine-AP, 10 for D-spine-Lat.

Data regarding patient height, weight recorded after the radiography has been taken. The age group ranged from 14 to 83 years and Weight ranged from 30 to 90 kg. Height ranged from 127 to 182 cm and Body Mass Index (BMI) ranged from 14 to 44 kg/m^2. Exposure and other parameters such as kVp, mA, mAs, (Focus to Film Distance) FFD were also recorded. All radiographic exposures were made at FFD of 100 cm except for Chest-PA view where the FFD was 180 cm. 120 kVp for Chest-PA, 100 kVp for Chest-AP, 80 kVp for Abdomen-AP, Pelvis-AP, D-Spine-AP, L-S Spine-AP. 90 kVp for L-S Spine-Lat, D-Spine-Lat. 70 kVp for Shoulder-AP, Knee-AP, Knee-Lat, Leg-AP, and Leg-Lat. 75 kVp for C-Spine-AP, C-Spine-Lat. 60 kVp for Forearm-AP, Forearm-Lat, Elbow-AP, and Elbow-Lat was used.

Mean ± SD for mAs was taken and it was found to be 7.553 ± 3.650, 1.77 ± 1.16, 4.106 ± 2.504, 8.118 ± 3.398, 10.98 ± 4.513 for Abdomen-AP, Chest-PA, Pelvis-AP, Lumbar-AP and Lumbar-Lat respectively. Measured value of DAP was also recorded from DAP meter display. The mean value with standard deviation for both the patient and exposure parameter was also determined. One sample t-test was used to compare effective dose.

Results

Measured DAP Values for each Radiographic examination as acquired from DAP meter were used to determine mean ± SD, 1st and 3rd quartile values of measured DAP as listed in table-1.

Table 1: Showing distribution of Mean ± SD of 1st and 3rd Quartile DAP (Gy.cm^2) of our study

S No.	Radiographs	Measured Dose Area Product (Gy.cm^2)		
		Mean ± SD	**1st Quartile value of DAP**	**3rd Quartile value of DAP**
1	Chest-PA	0.13 ± 0.09	0.07	0.13
2	Chest-AP	0.15 ± 0.07	0.08	0.21
3	Abdomen-AP	0.43 ± 0.22	0.30	0.50
4	Pelvis-AP	0.47 ± 0.39	0.20	0.56
5	Shoulder-AP	0.20 ± 0.06	0.18	0.22
6	L.S.-AP	0.50 ± 0.30	0.26	0.54
7	L.S.-Lat.	0.88 ± 0.44	0.58	1.15
8	Elbow-AP	0.08 ± 0.029	0.05	0.10
9	Elbow-Lat	0.09 ± 0.02	0.09	0.11
10	Wrist-AP	0.03 ± 0.01	0.02	0.03
11	Wrist-Lat	0.04 ± 0.01	0.03	0.03
12	Hand-PA	0.03 ± 0.01	0.01	0.04
13	Hand-Obl.	0.03 ± 0.02	0.02	0.03
14	Ankle-AP	0.07 ± 0.02	0.05	0.08
15	Ankle-Lat	0.06 ± 0.01	0.05	0.07
16	Knee-AP	0.29 ± 0.24	0.17	0.24
17	Knee-Lat	0.24 ± 0.05	0.21	0.27
18	Foot-AP	0.5 ± 0.01	0.04	0.06
19	Foot-Lat	0.06 ± 0.03	0.04	0.1
20	Forearm-AP	0.09 ± 0.04	0.08	0.12

21	Forearm-Lat	0.13 ± 0.04	0.06	0.09
22	C-Spine-AP	0.1 ± 0.04	0.08	0.11
23	C-Spine-Lat	0.12 ± 0.04	0.13	0.14
24	D.Spine-AP	0.35 ± 0.12	0.29	0.42
25	D-Spine-Lat	0.43 ± 0.19	0.31	0.57
26	Leg-AP	0.23 ± 0.11	0.15	0.32
27	Leg-Lat.	0.20 ± 0.07	0.16	0.26

The estimated effective doses of our study for each radiographic examination as calculated from measured DAP using the equation are represented with bar diagram as shown in figure-1. The mean effective dose of our study for Abdomen-AP, Chest-PA, Pelvis-AP, Lumbar-AP and Lumbar-Lat were 0.07 ± 0.04, 0.02 ± 0.01, 0.066 ± 0.05, 0.11 ± 0.06 and 0.29 ± 0.041 respectively.

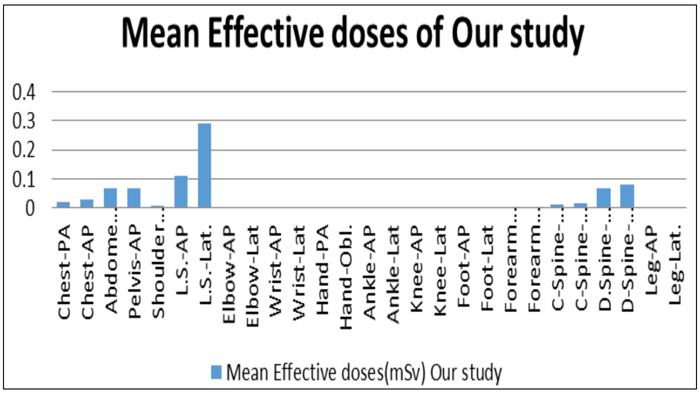

Fig 1: Mean Effective Doses

Results shows that our mean estimated effective doses are significantly different than mean effective doses from 2005 (NPDD) review of Hart *et al*., as the P value for each radiographic examination were significantly different P-value <0.002 (one sample t-test) as represented in table 2.

Table 2: Comparison of estimated mean effective doses of our study with typical effective doses from 2005 (NPDD) review of Hart *et al*. (One sample t-test).

SI No.	Radiographs	Effective doses (mSv)		P-Value	t-value
		Our Study Mean ± SD	Hart *et al*. NPDD(2005) UK		
1	Chest-PA	0.02 ± 0.01	0.014	0.0019	3.3941
3	Abdomen-AP	0.07 ± 0.04	0.43	0.0001	28.46
4	Pelvis-AP	0.066 ± 0.05	0.28	0.0001	13.53
6	L.S.-AP	0.11 ± 0.06	0.39	0.0001	14.75
7	L.S.-Lat.	0.29 ± 0.041	0.21	0.0002	6.1703

Fig 2-6: Shows results of comparing our mean measured DAP values with mean DAP of Menglong Zhang *et al.* study (2012) [14] and Hart *et al*. (2010) [12] review based on digital radiography machine.

Results indicates that our study shows mean DAP of 0.43 Gycm^2 for Abdomen-AP (Figure 2) which is close to mean DAP of 0.462 of Menglong Zhang *et al*. study and significantly lower than published DAP of 2 Gycm^2 of Hart *et al*. (2010) review. Variation of 7% and 78.5% were found between our study and Menglong Zhang *et al*. and Hart *et al*. respectively.

Pelvis-AP (Figure 3) showed mean DAP of 0.47 Gycm^2 in our study which was found to be nearly equal to 0.598 Gycm^2 DAP of Menglong Zhang *et al*. study and significantly lower than 1.8 Gycm^2 DAP as given by Hart *et al*. (2010) review with variation of 21.41% and 73.89% respectively.

Our study showed means DAP of 0.13 for Chest-PA (Figure 4) as compared to 0.112 and 0.09 DAP of Menglong Zhang *et al*. and Hart *et al*. studies respectively. Variation of our mean DAP with Menglong Zhang *et al*. and Hart *et al*. were found to be 16% and 30.77% respectively.

0.5 Gycm^2 value of DAP was noted for Lumbar-AP (Figure 5) in our study in comparison to 0.315 Gycm^2 of Menglong Zhang *et al*. study and 1.3 Gycm^2 of Hart *et al*. study with variation of 47% and 61.54% respectively.

For Lumbar-Lat (Figure 6) our mean DAP value was 0.88 whereas, Menglong Zhang *et al*. and Hart *et al*. published DAP values with % variation were 0.78 (12.8% variation) and 2.1 Gycm^2 (58.1% variation) respectively. Mean mAs of 40 was used in Menglong Zhang *et al*. study as compared to our mAs of 80 and therefore our mean DAP was lower. Thus our mean measured DAP values of radiographic examinations Abdomen-AP, Pelvis-AP, Lumbar-AP and Chest-PA were found to be in good agreement with Menglong Zhang *et al* study. However no separate exposure parameters (Dose Area Product data) based on DR system were available in Hart *et al* study. Thus we could not directly compare our mean DAP with it.

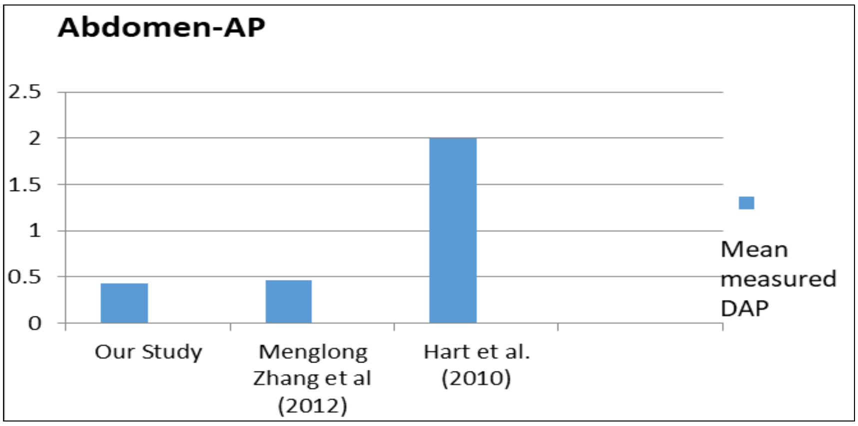

Fig 2: Bar diagram showing mean measured DAP of our study compared with Hart *et al*. (2010) and Menglong *et al*. (2012) studies.

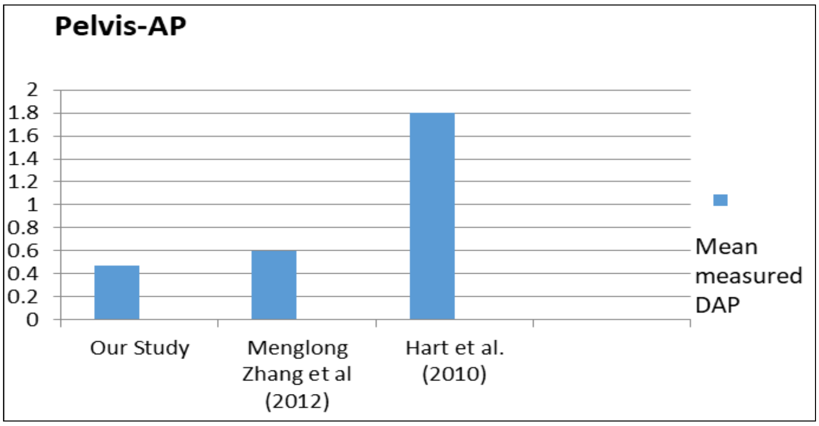

Fig 3: Bar diagram showing mean measured DAP of our study compared with Hart *et al*. (2010) and Menglong *et al*. (2012) studies.

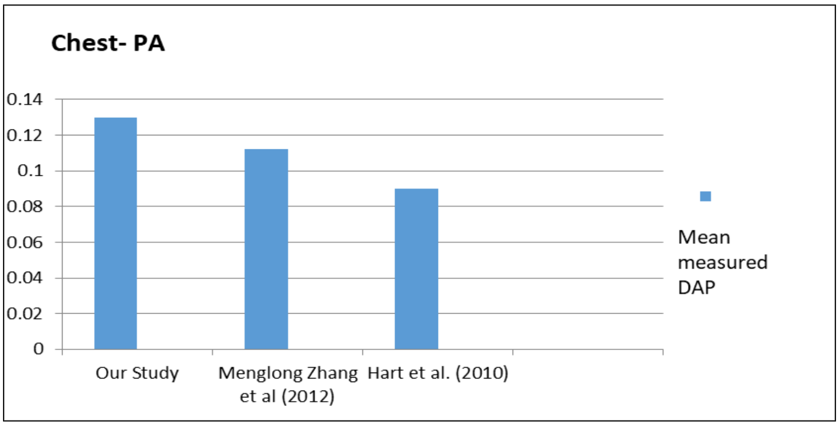

Fig 4: Bar diagram showing mean measured DAP of our study compared with Hart *et al*. (2010) and Menglong *et al*. (2012) studies.

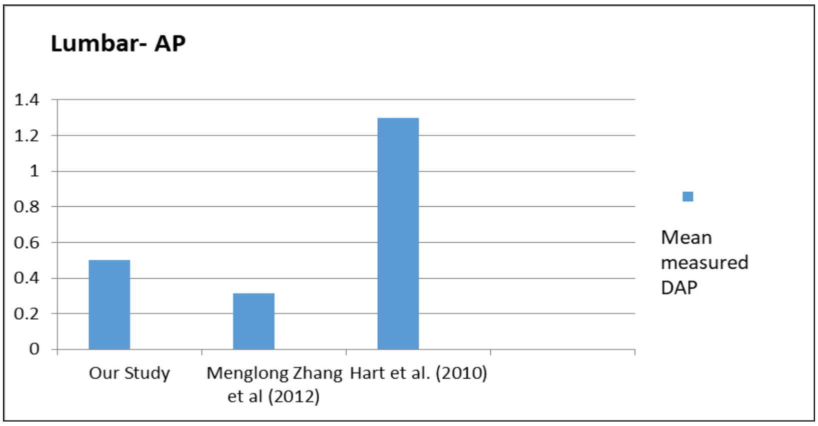

Fig 5: Bar diagram showing mean measured DAP of our study compared with Hart *et al*. (2010) and Menglong *et al*. (2012) studies.

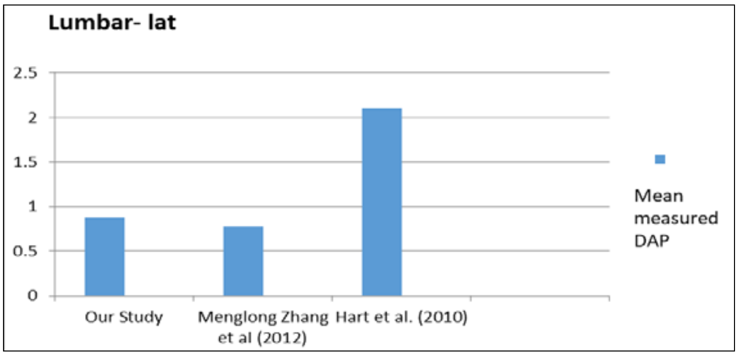

Fig 6: Bar diagram showing mean measured DAP of our study compared with Hart *et al*. (2010) and Menglong *et al*. (2012) studies.

Discussion

On comparing effective doses of our study with Hart *et al*. (2005) [11, 12] review and John E Aldrich *et al*. study (2006) [13] reference levels (as represented in Figure 7) results indicates that our mean effective dose for Abdomen-AP was significantly lower (0.078 mSv) than 0.43 and 0.24 mSv as given in previously published studies by Hart *et al*. and John E Aldrich *et al*. respectively. However no separate effective doses were shown in Hart *et al*. study thus we could not compare our study directly with it. Variation of our study effective dose with Hart *et al*. and John E. Aldrich *et al*. studies were found to be 81.87% and 67.5% respectively. Our effective doses were significantly lower than John E. Aldrich *et al*. study as they used mAs of 10.77 ± 2.31 as compared to our mAs of 7.553 ± 3.650, because of difference of height and weight of same age group.

Our mean effective dose 0.02 mSv for Chest-PA examination (Figure 8) was noted to be in good agreement with 0.023 mSv of John E Aldrich *et al*. study with 13% variation. The reference level for Chest given by Hart *et al*. is 0.014 and means that our doses are comparatively higher with variation of 30%. In our study 120 kVp was used. However they used 135 kVp.

Figure-9 represents the difference between mean effective doses of Pelvis x-ray examination with published reference levels. Results indicate that in our study it is 0.06 mSv, much lower in comparison to 0.28 mSv for Hart *et al* and 0.26 for John E.Aldrich *et al* with variation of 78.6% and 76.93% respectively. Our effective dose for Pelvis-AP was significantly lower than John E. Aldrich *et al* as they used mAs of 10.17 ± 4.49 as compared to our mAs of 4.106 ± 2.504. Reference levels given by Hart *et al* in 2005 review of NPDD,UK are based on average of DAP and ESD measurements including film Screen, Computed Radiography and flat panel detectors while effective doses of our study were on flat panel detectors (DR).

Our study shows mean effective dose of 0.11 mSv for Lumbar –AP view (Figure-10) which is lower in comparison to 0.39 mSv as given by Hart *et al*. and variation of 71.8% was noted. Our Lumbar –Lat showed 0.29 mSv mean Effective dose which is comparable to 0.21 mSv given by Hart *et al*. (Figure-11) Variation of 27.59% was noted.

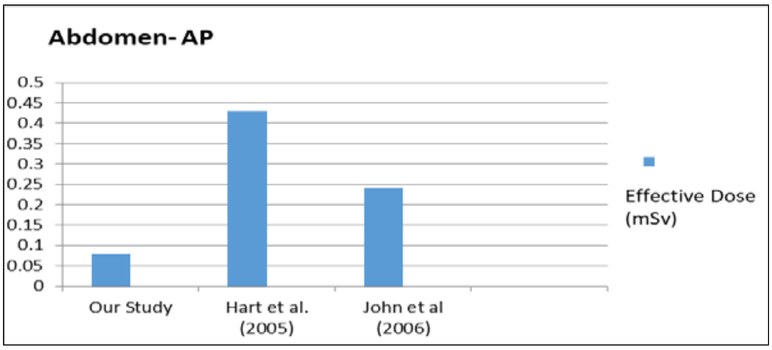

Fig 7: Bar diagram showing comparison of effective doses of our study with Hart *et al* (2005) review and John E. Aldrich *et al* (2006) studies.

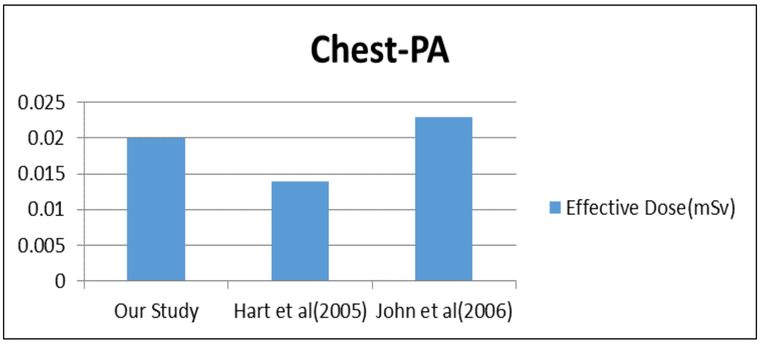

Fig 8: Bar diagram showing comparison of effective doses of our study with Hart *et al* (2005) review and John E. Aldrich *et al* (2006) studies.

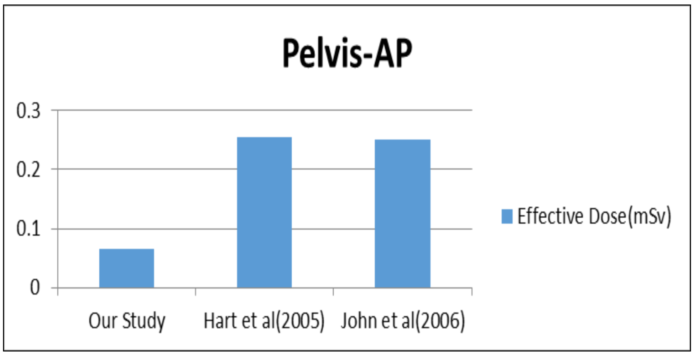

Fig 9: Bar diagram showing comparison of effective doses of our study with Hart *et al* (2005) review and John E. Aldrich *et al* (2006) studies.

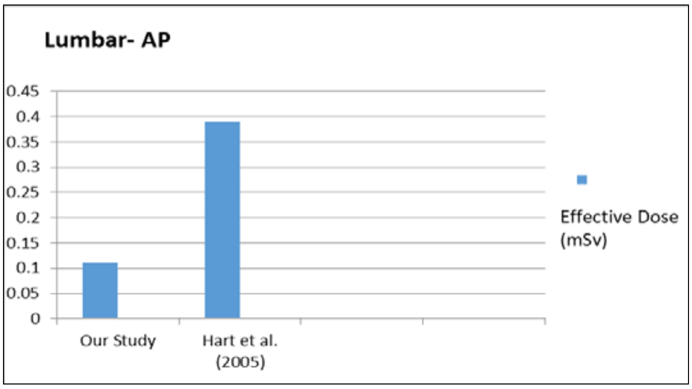

Fig 10: Bar diagram showing comparison of effective doses of our study with Hart *et al* (2005) review and John E. Aldrich *et al* (2006) studies.

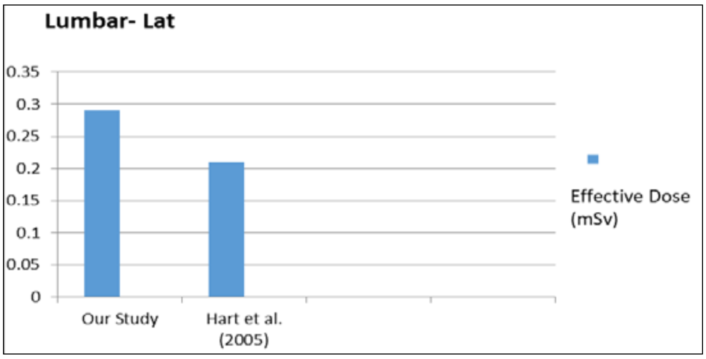

Fig 11: Bar diagram showing comparison of effective doses of our study with Hart *et al* (2005) review and John E. Aldrich *et al* (2006) studies.

Conclusion

This study of estimating the effective dose using DAP meter for the patients undergoing digital radiographic examinations comprised of 232 male patients and 118 female patients. The age group ranged from 14–83 years and BMI ranged from 14-44 kg/m^2. mAs level was found to be 1.77 ± 1.16, 7.553 ± 3.65, 4.106 ± 2.504, 8.118 ± 3.398, 10.98 ± 4.513 for Chest-PA, Abdomen-AP, Lumbar-AP, Lumbar-Lat and Pelvis-AP respectively. Measured DAP values (Gycm^2), mean ± SD were found to be 0.43 ± 0.22, 0.13 ± 0.09, 0.47 ± 0.39, 0.50 ± 0.30, 0.88 ± 0.44 for Abdomen-AP, Chest-PA, Pelvis-AP, Lumbar-AP and Lumbar-Lat respectively. The estimated effective doses for each radiographic examination has calculated from measured DAP were found to be 0.07 ± 0.04, 0.02 ± 0.01, 0.066 ± 0.05, 0.11 ± 0.06, 0.29 ± 0.041 for Abdomen- AP, Chest-PA, Pelvis-AP, Lumbar-AP and Lumbar-Lat respectively.

Our 3rd quartile values of measured DAP when compared with Hart *et al* study (2005 & 2010) reviews of NPDD,UK found out to be lower for Abdomen-AP, Pelvis-AP and Lumbar-AP due to reason that our study represents DAP values acquired with digital radiography while Hart *et al* study were carried including film-screen, CR and flat panel detector. However the data for flat panel detector (DR) is not specific in the study. Chest-PA and Lumbar-Lat showed higher value of 3rd quartile DAP as compared to Hart *et al* study and can be explained by the kVp used in our study for chest-PA was 120 while that of Hart *et al* studies was in the range of 60-135. mAs used in our study for Lumbar lat was 10.98 as compared to mean mAs of 48 of Hart *et al.*

Our estimated mean effective dose when compared with Hart *et al* (2005) was found to be significantly different. Our effective dose for Abdomen and Pelvis-AP came out to be lower than Hart *et al* (2005) and John E. Aldrich eta l (2006) provided reference levels. Our mean effective dose 0.11 mSv for Lumbar spine-AP was lower in comparison to Hart *et al*. Our mean effective dose for Chest-PA and Lumbar-Lat were noted to be .02 mSv and .29 mSv respectively. Our effective doses were significantly lower than John E, Aldrich study as than used higher mAs as compared to mAs used in this study due to difference of Height and weight of same age group in these two studies.

Reference level given by Hart *et al* in 2005 review were based on combination of FS,CR and FPD while effective dose of our study is on FPD. The significant difference was found between effective dose of two studies. Dose Reference Levels are essential for establishing guidance level. This study is important as it provides DRLs in common radiographic examinations primarily in Chest-PA, Abdomen-AP, Lumbar-AP, Lumbar-Lat and Pelvis-AP using DAP meter in an Indian scenario. Therefore, our study provides Dose Reference Level in an Indian Scenario precisely.

Declarations

Funding: No funding was received for this study.

Conflict of Interest (COI): The authors declare that there is no conflict of interest regarding the publication of this paper.

Ethical Approval: The study was conducted in accordance with institutional ethical standards. Consent was obtained from all individual participants included in the study.

Author Contributions:

Acknowledgments

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Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request

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