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The Effect of Age and Body Mass on $CTDI_{Vol}$ and DLP Values in CT Scan Patients at Andalas University Hospital

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Abstract - *In the field of diagnostic radiology, a modality with advanced technology that utilizes X-rays is the Computed Tomography Scanner (CT-Scan). The radiation dose of CT scans is known to be greater compared to other modalities, making patient protection from excessive exposure a critical priority. Therefore, this study aimed to determine the effect of age and body mass on Computed Tomography Dose Index ($CTDI_{Vol}$) and Dose Length Product (DLP) values in CT Scan patients at the Radiology Installation of Andalas University Hospital, to provide the right and appropriate radiation dose for diagnostic purposes. The process included collecting radiation dose data on adult patients (≥ 15 years) with normal body mass (60±10) kg on patient's non-contrast head and abdomen CT Scans with a total of 225 patients. The distribution of age and body mass data was carried out by averaging the radiation dose values at the same age and body mass. The results showed that age had an R^2 value ranging from 0.1 to 0.2, indicating a very low correlation in non-contrast head and abdomen examinations. Body mass had an R^2 value of 0.1, indicating a low correlation in non-contrast head examinations and an R_2 value of 0.5, indicating a fairly high correlation in non-contrast abdomen examinations. Based on this study, it is recommended to optimize the radiation dose by considering body mass and using Automatic Exposure Control (AEC). Radiographers and medical physicists pay more attention to the accuracy of measuring the length of the radiation to optimize the radiation dose value.*

Keywords*: CT-Scan; $CTDI_{vol}$; DLP*

INTRODUCTION

The increasing use of X-rays in the medical field is accompanied by rapid advancement in technology and has significantly impacted both therapeutic and diagnostic radiology (Bibbo et al., 2016; Fardela et al., 2023, 2024; Muhammad et al., 2021; Oliveira Bernardo et al., 2023; Radaideh et al., 2023). To facilitate more efficient examination and treatment processes, several modalities are combined using advanced technology. This includes the Computed Tomography Scanner (CT Scan) which incorporates X-rays in the field of diagnostic radiology (Almohiy, 2014; Joseph Zira et al., 2021; Lyons et al., 2024; Shirazu et al., 2018). The modality operates through modern computerized tomography techniques to detect human body anatomy such as the head, chest cavity, and abdominal cavity (Alkhidir et al., 2019; Ekpo et al., 2019; Kalender, 2014; Osman et al., 2023; Vassileva et al., 2015; Vawda et al., 2015).

The radiation dose in CT Scan tends to be higher compared to other modalities, generating a more accurate and detailed image quality (Aldahery, 2023; Alzimami et al., 2021; Garcia-Sanchez et al., 2018; Latifah et al., 2019; Lee et al., 2015, 2019; Salama et al., 2017). Despite the significant benefit of CT Scan, it also poses potential health risks, including damage to tissue cells and body genetics when the patient is exposed to an excessive dose (Aamry et al., 2020; Al Mahrooqi et al., 2015; Aloufi et al., 2024). Therefore, exposure to ionizing radiation should be considered, specifically during repeated examination, to minimize health risks. Radiation dose in CT Scan can be identified by Computed Tomography Dose Index ($CTDI_{Vol}$) and Dose Length Product (DLP) which are observable on the console monitor screen (Arlany et al., 2023; Costa et al., 2024; Guðjónsdóttir et al., 2023; Isa et al., 2019; Reza Deevband, 2018; Sulieman et al., 2020; Tan et al., 2023).

Rawashdeh et al. (2023) investigated dose reference levels in pediatric CT, focusing on Age and size-specific dose estimation. This study comprised an examination of the head, chest, and abdomen-pelvis. According to the results, age was directly proportional to the radiation dose received by the patient due to differences in tissue factors. However, in some cases, the age is inversely proportional to the radiation dose.

Kharita et al. (2020) studied the relationship between age and CT radiation dose. Analysis was conducted on dose trends in 705 pediatric head CT Scans. The results showed a correlation between age with $CTDI_{Vol}$ and DLP values, where younger patients (specifically infants and toddlers) received higher radiation doses. This increased exposure was necessitated by the need for better image quality in small and developing brain structures.

Brat et al. (2019) conducted a study on Local Clinical Diagnostic Reference Levels for Chest and Abdominal CT Examination in Adults as a Function of Body Mass Index and Clinical Indications. The results showed a correlation between body mass with $CTDI_{vol}$ and DLP values. Furthermore, body mass was directly proportional to the radiation dose required. This is because irradiated body parts are influenced by fat and the length of the scan during the examination. A study on the Use of Body Mass Index to Estimate Individual Patient Radiation Dose in Abdominal Computed Tomography has been conducted by O'Neill et al., (2018). The results showed that body mass affected the amount of radiation dose received.

Based on previous studies, radiographers and medical physicists need to provide the right radiation dose according to age and body mass to prevent unnecessary exposure. Implementing strategies to optimize radiation protection and safety ensures that patients receive the lowest possible radiation dose while maintaining sufficient image quality for diagnostic purposes. Therefore, further studies on the effect of age and body mass on $CTDI_{Vol}$ and DLP in CT Scan patients are necessary to determine the right and correct radiation dose.

RESEARCH METHODS

This study was conducted at the Radiology Installation of Andalas University Hospital using a retrospective method. The process included collection of dose data on patients subjected to non-contrast head and abdomen CT Scan examinations with the Philips Ingenuity CT type. Figure 1 shows a CT Scan.

Figure 1. CT Scan Andalas University Hospital

Figure 2 shows the stages adopted to determine typical dose values and the correlation of age and body mass with $CTDI_{Vol}$ and DLP values.

Permits and ethical approvals were obtained, which gave access to conduct the study in the hospital. Patient data, including dose measurements and body mass, were recorded. The collected data were in the form of serial numbers, initials, age, body mass, kV, mAs, $CTDI_{Vol}$, and DLP. Radiation dose data was collected in adult patients (≥ 15 years) with normal body mass (60±10) kg in non-contrast head and abdominal CT scan patients with a total of 225 patients. This information was entered and sorted into Microsoft Excel based on age and body mass, to facilitate correlation analysis. The distribution of age and body mass data was carried out by averaging the radiation dose values at the same age and body mass. The relationship between age and body mass with $CTDI_{Vol}$ and DLP values was presented in graphical form. Correlation data processing is conducted using statistical and linearity tests, with a coefficient of determination (R^2 or R-Square) adopted to assess the extent of the influence between the variables. The coefficient of determination value ranges from 0 to 1. The interpretation of correlation coefficient values, as outlined by Guilford (1956), is presented in Table 1. The correlation obtained will be compared with previous research to determine whether the results are consistent and to identify the factors that may explain any differences.

Correlation analysis between age and body mass on $CTDI_{Vol}$ and DLP values was only performed on non-contrast media CT Scan examinations, while correlation analysis was not used on contrast media CT Scan examinations because contrast media CT Scan examinations have a different number of sequences.

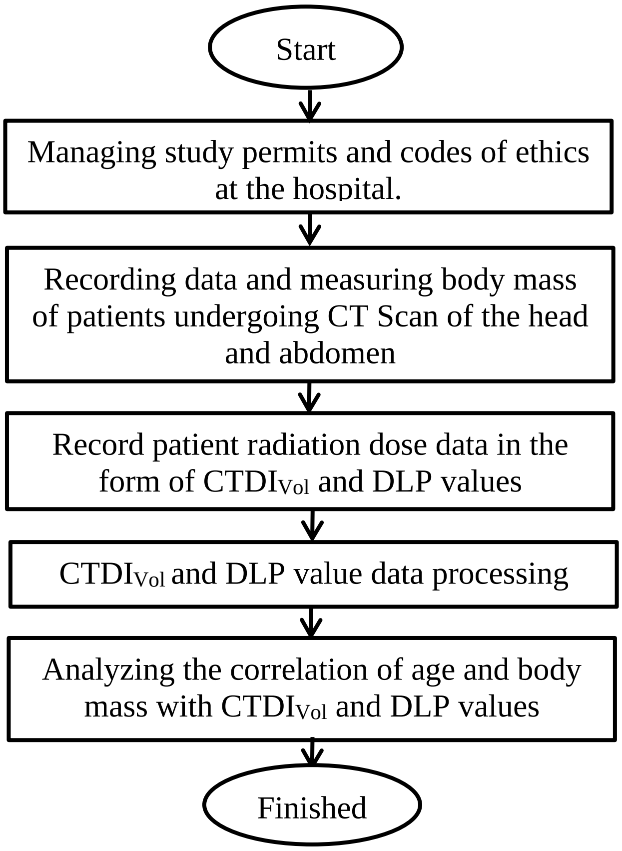

Figure 2. Study stages

Table 1. Interpretation of correlation coefficient values

No	Correlation coefficient	Interpretation
1	0,80-1,00	Very high
2	0,60-0,80	High
3	0,40-0,60	Fair
4	0,20-0,40	Low
5	0,00-0,20	Very low

RESULTS AND DISCUSSION

Results

The correlation analysis between age and body mass with $CTDI_{Vol}$ and DLP was conducted using patient dose data in each non-contrast media CT Scan examination. Data from contrast-enhanced CT Scans were excluded from the analysis due to variations in the number of sequences used in these examinations. The following shows the correlation between age and body mass with $CTDI_{Vol}$ and DLP.

1. Correlation between age and $CTDI_{Vol}$ and DLP

The correlation of age with $CTDI_{Vol}$ and DLP values in non-contrast head and abdomen CT Scans is presented in Figures 3 and 4, respectively.

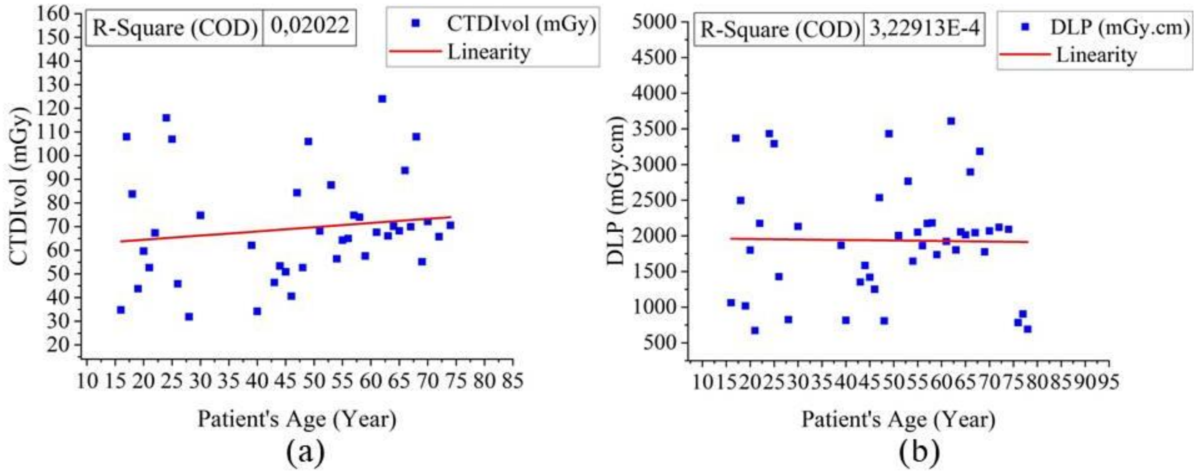

Figure 3. (a) Correlation of age with $CTDI_{Vol}$ on non-contrast head CT Scan examination (b) Correlation of age with DLP on non-contrast head CT Scan examination

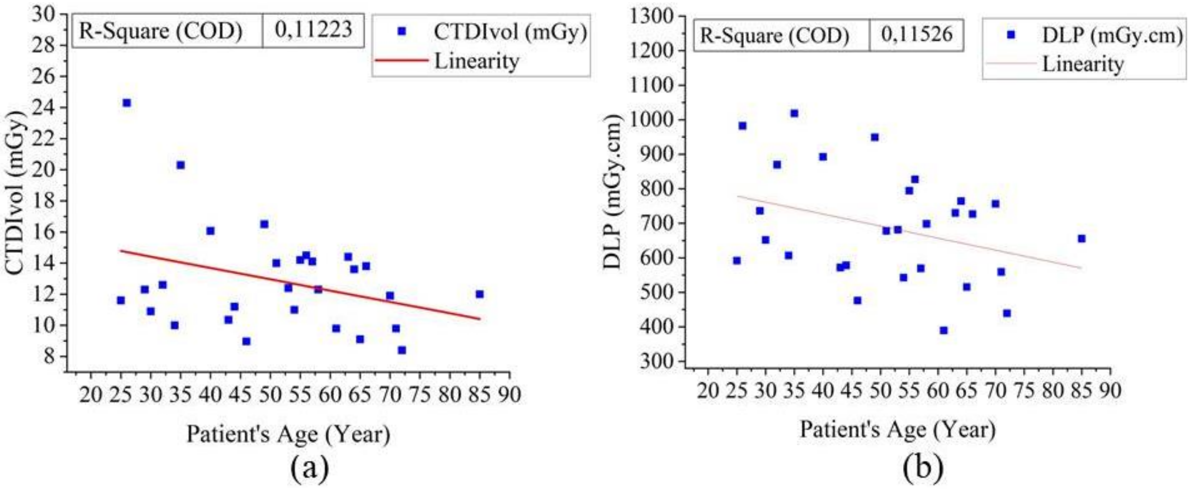

Figure 4. (a) Correlation of age with $CTDI_{Vol}$ on non-contrast abdominal CT Scan examination (b) Correlation of age with DLP on non-contrast abdominal CT Scan examination

2. Correlation between body mass to CTDI$_{Vol}$ and DLP

The correlation of body mass with CTDI$_{Vol}$ and DLP values in non-contrast head and abdominal CT Scans is shown in Figures 5 and 6.

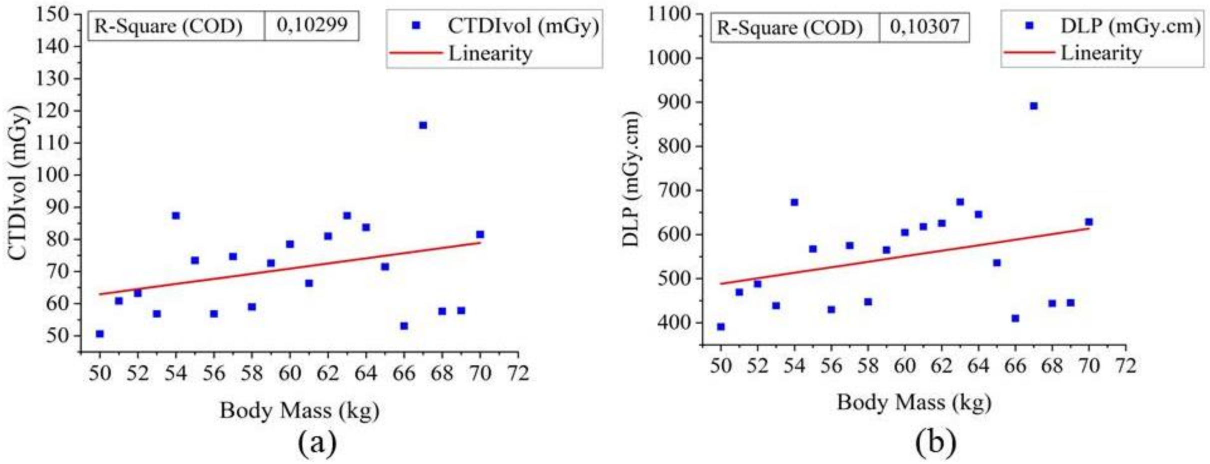

Figure 5. (a) Correlation of body mass to CTDI$_{Vol}$ in non-contrast head CT Scan examination (b) Correlation of body mass to DLP in non-contrast head CT Scan examination

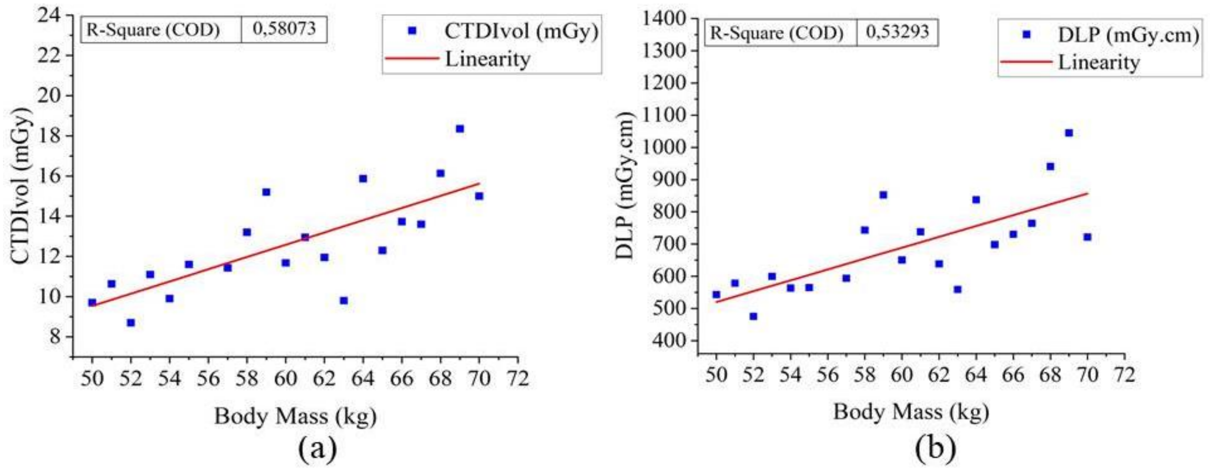

Figure 6. (a) Correlation of body mass to CTDI$_{Vol}$ in non-contrast abdominal CT scan examination (b) Correlation of body mass to DLP in non-contrast abdominal CT scan examination

Discussion

Based on Figures 3 and 4, the correlation of age with CTDI$_{Vol}$ and DLP in each CT Scan examination was conducted using statistical and linearity tests. The results showed an R^2 value ranging from 0.1 to 0.2, suggesting a very low or insignificant correlation, as the data points were spread around the middle region. Examination of the head section was influenced by the high exposure factor (mAs) and the length of the scan which varied according to medical needs. The results are in line with the study conducted by Saeed & Almalki, (2021) which discovered a direct proportionality between age with CTDI$_{Vol}$ and DLP values. Similarly, Yang & Gao (2024) reported higher radiation doses in older patients. The correlation between age with CTDI$_{Vol}$ and DLP values is not often directly proportional. This observation was obtained by Rawashdeh et al. (2023), who discovered that older patients received lower radiation doses.

Based on Figure 5, a correlation of body mass to $CTDI_{Vol}$ and DLP was performed on non-contrast head CT scans using statistical and linearity tests. The results showed an R^2 value of 0.1, suggesting a very low or insignificant correlation. The head has a denser structure than other parts, requiring a higher dose during the examination, leading to greater radiation absorption. This could be attributed to the head not being affected by fat and the circumference of the adult patient's skull.

The correlation of body mass to $CTDI_{Vol}$ and DLP values in non-contrast abdominal CT Scan examinations is shown in Figure 6. A sufficient correlation was observed with a coefficient of determination greater than 0.5. Abdominal examinations had a longer scan length and required a higher radiation dose. However, in abdominal examinations, there is a difference in excessive scan lengths up to the pelvis (pelvic cavity).

The results obtained in this study are in line with the report of Brat et al., (2019), that body mass correlates with $CTDI_{Vol}$ and DLP values. Patients with large body mass and thickness tend to use larger mAs, hence, the amount of radiation received influenced the high $CTDIV_{ol}$ and DLP values. The same results were obtained in the study by O’Neill et al., (2018) where body mass was directly proportional to the radiation dose required.

The results of Inoue et al., (2023) study indicate that body mass significantly affects the CT scan dose for patients, but this was not observed in the results of this study. Medical physicists and radiographers should consider body mass when setting parameters for administering radiation doses to patients. Additionally, optimization of patient examinations using CT scans at Andalas University Hospital should be improved through the use of Automatic Exposure Control (AEC), which assesses the attenuation strength of the patients image section, particularly based on localization images, and automatically modulates the tube current. AEC adjusts radiation exposure for each patient and position according to attenuation strength, contributing to the optimization of radiation doses.

This study shows that the patient's body mass does not significantly affect CT scan examinations at Andalas University Hospital. It is recommended to optimize the radiation dose by considering body mass and using Automatic Exposure Control (AEC). Radiographers and medical physicists pay more attention to the accuracy of measuring the length of the radiation to optimize the radiation dose value.

CONCLUSION

In conclusion, age had a very weak correlation with $CTDI_{Vol}$ and DLP values, while body mass had a fairly low correlation, except in non-contrast abdominal CT Scan examinations.

The influence of the patient's body mass factor on CT scan examinations at Andalas University Hospital has not been found to be significant. Therefore, it is recommended to optimize the administration of radiation doses to patients, considering their body mass. Additionally, optimization can be achieved through the use of Automatic Exposure Control (AEC). The limitation of this study is that the patient's height factor has not been considered, so a comparison between body mass and patient height has not been made. This study could be continued by incorporating the AEC factor and the height factor for CT scan radiation dose management in hospitals.

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REFERENCES

Aamry, A., Alsufayan, M., Aldossari, H., Alonazi, B., & Sulieman, A. (2020). Assessment of imaging protocol and patient radiation exposure in pediatric computed tomography angiography. *Radiation Physics and Chemistry*, *172*(March), 108807. https://doi.org/10.1016/j.radphyschem.2020.108807

Al Mahrooqi, K. M. S., Ng, C. K. C., & Sun, Z. (2015). Pediatric computed tomography dose optimization strategies: A literature review. *Journal of Medical Imaging and Radiation Sciences*, *46*(2), 241–249. https://doi.org/10.1016/j.jmir.2015.03.003

Aldahery, S. T. (2023). Assessment of radiographers' knowledge about radiation doses and DRLs in computed tomography departments in Jeddah, Saudi Arabia: A cross-sectional study. *Saudi Pharmaceutical Journal*, *31*(11), 101820. https://doi.org/10.1016/j.jsps.2023.101820

Alkhidir, N., Hamdan, A., Saeed, A., & Hamed, S. (2019). Correlation between the Exposure Parameters and Dose Values of Different CT Examinations. *Iosr-Jdms*, *18*(4), 81–86. https://doi.org/10.9790/0853-1804178186

Almohiy, H. (2014). Pediatric computed tomography radiation dose: A review of the global dilemma. *World Journal of Radiology*, *6*(1), 1. https://doi.org/10.4329/wjr.v6.i1.1

Aloufi, K. M., Alhazmi, F. H., Alrehily, F. A., Alraddadi, N. S., Alharbi, A. S., Alamin, A. M., Alraddadi, N. S., Alenezi, A. A., & Hadi, F. H. (2024). Assessing Effective Doses and Proposing DRLs for Pediatric CT Procedures in Madinah (Single Hospital), Saudi Arabia. *Applied Sciences (Switzerland)*, *14*(17). https://doi.org/10.3390/app14177583

Alzimami, K., Sulieman, A., Omer, H., Jambi, L. K., Alfuraih, A., Al Hossain, N., Babikir, E., Alkhorayef, M., Khandaker, M. U., & Bradley, D. A. (2021). Evaluation of pediatric radiation doses in computed tomography procedures in the Kingdom of Saudi Arabia. *Radiation Physics and Chemistry*, *188*(June), 109679. https://doi.org/10.1016/j.radphyschem.2021.109679

Arlany, L., Toh, H. G., Nazir, B., Ng, J. J., Tay, Y. H., Tay, Y. S., Poon, C. J. X., Lee, L. N., Fum, W. K. S., Lee, E. Y. T., Mariah, S. I., Fortier, M. V., Tham, W. P., Chew, L. L., Chong, K. H. E., & Chong, L. R. (2023). Establishment of CT diagnostic reference levels (DRLs) for a Singapore healthcare cluster. *Radiography*, *29*(1), 184–189. https://doi.org/10.1016/j.radi.2022.11.002

Bibbo, G., Brown, S., & Linke, R. (2016). Diagnostic reference levels of paediatric computed tomography examinations performed at a dedicated Australian paediatric hospital. *Journal of Medical Imaging and Radiation Oncology*, *60*(4), 475–484. https://doi.org/10.1111/1754-9485.12488

Brat, H., Zanca, F., Montandon, S., Racine, D., Rizk, B., Meicher, E., & Fournier, D. (2019). Local clinical diagnostic reference levels for chest and abdomen CT examinations in adults as a function of body mass index and clinical indication: a prospective multicenter study. *European Radiology*, *29*(12), 6794–6804. https://doi.org/10.1007/s00330-019-06257-x

Costa, P. R., Castro, J. C. de O., Nunes, I. P.

F., Nersissian, D. Y., Sawamura, M. Y., Leão Filho, H., & Tomal, A. (2024). Typical values statistical analysis for adult chest and abdomen-pelvis CT examinations. *Radiation Physics and Chemistry*, *221*(November 2023). https://doi.org/10.1016/j.radphyschem.2024.111669

Ekpo, E. U., Adejoh, T., & Erim, A. E. (2019). Dose benchmarks for paediatric head computed tomography examination in Nigeria. *Radiation Protection Dosimetry*, *185*(4), 464–471. https://doi.org/10.1093/rpd/ncz036

Fardela, R., Milvita, D., Almuhayar, M., Mardiansyah, D., Rasyada, L. A., & Hakim, L. M. (2024). Classification of Thoracic X-Ray Images of COVID-19 Patients Using the Convolutional Neutral Network (CNN) Method. *Journal of Computer Science*, *20*(4), 357–364. https://doi.org/10.3844/jcssp.2024.357.364

Fardela, R., Milvita, D., Rasyada, L. A., Almuhayar, M., Diyona, F., & Mousa, A. (2023). Radiation Dose Evaluation for Radiotherapy Workers at Unand Hospital Using Four-Element Thermoluminescence Dosimetry. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *12*(2), 143. https://doi.org/10.24042/jipfalbiruni.v12i2.18101

Garcia-Sanchez, A. J., Angosto, E. A. G., Riquelme, P. A. M., Berna, A. S., & Ramos-Amores, D. (2018). Ionizing radiation measurement solution in a hospital environment. *Sensors (Switzerland)*, *18*(2). https://doi.org/10.3390/s18020510

Guilford, J., P. (1956). Fundamental Statistic in Psychology and Education. Third Edition. Mc Graw-Hill Book Company.

Guðjónsdóttir, J., Michelsen, S. S., Björnsdóttir, G., & Guðmundsdóttir, V. K. (2023). CT doses based on clinical indications. New national DRL's in Iceland. *Physica Medica*, *109*(March). https://doi.org/10.1016/j.ejmp.2023.102576

Inoue, Y., Itoh, H., Nagahara, K., Hata, H., & Mitsui, K.. (2023). Relationships of Radiation Dose Indices with Body Siza Indices in Adult Body Computed Tomography. *Tomography*, *9*, 1381-1392. https://doi.org/10.3390/tomography9040110

Isa, I. N. ., Rahmat, S. M. S., Dom, S. M., Kayun, Z., & Karim, M. K. (2019). The effects of mis-centering on radiation dose during CT head examination: A phantom study. *Journal of X-Ray Science and Technology*, *27*(4), 631–639. https://doi.org/10.3233/xst-190491

Joseph Zira, D., Haruna Yahaya, T., Umar, M. S., Nkubli B, F., Chukwuemeka, N. C., Sidi, M., Emmanuel, R., Ibrahim, F. Z., Laushugno, S. S., & Ogenyi, A. P. (2021). Clinical indication-based diagnostic reference levels for paediatric head computed tomography examinations in Kano Metropolis, northwestern Nigeria. *Radiography*, *27*(2), 617–621. https://doi.org/10.1016/j.radi.2020.11.021

Kalender, W. A. (2014). Dose in x-ray computed tomography. *Physics in Medicine and Biology*, *59*(3). https://doi.org/10.1088/0031-9155/59/3/R129

Kharita, M. H., Al-Naemi, H., Arru, C., Omar, A. J., Aly, A., Tsalafoutas, I., Alkhazzam, S., Singh, R., & Kalra, M. K. (2020). Relation between age and CT radiation doses: Dose trends in 705 pediatric head CT. *European Journal of Radiology*, *130*(May), 109138. https://doi.org/10.1016/j.ejrad.2020.109138

Latifah, R., Jannah, N. Z., Nurdin, D. Z. ., &

P, B. (2019). Determination of Local Diagnostic Reference Level (Ldl) Pediatric Patients on Ct Head Examination Based on Size-Specific Dose Estimates (Ssde) Values. *Journal Of Vocational Health Studies*, *2*(3), 127. https://doi.org/10.20473/jvhs.v2.i3.2019.127-133

Lee, C., Journy, N., Moroz, B. E., Little, M., Harbron, R., McHugh, K., Pearce, M., & Berrington De Gonzalez, A. (2019). Organ Dose Estimation Accounting For Uncertainty For Pediatric And Young Adult Ct Scans in the United Kingdom. *Radiation Protection Dosimetry*, *184*(1), 44–53. https://doi.org/10.1093/rpd/ncy184

Lee, C., Kim, K. P., Bolch, W. E., Moroz, B. E., & Folio, L. (2015). NCICT: A computational solution to estimate organ doses for pediatric and adult patients undergoing CT scans. *Journal of Radiological Protection*, *35*(4), 891–909. https://doi.org/10.1088/0952-4746/35/4/891

Lyons, A., Mohammed Ali, A., England, A., Moore, N., Young, R., Leamy, B., Tam, W., Bezzina, P., Pongnapang, N., & McEntee, M. F. (2024). Expansion of Typical Values for Paediatric Patients in Ireland and Comparison with Published DRLs - Experiences of a Single Institution. *Journal of Medical Imaging and Radiation Sciences*, *55*(3), 101421. https://doi.org/10.1016/j.jmir.2024.04.014

Muhammad, N. A., Sabarudin, A., Ismail, N., & Karim, M. K. A. (2021). A systematic review and meta-analysis of radiation dose exposure from computed tomography examination of thorax-abdomen-pelvic regions among paediatric population. *Radiation Physics and Chemistry*, *179*(August 2020), 109148. https://doi.org/10.1016/j.radphyschem.2020.109148

O'Neill, S., Kavanagh, R. G., Carey, B. W., Moore, N., Maher, M., & O'Connor, O. J. (2018). Using body mass index to estimate individualised patient radiation dose in abdominal computed tomography. *European Radiology Experimental*, *2*(1), 0–7. https://doi.org/10.1186/s41747-018-0070-5

Oliveira Bernardo, M., Karout, L., Morgado, F., Ebrahimian, S., Sarmet Santos, A., Amorim, C., Muniz Filho, H., Moscatelli, A., Francisco Muglia, V., Schroeder, H., Moulin Sales, D., Gandolpho Henschel, R., Giovanni Valese, B., Kiipper, F., Cesar Cavalcanti, P., Lucena, R., Jornada, T., de Paula, V., Zago, M., … Roberto Costa, P. (2023). Establishing national clinical diagnostic reference levels and achievable doses for CT examinations in Brazil: A prospective study. *European Journal of Radiology*, *169*(August). https://doi.org/10.1016/j.ejrad.2023.111191

Osman, H., Alosaimi, M., Alghamdi, F., Aljuaid, A., Alqurashi, M., Aldajani, S., Faizo, N. L., Alamri, S., Althobaiti, Y. S., Khandaker, M. U., & Suleiman, A. (2023). Evaluation of CT dose and establishment of local DRLs for abdomen and pelvis examinations in hospitals in Taif City, Saudi Arabia. *Radiation Physics and Chemistry*, *202*(May 2022), 110206. https://doi.org/10.1016/j.radphyschem.2022.110206

Radaideh, K., Al-Radaideh, A., Ramli, R. M., Saleh, A., & Alshayeb, R. (2023). Establishment of national diagnostic dose reference levels (DRLs) for routine computed tomography examinations in Jordan. *Polish Journal of Medical Physics and Engineering*, *29*(1), 26–34. https://doi.org/10.2478/pjmpe-2023-0003

Rawashdeh, M., Saade, C., Al Mousa, D. S., Abdelrahman, M., Kumar, P., &

McEntee, M. (2023). A new approach to dose reference levels in pediatric CT: Age and size-specific dose estimation. *Radiation Physics and Chemistry*, *205*(November 2022), 110698. https://doi.org/10.1016/j.radphyschem.2022.110698

Reza Deevband, M. (2018). A New Method for Estimating of Patient Effective Dose in Computed Tomography Based on Body Mass Index: Performance of the Method in Abdomen-Pelvic Examination. *Current Trends in Clinical & Medical Imaging*, *2*(2), 27–31. https://doi.org/10.19080/ctcmi.5018.02.555584

Saeed, M. K., & Almalki, Y. (2021). Assessment of computed tomography radiation doses for paediatric head and chest examinations using paediatric phantoms of three different ages. *Radiography*, *27*(2), 332–339. https://doi.org/10.1016/j.radi.2020.09.007

Salama, D. H., Vassileva, J., Mahdaly, G., Shawki, M., Salama, A., Gilley, D., & Rehani, M. M. (2017). Establishing national diagnostic reference levels (DRLs) for computed tomography in Egypt. *Physica Medica*, *39*, 16–24. https://doi.org/10.1016/j.ejmp.2017.05.050

Shirazu, I., Sackey, T. A., Eduful, E. K., Dery, T. B., Pokoo-Aikins, M., Sosu, E., Hasford, F., & Boadu, M. (2018). Measurements of CTDI and DLP from CT image data for pediatrics radiological performance evaluation and dose optimization in Ghana. *International Journal of Scientific Research in Science and Technology*, *December*, 162–166. https://doi.org/10.32628/ijsrst18401134

Sulieman, A., Elnour, A., Mahmoud, M. Z., Alkhorayef, M., Hamid, O., & Bradley, D. A. (2020). Diagnostic reference level for computed tomography abdominal examinations: A multicentre study. *Radiation Physics and Chemistry*, *174*(May), 108963. https://doi.org/10.1016/j.radphyschem.2020.108963

Tan, W. S., Foley, S., & Ryan, M. L. (2023). Investigating CT head diagnostic reference levels based on indication-based protocols – a single site study. *Radiography*, *29*(4), 786–791. https://doi.org/10.1016/j.radi.2023.05.003

Vassileva, J., Rehani, M., Kostova-Lefterova, D., Al-Naemi, H. M., Al Suwaidi, J. S., Arandjic, D., Bashier, E. H. O., Kodlulovich Renha, S., El-Nachef, L., Aguilar, J. G., Gershan, V., Gershkevitsh, E., Gruppetta, E., Hustuc, A., Jauhari, A., Kharita, M. H., Khelassi-Toutaoui, N., Khosravi, H. R., Khoury, H., … Zaman, A. (2015). A study to establish international diagnostic reference levels for paediatric computed tomography. *Radiation Protection Dosimetry*, *165*(1–4), 70–80. https://doi.org/10.1093/rpd/ncv116

Vawda, Z., Pitcher, R., Akudugu, J., & Groenewald, W. (2015). Diagnostic reference levels for paediatric computed tomography. *South African Journal of Radiology*, *19*(2), 10–13. https://doi.org/10.4102/sajr.v19i2.846

Yang, F., & Gao, L. (2024). Age-based diagnostic reference levels and achievable doses for paediatric CT: a survey in Shanghai, China. *Journal of Radiological Protection*, *44*(2). https://doi.org/10.1088/1361-6498/ad3ce5