

Pediatric effective dose assessment for routine computed tomography examinations in Tehran, Iran

Abstract

Background: The purpose of this study is to evaluate the effective dose (ED) for computed tomography (CT) examination in different age groups and medical exposure in pediatric imaging centers in Tehran, Iran. **Methods:** Imaging data were collected from 532 pediatric patients from four age groups subjected to three prevalent procedures. National Cancer Institute CT (NCICT) software was used to calculate the ED value. **Results:** The mean ED values were 1.60, 4.16, and 10.56 mSv for patients' procedures of head, chest, and abdomen–pelvis, respectively. This study showed a significant difference of ED value among five pediatric medical imaging centers ($P < 0.05$). In head, chest, and abdomen–pelvis exams, a reduction in ED was evident with decreasing patients' age. **Conclusion:** As there were significant differences among ED values in five pediatric medical imaging centers, optimizing this value is necessary to decrease this variation. For head CT in infants and also abdomen–pelvis, further reduction in radiation exposure is required.

Keywords: Computed tomography scan, effective radiation dose, National Cancer Institute CT (NCICT), pediatric

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Introduction

Computed tomography (CT) is an important diagnostic modality which has several unique applications,^[1] and patient radiation dose is considerably higher than other diagnostic modalities. Recently, and with the introduction of multidetector row CT (MDCT), the clinical application of CT imaging has drastically increased.^[1-4] The ability to diagnose different kinds of disease increased by both spatial and temporal resolution of CT^[5] examination.

It should be noted that the more frequent use of CT has increased the total radiation dose increased either. Studies of exposed pediatrics to CT scan radiation have shown that these groups have an increased risk of cancer when compared to their peers who have not been exposed to CT.^[6-8] Risk models based on epidemiologic findings have recommended that pediatric patients undergoing CT have a significantly increased lifetime risk of developing radiation-related cancer compared to adults, and the reason of this subject is related to their greater

radiosensitivity and longer life expectancy.^[8] The risk models have found an even higher risk of radiation-associated cancer in infants in comparison to older children.^[8] Based on as low as reasonably achievable principle, optimizing radiation exposure levels in patients will reduce the potentially harmful effect of ionizing radiation.^[9] Accordingly, the radiation dose must not be greater than what is clinically required.

Effective dose quantity has been recommended for comparing radiation dose values in different populations, protocols and institutions.^[10,11] The effective radiation dose is probably the most widely and important radiation dose metric used for quantifying amount of absorbed dose in medical imaging procedures. The effective dose (ED) value is defined by the International Commission on Radiological Protection publication 103^[11] as a weighted mean of organ radiation doses that has been chosen on the basis of the relative radiosensitivity of each organ. The ED value, therefore, presents the risk of radiation exposure in a population. In CT, the ED value is commonly

Atefeh

Tahmasebzadeh¹,
Asghar Maziyar²,
Reza Reiazi³,
Mojtaba Soltani
Kermanshahi⁴,
Seyyed Hossein
Mousavie Anijdan⁵,
Reza Paydar⁶

¹Research Committee, School of Medicine, Iran University of Medical Sciences, Tehran, Iran, ²Radiation Biology Research Center, Iran University of Medical Sciences, Tehran, Iran, ³Department of Radiation Physics, Division of Radiation Oncology, University of Texas MD Anderson Cancer Center, Houston, TX 77030, USA, ⁴Social Determinants of Health Research Center, School of Medicine, Semnan University of Medical Sciences, Semnan, Iran, ⁵Department of Radiation Technology, Allied Medicine Faculty, Babol University of Medical Sciences, Babol, Iran, ⁶Department of Radiation Science, Faculty of Allied Medicine, Iran University of Medical Sciences, Tehran, Iran

Address for correspondence:

Dr. Reza Paydar,
Radiation Biology Research
Center, Iran University of
Medical Sciences, Tehran,
Iran, Department of Radiation
Science, Faculty of Allied
Medicine, Iran University of
Medical Sciences, Tehran, Iran.
E-mail: paydar.r@iums.ac.ir

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estimated by multiplying a console-reported radiation dose index (radiation dose-length product [DLP]) by a conversion factor (k factor).^[11] Organ radiation dose and effective radiation dose are required to estimate the risk of radiation-induced stochastic effects;^[12] however, they are not readily available in scan records or image metadata.

Previous studies had evaluated diagnostic reference level of CTDI_{vol} and DLP of pediatrics in Tehran province.^[13,14] Two approaches were considered for the calculation of effective radiation dose.^[13] First, by National Cancer Institute CT (NCICT) software or the other dosimetric software such as Impact CT which are based on Monte Carlo simulation.^[13] Second, by using DLP and conversion factor to calculate the effective radiation dose separately for different irradiated part of the body.^[13] Previous studies indicated that the use of DLP method always underestimated the effective radiation dose and it will have underestimation in calculation of radiation cancer risk.^[15] Therefore, we applied NCICT software to calculate the ED value and ultimately the results compared with previous study of DLP methods and Impact CT software. In this study, we evaluate the pediatric effective radiation dose in routine CT procedures for pediatric medical imaging centers in Tehran province. Better estimation of effective radiation doses will be helpful to optimize clinical protocol, developing clinical decision-making models and future epidemiologic studies.

Materials and Methods

Computed tomography scanners and data collection

There were five referrals pediatric medical imaging centers which have been using a CT scanner in Tehran province. All of them have been reviewed for quality assurance and control certification. Patient cohort has been retrospectively collected by searching our institutional database for pediatric patients who have undergone CT examination between January 1, 2019, and March 30, 2019. Patients were stratified into four age groups (<1, 1–5, 5–10, and 10–15-year-old). In order to estimate effective radiation dose, the following parameters were recorded: tube voltage (kVp), tube current (mAs), scan length, CT radiation dose index volume (CTDI_{vol}), radiation DLP, scanner specifications (model and manufacture), patient characteristic (age and sex), type of scan, and presence or absence of automatic exposure control (AEC) [Tables 1 and 2].

Radiation dose estimation

The estimation of effective radiation dose performed by NCICT software (version 2.01)^[13] is shown in Figure 1. To estimate the absorbed dose received by organs, scan parameters such as kVp, mAs, pitch number, and scan length (distance from top of the scan range), volumetric CT dose index (CTDI_{vol}), DLP, CT scanner specifications (model and manufacturer), and demographic information were extracted metadata available in dose report pages, then the absorbed organ doses (mGy) and ED (mSv) were estimated for 532 patients by NCICT software.

Statistical analysis

One-way analyses of variance were used to compare the average of ED values and Tukey's *post hoc* test was used to compare ED values in different hospitals two by two. All analysis has been performed at a significance level of $\alpha = 0.05$. The average of ED values and *P* value were calculated using SPSS version 22.0 (IBM, USA) and Excel version 2013.

Results

Patient cohort includes 583 patients that 532 of them were eligible and patient information was correctly recorded in this survey (median age was 4 years and male patients were 302 [56.7%]). The contrast agent administration has been done for 18.8% of patients (intravenous contrast media, oral contrast media or both). According to statistical analysis, head (41.47%), chest (23.55%), and abdomen–pelvis (23.04%) were among the most common scans in five medical imaging centers followed by paranasal sinus, limb, and inner ears scan (12%). Therefore, head, chest, and abdomen–pelvis scans were evaluated [Figure 2].

There was a great variation in CT scanners among five centers; Table 1 summarizes the differences.

In most of the cases, the effective radiation dose results were lower than effective radiation dose which was calculated by impact CT and higher than values reported by DLP method [Figure 3]. Furthermore, scan parameters such as kVp, mAs, pitch factor, and scan length were different in five medical imaging centers ($P < 0.05$) [Table 3].

Also the average value of ED estimated, and the differences among centers were significant ($P < 0.05$). In head and chest exams, a reduction was evident by decreasing patients' ages, but it has the opposite pattern in the

Table 1: Characteristic of the computed tomography scanners in each center

| Center | CT company | Model | Number of slices | Year of installation | AEC presence |
|--------|------------|-------------------|------------------|----------------------|--------------|
| A | GE | Bright speed | MSCT (16 slice) | 2008 | Yes |
| B | Siemens | Somatom emotion16 | MSCT (16 slice) | 2009 | Yes |
| C | Hitachi | Eclos16 | MSCT (16 slice) | 2016 | Yes |
| D | GE | High speed | SSCT | 2000 | No |
| E | Siemens | Somatom emotion16 | MSCT (16 slice) | 2018 | Yes |

CT – Computed tomography; MSCT – Multislice CT; SSCT – Single-slice CT; AEC – Automatic exposure control

Table 2: Median, maximum and minimum value of scan parameters (kVp, mAs, pitch and scan length)

| | A | | | B | | | C | | | D | | | E | | | P* |
|------------------|--------|--------------|---------|--------|--------------|---------|--------|--------------|---------|--------------|---------|---------|-------------|---------|---------|--------|
| | Median | Minimum | Maximum | Median | Minimum | Maximum | Median | Minimum | Maximum | Median | Minimum | Maximum | Median | Minimum | Maximum | |
| Head | | <i>n</i> =99 | | | <i>n</i> =69 | | | <i>n</i> =19 | | <i>n</i> =56 | | | <i>n</i> =9 | | | |
| kVp | 100 | 100 | 120 | 80 | 80 | 110 | 120 | 100 | 120 | 80 | 80 | 120 | 110 | 110 | 130 | <0.001 |
| mAs | 100 | 100 | 120 | 114 | 40 | 154 | 110 | 82.5 | 125 | 200 | 60 | 250 | 157 | 50 | 186 | <0.001 |
| pitch | 0.56 | 0.56 | 0.56 | 1 | 1 | 1 | 1 | 0.81 | 1 | 1 | 1 | 1 | 1 | 0.6 | 1 | - |
| Scan length (cm) | 16.3 | 12.9 | 21.5 | 13.5 | 3.8 | 23.1 | 14 | 5.7 | 16.5 | 19 | 15 | 26 | 15.7 | 13.5 | 25.6 | <0.001 |
| Chest | | <i>n</i> =84 | | | <i>n</i> =30 | | | <i>n</i> =10 | | <i>n</i> =14 | | | <i>n</i> =5 | | | |
| kVp | 100 | 80 | 120 | 80 | 80 | 110 | 120 | 80 | 120 | 80 | 80 | 120 | 110 | 110 | 110 | <0.001 |
| mAs | 100 | 100 | 140 | 50 | 28 | 113 | 37.5 | 26.3 | 60 | 200 | 13 | 300 | 16 | 6.69 | 60 | <0.001 |
| pitch | 1.38 | 1.38 | 1.38 | 1.5 | 0.9 | 1.5 | 1.13 | 1.13 | 1.13 | 1.5 | 1.15 | 1.5 | 1.5 | 0.6 | 1.5 | - |
| Scan length (cm) | 22.5 | 6.4 | 33.8 | 24 | 15.1 | 36.6 | 18.3 | 9.1 | 23.4 | 23 | 14 | 30 | 16.1 | 10.5 | 19.28 | 0.001 |
| Abdomen-pelvic | | <i>n</i> =66 | | | <i>n</i> =53 | | | <i>n</i> =8 | | <i>n</i> =8 | | | <i>n</i> =2 | | | |
| kVp | 100 | 100 | 120 | 80 | 80 | 110 | 120 | 100 | 120 | 80 | 80 | 120 | 120 | 110 | 130 | <0.001 |
| mAs | 110 | 80 | 130 | 54.5 | 30 | 128 | 52.5 | 33.8 | 67.5 | 200 | 200 | 250 | 17.5 | 9 | 26 | <0.001 |
| pitch | 1.38 | 1.38 | 1.38 | 1.5 | 1.5 | 1.5 | 1.06 | 1.06 | 1.06 | 1.5 | 1.5 | 1.5 | 1.4 | 1.2 | 1.5 | - |
| Scan length (cm) | 30.7 | 2.2 | 55.1 | 36.5 | 6.5 | 61.1 | 36.3 | 12.7 | 47 | 30 | 30 | 41 | 19.7 | 13.1 | 26.4 | <0.001 |

abdomen–pelvic scans, the reason for this opposite pattern is the higher ratio of oral and intravenous contrast media abdomen pelvic scans in older patients [Table 3].

Discussion

Evaluating the ED is the purpose of this study, there are two standard methods for assessing the ED for patients, one is the use of dosimetry software and the other is the use of conversion factors to calculate the effective radiation dose for different irradiated part of the body separately. As previous studies showed that the application of the use of conversion factors always underestimated the effective radiation dose, we use NCICT software to calculate ED values and ultimately we compare the results of DLP methods with the results of dosimetric software such as Impact and NCICT [Figure 3].^[13] As shown in Figure 3, ED values in the DLP method are much lower than the values reported in the software's calculation. One of the reasons is that the ED calculation in software is done using computer simulations and is much closer to the actual ED values.

The effective radiation dose is greater in infants (<1 year) that may be due to the higher radiation sensitivity of this group and this is because the tissue half-value layer (HVL) in CT scanning is approximately 4 cm,^[16] so that even small infants have dimensions of two to three tissue HVLs.

In pediatric patients, due to less attenuation of the primary beam,^[16,17] the primary radiation intensities are higher than adults. In addition, pediatric patients are much smaller in comparison to adults, so attenuation of the resultant scattered photons is reduced. Finally, the mass of adjacent organs absorbs a much lower scattered radiation dose, therefore organ radiation dose increases. Scatter radiation is much more important in pediatric patients than in adults. Scatter radiations have particular importance in head CT examinations, where organs directly irradiated (e.g. brain) are relatively insensitive, whereas out of radiation field organs (e.g. thyroid and lungs) have relatively high radio sensitivity.

This study showed a wide range of CT scanners can result in significant radiation dose variation in different medical imaging centers [Table 3]. Huda and Tipnis reported that the effective radiation dose in neonates increases by 270% compared to adults when CT DIvol remains constant^[16] and also because of the lower radiation dose in conventional head CT scans, it is recommended for infants, but helical head CT scans are preferred if patients cannot control their body movements or multiplane reconstruction is required. All head scans have been done in conventional mode except scans in center A, and it is one of the reasons for the higher effective radiation dose of head scans in this center [Table 3]. Yamazaki *et al.* and Huda and Tipnis also indicated the higher radiation doses of spiral head scans in comparison to conventional scans and also decreasing patterns of effective radiation doses of head scans by age in their studies.^[16,18]

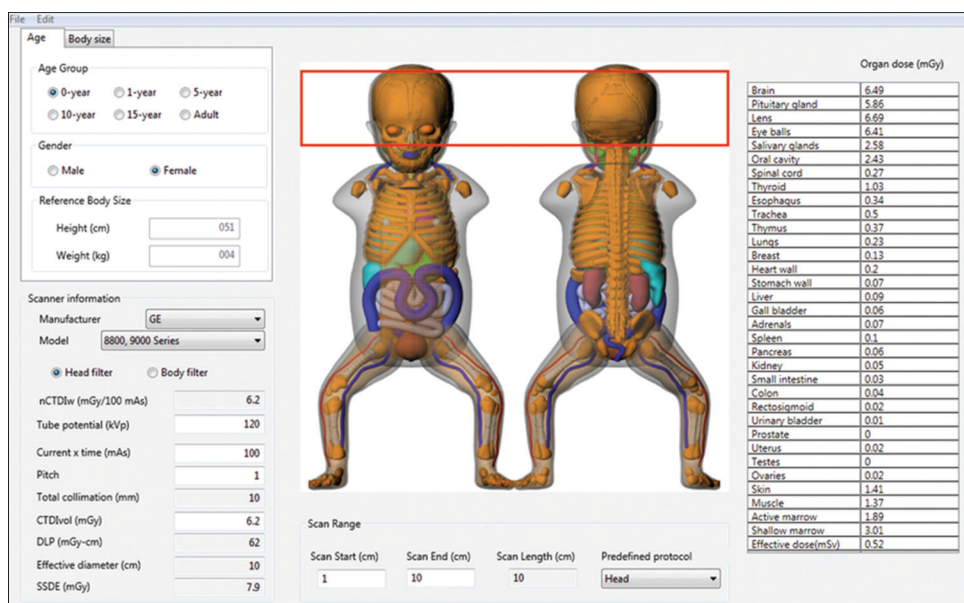


Figure 1: NCICT software work environment. NCICT: National Cancer Institute computed tomography

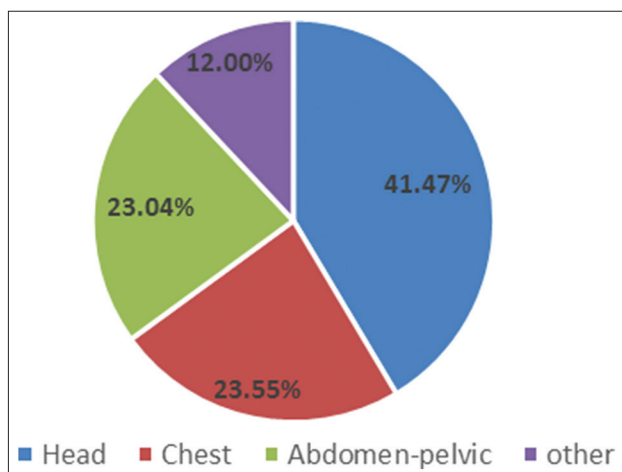


Figure 2: Frequency of CT examination in pediatric medical imaging centers of Tehran. CT: Computed tomography

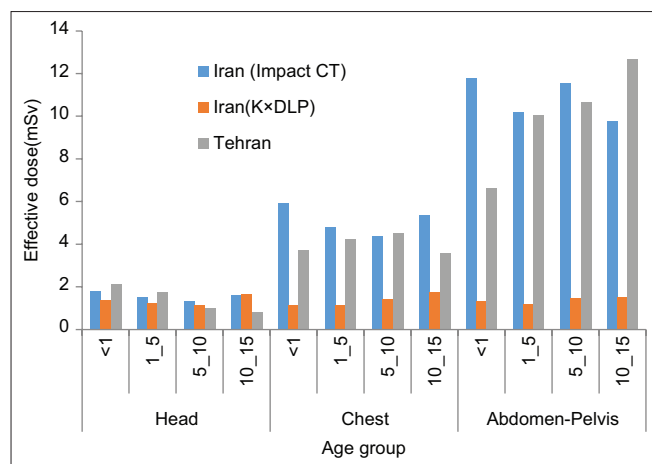


Figure 3: Comparison of ED (mSv) with data reported in Iran. ED: Effective dose

Another issue is the use of the AEC options such as tube control modulation (TCM) in pediatric CT scans. Different companies introduce this modulation by different settings in almost all MDCT scanners. Several studies affirmed the significant role of TCM in reducing the radiation dose without deteriorating the image quality in the neck, chest, abdominal, and pelvis in adult CT compared with fixed tube current.^[19,20] Recently, all multislice CT scanners are equipped with this option where radiation dose is adjusted according to the patient.^[21] In this study, we found that AEC is “ON” most of the time except in center D [Table 1] and it is the reason of increasing radiation dose in that center [Table 3]. Therefore, paying attention to this point can reduce patient radiation dose significantly. TCM changes the X-ray quantity by approximately 60% compared with the radiation dose from scans without this technique.^[22-24]

We also evaluate CT scans which have done with and without intravenous or oral contrast media (approximately 18.8% of patients). There are studies that confirmed the increasing effect of DNA damage by using contrast agents,^[25-27] so biological damage may decrease by using low radiation dose CT scan techniques in contrast phases.^[28] Center A is the only one that has a higher ratio of abdomen–pelvis exams with contrast media agent and it is one of the reasons for higher effective radiation dose in comparison to the other centers in the abdomen–pelvis procedures [Table 2]. The other reason for higher amounts of effective radiation dose in 10–15-year-old group in abdomen–pelvis scans is the high ratio of scans with contrast media in that group [Table 2].

One limitation of this study is that the population of this study was considered of five pediatric medical imaging

Table 3: Average value of effective dose (mSv) from pediatric head, chest, and abdomen–pelvis Computed tomographies in five centers

| | Age group | Center A | Center B | Center C | Center D | Center E | P |
|-----------------|-----------|----------|----------|----------|----------|----------|---------|
| Head | <1 | n=18 | n=21 | n=3 | n=16 | n=0 | <0.001* |
| | | 2.8 | 0.62 | 1.8 | 3.3 | NA** | |
| | 1-5 | n=49 | n=22 | n=10 | n=29 | n=7 | <0.001* |
| | | 1.6 | 0.4 | 1.1 | 3 | 3.5 | |
| | 5-10 | n=24 | n=21 | n=5 | n=8 | n=1 | 0.832 |
| 10-15 | n=8 | n=5 | n=1 | n=3 | n=1 | 0.001* | |
| Chest | <1 | n=13 | n=8 | n=3 | n=3 | n=2 | 0.001* |
| | | 5 | 2 | 5 | 3.3 | 1 | |
| | 1-5 | n=38 | n=8 | n=4 | n=6 | n=2 | 0.201 |
| | | 4.8 | 2.8 | 4 | 4.5 | 3.6 | |
| | 5-10 | n=23 | n=11 | n=2 | n=5 | n=1 | 0.058 |
| 10-15 | n=10 | n=3 | n=1 | n=0 | n=0 | 0.161 | |
| Abdomesn-pelvis | <1 | n=4 | n=5 | n=2 | n=0 | n=1 | <0.001* |
| | | 15.5 | 1.7 | 4.4 | NA** | 1 | |
| | 1-5 | n=22 | n=23 | n=1 | n=3 | n=1 | <0.001* |
| | | 17.3 | 2.5 | 12.2 | 9.8 | 2.7 | |
| | 5-10 | n=20 | n=16 | n=3 | n=4 | n=0 | <0.001* |
| 10-15 | n=20 | n=9 | n=2 | n=1 | n=0 | 0.001* | |
| | | 15.5 | 3.9 | 24 | 10.7 | NA | |

*Significant at 0.05 level. NA – Not available

centers in Tehran province. Therefore, our results might not represent the definite estimation of pediatric CT radiation dosage in Iran. Participating of more hospitals and medical imaging centers in other province is necessary in order to establish the national radiation dose reference level.

Conclusion

This study tried to assess the effective radiation dose in pediatric CT scan in medical imaging centers in Tehran province. Variation of effective radiation dose in different medical imaging centers has been observed. This is mostly because of the following reasons: different type of CT scanners, presence or absence of AEC, and quantities of different exposure parameters such as kVp, mAs, pitch factor, slice thickness, and scan length. Radiation dose optimization is vital in pediatric imaging in any society because of the higher life expectancy to express the late effects of radiation. Radiation technologists can reduce ED by applying high-quality scanners, appropriate exposure factors, and low-dose protocols. The differences in scanner models and exposure parameters in different medical imaging centers are an important issues, especially in newborn head CT examinations.

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Conflicts of interest

There are no conflicts of interest.

References

1. Foley SJ, McEntee MF, Rainford LA. Establishment of CT diagnostic reference levels in Ireland. *Br J Radiol* 2012;85:1390-7.
2. Dougeni E, Faulkner K, Panayiotakis G. A review of patient radiation radiation dose and optimisation methods in adult and paediatric CT scanning. *Eur J Radiol* 2012;81:e665-e83.
3. European Colorectal Cancer Screening Guidelines Working Group, von Karsa L, Patnick J, Segnan N, Atkin W, Halloran S, *et al.* European guidelines for quality assurance in colorectal cancer screening and diagnosis: Overview and introduction to the full supplement publication. *Endoscopy* 2013;45:51-9.
4. Rehani MM, Berry M. Radiation doses in computed tomography. The increasing doses of radiation need to be controlled. *BMJ* 2000;320:593-4.
5. Halliburton S, Arbab-Zadeh A, Dey D, Einstein AJ, Gentry R, George RT, *et al.* State-of-the-art in CT hardware and scan modes for cardiovascular CT. *J Cardiovasc Comput Tomogr* 2012;6:154-63.
6. Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP,

- et al.* Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: A retrospective cohort study. *Lancet* 2012;380:499-505.
7. Mathews JD, Forsythe AV, Brady Z, Butler MW, Goergen SK, Byrnes GB, *et al.* Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: Data linkage study of 11 million Australians. *BMJ* 2013;346:f2360.
 8. Huang WY, Muo CH, Lin CY, Jen YM, Yang MH, Lin JC, *et al.* Paediatric head CT scan and subsequent risk of malignancy and benign brain tumour: A nation-wide population-based cohort study. *Br J Cancer* 2014;110:2354-60.
 9. Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology. *Br J Radiol* 2008;81:362-78.
 10. American Association of Physicists in Medicine. The Measurement, Reporting, and Management of Radiation Radiation Dose in CT: AAPM Report No. 96. College Park, MD: American Association of Physicists in Medicine; 2008.
 11. ICRP. The 2007 Recommendations of the International Commission on Radiological Protection: ICRP publication 103. *Ann ICRP* 2007;37:1-332.
 12. National Research Council. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. Washington, DC: National Academies Press; 2006.
 13. Lee C, Kim KP, Bolch WE, Moroz BE, Folio L. NCICT: A computational solution to estimate organ doses for pediatric and adult patients undergoing CT scans. *J Radiol Prot* 2015;35:891-909.
 14. Tahmasebzadeh A, Paydar R, Soltani Kermanshahi M, Maziar A, Rezaei M, Reiazi R. Pediatric Regional Drl Assessment in Common Ct Examinations for Medical Exposure Optimization in Tehran, Iran. *Radiat Prot Dosimetry* 2020;192:341-9.
 15. Deevband MR, Ghorbani M, Eshraghi A, Salimi Y, Saeedzadeh E, Kardan MR, *et al.* Patient effective radiation radiation dose estimation for routine computed tomography examinations in Iran. *Int J Radiat Res* 2021;19:63-73.
 16. Huda W, Tipnis SV. Radiation radiation doses metrics and patientage in CT. *Radiat Prot Dosimetry* 2016;168:374-80.
 17. Boone JM, Cooper VN 3rd, Nemzek WR, McGahan JP, Seibert JA. Monte Carlo assessment of computed tomography radiation radiation dose to tissue adjacent to the scanned volume. *Med Phys* 2000;27:2393-407.
 18. Yamazaki D, Miyazaki O, Takei Y, Matsubara K, Shinozaki M, Shimada Y, *et al.* Usefulness of size-specific dose estimates in pediatric computed tomography: Revalidation of large-scale pediatric CT dose survey data in Japan. *Radiat Prot Dosimetry* 2018;179:254-62.
 19. Rizzo S, Kalra M, Schmidt B, Dalal T, Suess C, Flohr T, *et al.* Comparison of angular and combined automatic tube current modulation techniques with constant tube current CT of the abdomen and pelvis. *AJR Am J Roentgenol* 2006;186:673-9.
 20. Russell MT, Fink JR, Rebeles F, Kanal K, Ramos M, Anzai Y. Balancing radiation dose and image quality: Clinical applications of neck volume CT. *AJNR Am J Neuroradiol* 2008;29:727-31.
 21. Suliman II, Khamis HM, Ombada TH, Alzimami K, Alkhorayef M, Sulieman A. Radiation exposure during paediatric CT in Sudan: CT dose, organ and effective doses. *Radiat Prot Dosimetry* 2015;167:513-8.
 22. Khatonabadi M, Kim HJ, Lu P, McMillan KL, Cagnon CH, DeMarco JJ, *et al.* The feasibility of a regional CT DIvol to estimate organ dose from tube current modulated CT exams. *Med Phys* 2013;40:051903.
 23. Schlattl H, Zankl M, Becker J, Hoeschen C. Dose conversion coefficients for paediatric CT examinations with automatic tube current modulation. *Phys Med Biol* 2012;57:6309-26.
 24. Papadakis AE, Perisinakis K, Damilakis J. Development of a method to estimate organ radiation radiation doses for pediatric CT examinations. *Med Phys* 2016; 43:2108.
 25. Pathe C, Eble K, Schmitz-Beuting D, Keil B, Kaestner B, Voelker M, *et al.* The presence of iodinated contrast agents amplifies DNA radiation damage in computed tomography. *Contrast Media Mol Imaging* 2011;6:507-13.
 26. Kuefner MA, Brand M, Engert C, Schwab SA, Uder M. Radiation induced DNA double-strand breaks in radiology. *Rof* 2015;187:872-8.
 27. Jost G, Golfier S, Pietsch H, Lengsfeld P, Voth M, Schmid TE, *et al.* The influence of X-ray contrast agents in computed tomography on the induction of dicentric and gamma-H2AX foci in lymphocytes of human blood samples. *Phys Med Biol* 2009;54:6029-39.
 28. Ippolito D, Talei Franzesi C, Fior D, Bonaffini PA, Minutolo O, Sironi S. Low kV settings CT angiography (CTA) with low radiation radiation dose contrast medium volume protocol in the assessment of thoracic and abdominal aorta disease: A feasibility study. *Br J Radiol* 2015;88:20140140.