Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/23915
DOI URL: http://dx.doi.org/10.21474/IJAR01/23915

ISSN (O): 2320-5407
ISSN (P): 3107-4928

RESEARCH ARTICLE

QUANTITATIVE ESTIMATION OF EFFECTIVE DOSE USING DOSE LENGTH PRODUCT IN CT HEAD AT UNIVERSITY HOSPITAL

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Manuscript Info

Manuscript History
Received: 18 May 2026
Final Accepted: 20 June 2026
Published: July 2026

Key words: -
Computed Tomography, Dose Length Product, Effective dose, Radiation, Exposure

Abstract

Background: Effective dose is the whole-body equivalent dose of partial- body radiation exposure received during a radiological examina tion involving ionizing radiation. This study aimed to estimate the effective dose of radiation exposure in CT head scans, thus establishing a more comprehensive understanding of the potential health risks associated with CT head scans and providing a guideline to minimize those radiation-induced risks during a Head CT.
Objectives: To estimate the effective dose in CT head scans among the patients attending CT head scans at the Department of Radiology, Dhulikhel Hospital, a University hospital
Methods: A retrospective, quantitative, and cross-sectional study was conducted to study the effective dose in CT Head among 150 patients, aged between 18 and 80 years, who requested CT head examination at the Department of Radiology, Dhulikhel Hospital (Kavre, Nepal), using a 128-slice Siemens SOMATOM Perspective CT.Patient data regarding clinical history, investigation types, socio-demographic variables, and lifestyle factors were collected by developing questionnaire. Also, data related to radiation exposure parameters (kVp, mAs, CTDIvol, and Dose Length Product) were recorded for each patient and displayed on the CT scanner console. The effective dose was calculated using DLP and the conversion factor (k) for CT head. The estimated results were graphically analyzed using multivariable linear regression analysis and correlated with different study variables for each CT Head examination
Results: Out of the total 150 respondents, the estimated mean DLP for the CT head was 1083.497±115.76 mGy-cm, and the mean mAs and CTDIvol were 209.22±19.50 mAs and 48.34±4.18 mGy, respectively. The result showed a mean effective dose of 2.27±0.24 mSv.

Conclusion: The calculated effective dose for CT head was slightly higher in this study as compared to ICRP standards and previous studies. This study helps to suggest that further optimization may be achievable, and our data's specificity may enable researchers to provide more helpful recommendations than in the past. The survey's findings may spur additional research on radiation exposure in other healthcare settings and aid in the establishment of national diagnostic reference standards.

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Introduction: -

Computed Tomography (CT) scan has been widely used in medical imaging for diagnostic purposes.[1]Continuing advances in CT technology, such as the development of fast, helical scanning using multi-detector rows (MDCT),also known as multi-slice CT (MSCT), have promoted the increasing clinical application of CT and undoubted improvements in health care for populations.[2]Contemporary CT scanners facilitate the rapid imaging of large volumes of the patient and therefore promoting the development of new and complex diagnostic interventional procedures, with clear potential for further increases in the doses to individuals and populations.[3]The dose distribution inside the patient in CT is completely different from that for a conventional radiography. In conventional projection radiography, the dose decreases continuously from the entrance of the X-ray beam to its exit. In the case of modern CT, due to its rotational geometry, the dose is almost equally distributed in the scanning plane.[4]With an increasing radiation dose to the patients who undergo head computed tomography (CT) are significantly at higher risk of developing cataracts, and this risk may increase gradually with repeated CT Head examinations.[5]

Since the eyes and thyroid glands are close to the area of interest during a CT head procedure, radiation exposure to these radiosensitive organs becomes a major concern. Various dose descriptors such as MSAD, CTDI, $CTDI_{FDA}$, $CTDI_{100,}$ $CTDI_w$, $CTDI_{vol}$, DLP, and effective dose were used in CT for the assessment of potential radiation exposure to patients.[6] Effective dose can be considered an important descriptor of radiation exposure of the patient. The next stage in this area of patient dose assessment is to address or estimate the risk of a CT examination, and it requires the use of effective dose. Effective dose was originally developed by the International Commission on Radiological Protection (ICRP) as a risk-adjusted dosimetry quantity for the management of protection against stochastic effects, principally cancer, enabling comparison of planned or received doses with dose limits, dose constraints, and reference levels expressed in the same quantity.[7]Effective dose is used in radiation protection to relate risk exposure, and it takes into account that different tissues have different radio-sensitivities and the absorbed dose to specific organs. Effective dose can be conveniently estimated by multiplying the conversion factors by the DLP values readily available from CT scanners.[8] Effective dose (E) = k x DLP, where the "k" coefficient is specific only to the anatomic region scanned; and the conversion factor for head =0.002.

Methods: -

Study design and Population: -

A quantitative, non-interventional, descriptive, cross-sectional study was conducted among patients who were referred for CT head scans visiting at of Radiology, Dhulikhel Hospital. Data were collected and analyzed to objectively measure and quantify the amount of radiation exposure delivered during CT head scans. Majority of the participants were found form Kavre district that underwent CT Head scan from September to December-2023 referred from various departments (e.g. Emergency, Neurosurgery, Medicine, Surgery, Orthopedic, ENT and Ophthalmology) and the emergency department of the Dhulikhel Hospital, who underwent CT head scans. All age groups, irrespective of age, sex, and ethnicity, who underwent the CT head scan procedure were included. Patient's age ranging between 18 -80 years who provided consent for this study were included in this study. Also, patients with metallic jewelry and ornaments in the head, traumatic patients, as well as severe hemodynamic instability, and patients who required immediate medical intervention in case of patients from the emergency department were excluded. Also, patients who had undergone multiple CT scans over time and those who refused to participate in this study were also excluded from the study.

Sample Size: -

Sample size was estimated using the prevalence of effective dose from CT scanning using dose length product in a Nepalese hospital.[9]The prevalence of effective dose from CT scanning using Dose Length Product (3%) was used in this study based on previous literature.

With this, the initial sample size was estimated using the formula: -

$$n = \frac{vZ^2\alpha_{/2}S^2}{d^2}$$

The sample size was calculated to be 84. Then, considering and including the margin of error, we planned to collect data from all male and female patients undergoing CT head in the radiology department of DhulikhelHospital during 4 months (September to December 2023), i.e., 140 patients.

Data Collection: -

Data were collected from patients who underwent CT head scans at the Department of Radiology, Dhulikhel Hospital. CT Head scan was performed using 128 multi-slice SEIMEINS SOMATOM-perspective CT system, and the scan was obtained in the helical axial plane from the level just above the occipital squamae to the level of the vertex. After the completion of the scan, CT dose indicators were displayed at the operating console. Scanning parameters (kVp and mAs) as well as CT dose descriptors (CTDIvolume, andDose Length Product) were recorded, and DLP was multiplied by the conversion factor (k), where the conversion factor for head =0.002.[8]

Statistical Analysis: -

The collected data were tabulated using MS Excel 2007, and STATA version 15(STATA Corporation, College Station, Texas 77845, USA. STATA 15) was used for statistical analysis. Descriptive statistical analysis was done by calculating frequencies and percentages for categorical variables, while means and standard deviations were calculated for continuous variables. All the dependent variables like the socio demographic, life-style related and CT related factor were correlated using multivariable simple linear regression with the calculated effective dose.In the multivariable simple linear regression models, socio-demographic characteristics (age, gender, body mass index, height, weight, marital status, occupation, religion and ethnicity, residency, Smoking, alcohol consumption) and CT-related factors (peak-kilovoltage, milliampere-second, computed tomography dose index and dose length product) were adjusted to identify the association with effective dose. Descriptive statistical analysis was performed by estimating frequency, percentage, mean, and SD with graphical and tabular presentations. For inferential statistics, a t-test was applied to find significant differences between dependent and independent variables at 95% CI (confidence interval), where p<=0.05.

Results: -

Socio-demographic characteristics: -

Participants meeting the inclusion criteria were included in this study. Among them, 57.1% of respondents were found to be male and 42.9% were female. Also, 77.1% were found to be married, and the remaining 22.9% were unmarried. The mean age distribution of the respondents was found to be 45.6 years (±17.76). The respondents' minimum age was 18 years, and the maximum age was 80 years, while the median age of the respondents was found to be 45 years. Similarly, the minimum height obtained was 4.11 feet, and the maximum was about 6 feet, with a median height of 5.3 feet (±0.34). Similarly, the mean body mass index was found to be 23.30, with a median of 23.3(± 3.17). Of the study respondents, the majority 33.6%) were employed. At all, 25.7% were smokers, and also around 35.0% consumed harmful amounts of alcohol.

CT-related Factors: -

Throughout the study, the mean milliampere-seconds was 209.2 (±19.50), in which a minimum of 130mAs and a maximum of 251 mAswere obtained. Also, the mean CTDIvol was found to be 48.34 mGy (±4.18), and the mean DLP was 1083.497mGy-cm (±115.76).Similarly, on the basis of the Karl-Pearson correlation coefficient, the correlation value of mAs, CTDIvol, and DLP was found to be 0.74,0.79 and 0.99, respectively, which shows they are found to be highly correlated with effective dose.

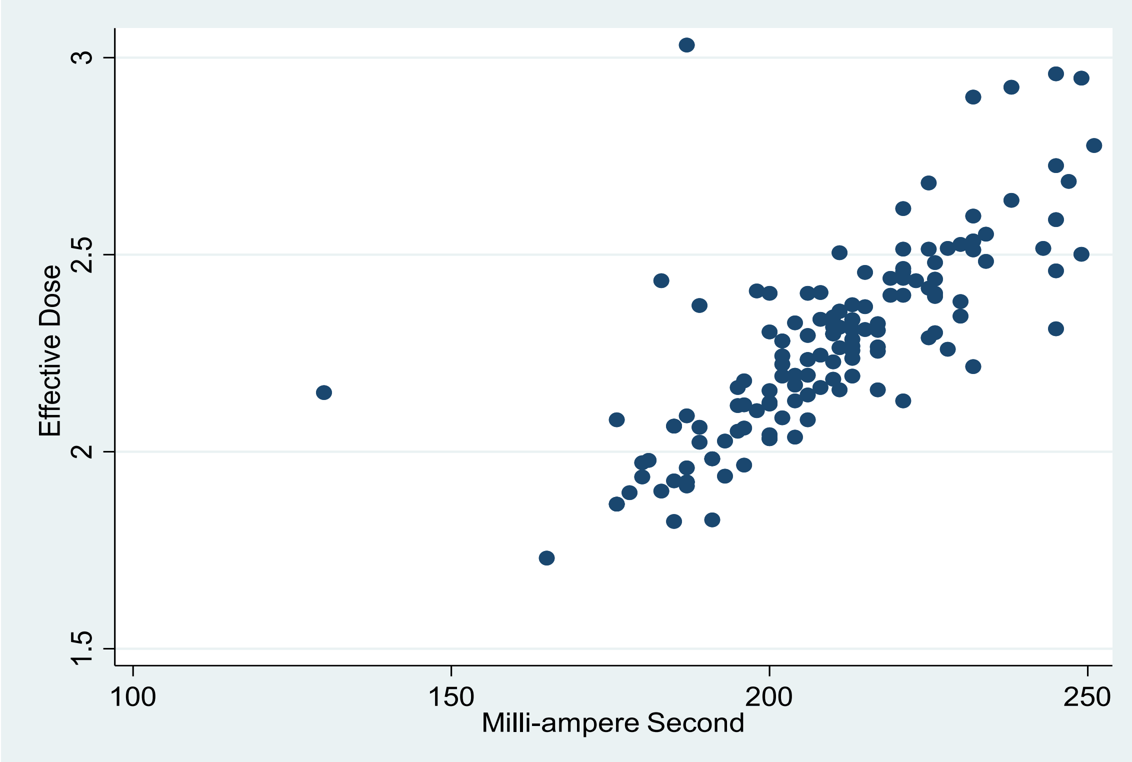

Fig 1: Correlation of mAs with effective dose

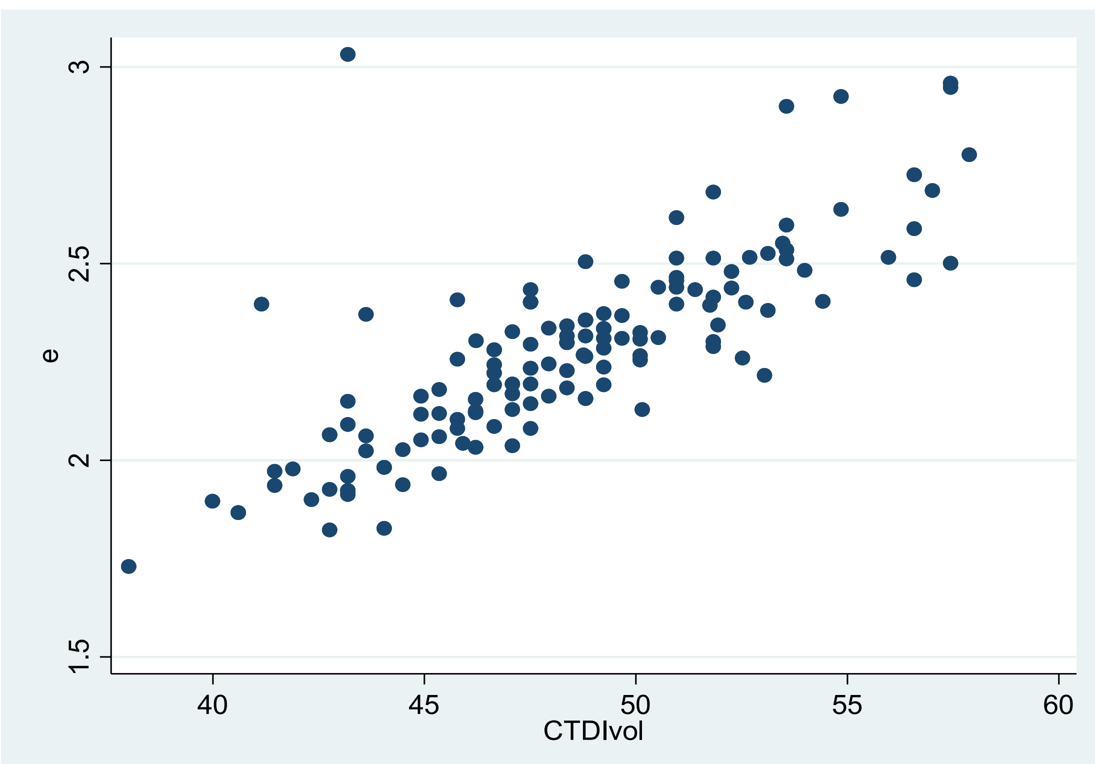

Fig 2: Correlation of CTDIvol with effective dose

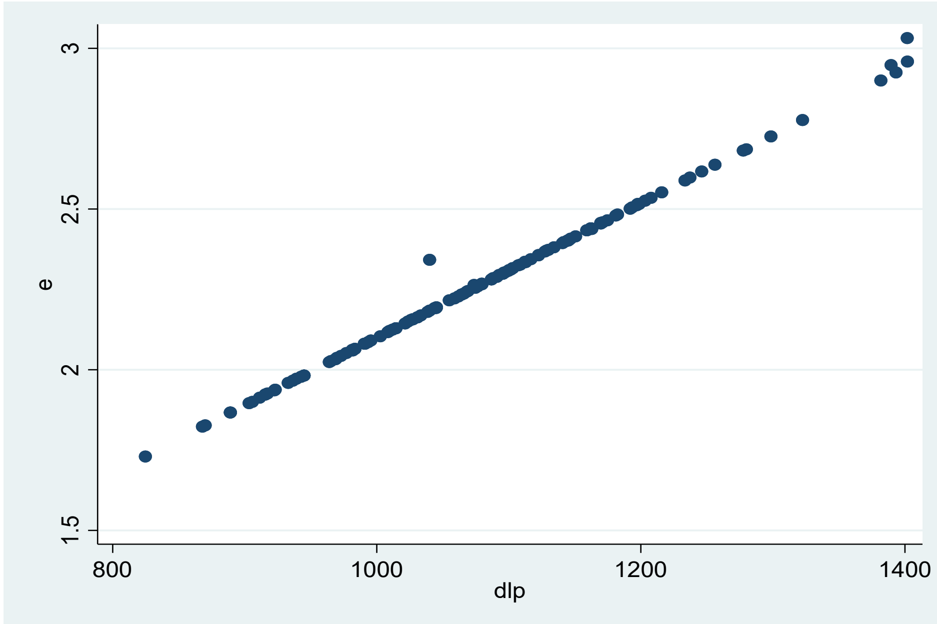

Figure 3: Correlation of DLP with effective dose

Table 1: Baseline characteristics presented with numbers and percentages (n = 140)

Characteristics	**Number**	**Percentage (%)**
Age of Participants (in years)		
Under 20	9	6.43
20-39	46	32.86
40-59	51	36.43
Above 60	34	24.29
Mean (±SD)	45.55, ±17.76	
Median (min: max)	45 (18:80)	
Gender		
Female	60	42.86
Male	80	57.14
Body Mass Index of Participants(kg/m^2)		
Below 18.5	3	2.14
18.5-24.9	96	68.57
25-31.4	41	29.29
Mean (±SD)	23.30 ± 3.17	
Median (min: max)	23.25 (17.2:30.6)	
Height of Participants (Ft)		
<5 feet	11	7.86
5-5.4 feet	72	51.43
>5.5	57	40.71
Mean (±SD)	5.31 ±0.34	
Median (min: max)	5.3 (4.11:6)	
Marital status of participants		
Unmarried	32	22.86
Married	108	77.14
Occupation of participants		
Housewife	27	19.29

Un-employed	35	25.00
Students	31	22.14
Employed	47	33.57
Place of residence of participants		
Kavre	140	100
Smoking status of participants		
No	104	74.29
Yes	36	25.71
Alcohol Consumption of Participants		
No	91	65.00
Yes	49	35.00
Peak Kilo-Voltage(kVp)		
130	140	100
Milli-Amperesecond(mAs)		
<176	2	1.43
176-199	36	25.71
200-223	69	49.29
>224	33	23.57
Mean (±SD)	209.22, ±19.50	
Median (min: max)	210 (130:251)	
Computed Tomography DoseIndexvolume (CTDIvol)(mGy)		
<44	23	16.43
44-47	46	32.86
48-51	45	32.14
>52	26	18.57
Mean (±SD)	48.34, ±4.18	
Median (min: max)	48.37 (38.01:57.88)	
Dose Length Product(dlp)(mGy-cm)		
800-949	19	13.57
950-1100	63	45.00
>1101	58	41.43
Mean (±SD)	1083.497, ±115.76	
Median (min: max)	1083.265, (824.77:1401.89)	

The mean effective dose found was 2.27 mSv (95% CI: 2.23 to 2.31). The study revealed that the effective dose ranged from 1.73mSv to 3.032mSv, with a median of 2.28 mSv.

Table 2. Baseline characteristics of effective dose

Effective dose(mSv)	Mean (±SD)	Median (min: max)	95% CI
	2.27±0.24	2.28 (1.73:3.032)	2.23 - 2.31

Multivariable linear regression analysis was used to determine the association between socio-demographic and CT-related factors and effective dose.The obtained mean difference for males in the adjusted model was 0.15 (95% CI: 0.07-0.23, P-value<0.001), and the mean was 2.34 with a standard deviation of ±0.23.In the same way, respondents who were taller than 5 feet had a mean height of 2.32 and mean difference of 0.17(95% CI: 0.08-0.39, P-value = 0.009)with a standard deviation ± 0.24, which was higher than respondents who were taller than 5-5.4 feet, whose mean height was 2.26 and mean difference of 0.23 (95% CI: 0.02-0.33, P-value = 0.009) with a standard deviation ± 0.24. Similarly, smokers' mean was 2.32 and ±0.20, respectively, with a 95% confidence interval (CI) of -0.02-0.15

and a p-value of 0.167.The mean mAs above 224 was also higher than the mean mAs between 200-223 and 176-199, which had mean 2.27 with mean difference of 0.33 (95% CI: 0.08-0.58, P-value=0.001) and 2.05 with mean difference of 0.11(95% CI: -0.13-0.36, P-value=0.001), respectively. Additionally, the mean CTDIvol above 52 was 2.57mGy with mean difference 0.53 (95% CI: 0.43-0.63, P-value=0.001), which was higher than the mean CTDIvol between 48-51mGy and 44-47 mGy, which had mean difference of 0.30 and 0.12, respectively, with 95% CI 0.22-0.39 and 0.03-0.20 respectively. Comparably, the mean DLP above 1101mGy-cm was 2.50, with mean difference of 0.58(95% CI: 0.52-0.65, P-value=0.001) was greater than the mean DLP between 950-1100 mGy-cm with mean difference of 0.27(0.09, 95% CI: 0.20-0.33, P-value=0.001).The overallmean difference in effective dose between each category of factors based on simple linear regression was illustrated in Table 3.

Table 3 Mean difference of effective dose between each category of factors based on simple linear regression (n=140)

Characteristics	number	Mean (SD)	Mean difference (Coef.)	95% CI	P-value
Age of Participants					
Under 20	9	2.20(±0.28)	Ref	Ref	
20-39	46	2.28(±0.21)	0.08	-0.96 - 0.25	0.684
40-59	51	2.29(±0.26)	0.09	-0.85 - 0.26	
Above 60	34	2.25(±0.24)	0.04	-0.13 - 0.22	
Gender					
Female	60	2.19(±0.23)	Ref	Ref	0.000
Male	80	2.34(±0.23)	0.15	0.07 - 0.23	
Body Mass Index of participants (Kg/m^2)					
Below 18.5	3	2.19(±0.28)	Ref	Ref	0.755
18.5-24.9	96	2.27(±0.23)	0.06	-0.18 - 0.31	
25-31.4	41	2.29(±0.26)	0.08	-0.16 - 0.34	
Height of participants (Ft)					
Below 5					
5-5.4	11	2.08(±0.19)	Ref	Ref	0.009
Above 5.5	72	2.26(±0.24)	0.17	0.02 - 0.33	
	57	2.32(±0.24)	0.23	0.08 - 0.39	
Marital Status of Participants					
Unmarried	32	2.27 (±0.23)	Ref	Ref	0.879
Married	108	2.27 (±0.24)	0.00	-0.09- 0.10	
Occupation of Participants					
Housewife					
Un-employed	27	2.23 (±0.27)	Ref	Ref	0.525
Students	35	2.26 (±0.23)	0.03	-0.09 - 0.15	
Employed	31	2.27 (±0.20)	0.03	-0.08 - 0.16	
	47	2.31 (±0.26)	0.08	-0.03 - 0.20	
Place of Residence of Participants					
Kavre	140	2.27 (±0.24)	2.27	2.23 - 2.31	
Smoking Status of Participants					
No	140	2.25 (±0.25)	Ref	Ref	0.167
Yes	36	2.32 (±0.20)	0.06	-0.02 - 0.15	
Alcohol consumption of Participants					
No	91	2.26 (±0.26)	Ref	Ref	0.354
Yes	49	2.30 (±0.21)	0.04	-0.04 - 0.12	

Milli-Ampere Second(mAs)					
<176					
176-199	2	1.94 (±0.29)	Ref	Ref	0.000
200-223	36	2.05 (±0.22)	0.11	-0.13 - 0.36	
>224	69	2.27 (±0.12)	0.33	0.08 - 0.58	
	33	2.53 (±0.19)	0.59	0.34 - 0.85	
Computed Tomography Dose Index volume (CTDIvol)(mGy)					
<44					
44-47	23	2.03 (±0.26)	Ref	Ref	0.000
48-51	46	2.16 (±0.13)	0.12	0.03 - 0.20	
>52	45	2.34 (±0.11)	0.30	0.22 - 0.39	
	26	2.57 (±0.19)	0.53	0.43 - 0.63	
Dose Length Product(dlp)(mGy-cm)					
800-949	19	1.91 (±0.06)	Ref	Ref	0.000
950-1100	63	2.18 (±0.09)	0.27	0.20 - 0.33	
>1101	58	2.50 (±0.17)	0.58	0.52 - 0.65	

In this study, DLP had a substantial correlation (P<0.001) with the outcome. The crude mean difference of 0.58 was 1.23 times higher than the adjusted mean difference of 0.47 (95% CI: 0.38-0.56) for DLP above 1101 mGy-cm. Similarly, the adjusted mean difference in DLP between 950-1100 mGy-cm was 1.12 times smaller than the crude difference of 0.27, at 0.22 (95% CI: 0.15-0.33).DLP has a significant impact on the effective dose based on the findings of the multiple linear regression models. Hence, in order to estimate the effective dose, the dose-length product needs to be appropriately addressed. The entire mean difference in effective dose between each category of factors based on multiple linear regression is illustrated in Table 4.

Table 4 Mean difference in effective dose of each category of factors based on multiple linear regression (n=140)

Characteristics	number	Mean (SD)	Mean difference (Coef.) (crude)	Mean difference (Coef.) (adjusted)	95%CI	P-value
Dose length Product(dlp)(mGy-cm)	19	1.91(±0.06)	Ref	Ref	Ref	0.000
800-949	63	2.18(±0.09)	0.27	0.22	0.14 - 0.30	
950-1100	58	2.50(±0.17)	0.58	0.47	0.38 - 0.56	
Above 1101						

Discussion: -

The study showed a strong correlation between DLP and effective dose, which reinforces the utility of DLP as a practical surrogate for estimating radiation risk in CT head imaging. The identified variations in effective dose among different scanners emphasize the need for standardized protocols and continuous quality assurance measures. The release of systematic estimates of organ and effective doses for various popular adult CT procedures in 1991, which resulted from a national survey done in the UK, brought attention to the comparatively high patient doses associated with CT.[9] New and complex diagnostic and interventional procedures are being developed as a result of the ability of modern CT scanners to promptly image large patient volumes in a single rotation. This has the potential to further increase radiation doses to both individuals and populations.[10] Simultaneously, with the potential of dose reduction, more attention should be paid to maximizing radiation safety through developments in CT practice and technology.[11]

In the present study, the computed effective dose was found to be 2.27±0.24mSv, while Z Brady et al.'s similar investigation demonstrated that the effective dose for the head was 1.0-1.6 mSv.[12]The increase in dosage may have resulted from the increased milliampere-second (mAs) employed during the CT Head examination in our study. Similarly, Kharuzhyk et al. estimated the effective dose for the head to be 1.4±0.4 mSv. 12 Moreover, a larger scan that avoided the topogram's field of view, or exceeding the limited scan coverage, may have contributed to the increase in radiation dosage in our investigation. In addition to the various investigations, the study conducted by A. J. Van der Molen et al. demonstrated that the effective dose was higher than what we found. The study did find a noteworthy variation in the effective dose for the head, which was 2.8 mSv.[13] These readings exceeded the 2.7mSv computed values in the study.

The larger scan area or higher irradiation volume may have had a significant role in the higher dose values observed, although the median CTDIvol values—which are used to calculate the DLP and, ultimately, the patient dose—appear to be lower than in the study by ErayAtl et al.[11]In addition, Nepalese individuals have smaller body habitus than people in European countries. Reducing the scan length as much as possible, without missing any vital anatomical regions essential for diagnosis, could be a first step for lowering DLP and subsequently the effective doses. In order to minimize the radiation exposure to the patient during CT examinations, it is crucial to reduce the milliampere-second (mAs) employed in the examination protocol in proportion to the patient's size.[14]

Furthermore, in clinical practice and in referral recommendations, the effective dose acquired for an adult patient may be utilized to estimate the population exposure dose, which would aid physicians in understanding the variances that occur throughout various examination approaches.[15]When planning and optimizing radiological protection, effective doses serve as a reference for the prospective dose assessment. They are also utilized to demonstrate regulatory compliance with dose restrictions. Therefore, for regulatory purposes, the effective dose is a central dose quantity for regulatory purposes.

Conclusion: -

This study provides valuable insights into the calculation of effective dose using DLP in CT head imaging. The findings of the study support the use of DLP as a reliable parameter for estimating radiation risk, while also highlighting the importance of optimizing imaging protocols to ensure patient safety. The study revealed a higher dose level for head CT examinations. This greater dose could've resulted from not applying the two dose modulation techniques, i.e., ATCM and ATVS. The higher milliampere-second (mAs) used during the CT scan in our investigation might have contributed to the dosage increase. Additionally, avoiding scan coverage limitations by increasing the scan could have resulted in a higher radiation exposure in our study. The diversity in CT effective dose suggests that there is still opportunity for optimization, and our data's specifics might render it feasible to provide more helpful suggestions than in the past.

Acknowledgement: -

With particular gratitude for MrRoshan Chaudhary, Dr. Akina Shrestha, and Mr. Vijay Sharma for their valuable support and advice in carrying out this study. I would like to express my sincere gratitude to all staff of the Radiology Department of Dhulikhel Hospital for their kind support and encouragement in this study

Conflicts of Interest: -

The authors have declared that no competing interests exist.

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