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Evaluation of Automatically Modulating X-Ray Tube Current Relative to a Constant Reference Tube Current Across Various Energy Settings Influencing Radiation Dose Optimization in Computed Tomography

Mr. Satnam Singh¹, Dr. Manish Shaw^{2*}, Kulwant Singh Kapoor³, Dr. Jayant Jagtap⁴¹Research Scholar, Department of Radiation and Imaging Technology, Nims College of Allied and Healthcare Sciences, Nims University Rajasthan, Jaipur, India. E-mail: Satnamsinghaiims@gmail.com²Professor, Department of Radiology and Interventional Radiology, NIMS&R, Nims University Rajasthan, Jaipur, India.³Statistician, Department of Biostatistics, AIIMS New Delhi, India.⁴Associate Professor, Nims Institute of Engineering & Technology, Nims University Rajasthan, Jaipur, India.

ABSTRACT

'Computed Tomography' (CT) is expected to play a crucial role in the field of medical imaging in the future, and combining CT with other imaging techniques, such as PET (molecular imaging), is a key aspect of the development of medical imaging. Computed Tomography (CT) started in the 1970s as a manual process involving single-slice scanning and evolved into automated multi-slice systems by the 1990s. Today, artificial intelligence is used for faster acquisition of scan, reduce radiation exposure, and improve image processing. Although diagnostic CT scans offer multiple benefits, evidence points to radiation-induced risks and Radiation can damage the DNA present in reproductive cells (such as sperm or eggs), which is linked to human genetics, underscoring the importance of optimizing radiation doses. This study focused on the fundamental aspects of computed tomography that influence radiation exposure and to explore the potential of automation and artificial intelligence in radiation dose optimization, this study evaluated a constant-reference X-ray tube current—alongside automated radiation exposure modulation strategies. constant-reference X-ray tube current and time product provides uniform radiation exposure if used without automatic modulation of the X-ray tube current and also serves as the baseline mAs during automatic modulation at various energy settings. In this study, patients were categorized into different groups based on their BMI. To evaluate the effectiveness and limitations of automotive modulation versus non-automotive uniform exposure techniques, comparisons were made regarding key facets influencing radiation dose exposure (such as kVp and mAs). Finally, the use and future prospects of automatic methods (including artificial intelligence) for optimizing radiation doses in computed tomography were assessed.

Keywords: Computed Tomography (CT); Radiation Dose Optimization; Automatic Exposure Control (AEC); Artificial Intelligence (AI); X-ray Tube Current Modulation; BMI-Based Dose Optimization

1. INTRODUCTION

1.1 Computed tomography

A CT scan uses X-rays to create detailed images of body parts or sections of the body. These images are produced by measuring the attenuation in the intensity of X-rays as they pass through the body. Computer then uses this information to generate clear, cross-sectional views of the internal structures of the organ being studied [1]. Since the advent of Computed Tomography (CT), there have been numerous improvements in CT technology—encompassing both the hardware and the supporting software. Computed Tomography (CT) started in the 1970s as a manual process involving single-slice scanning and evolved into automated multi-slice systems by the 1990s. Today, artificial intelligence is used for faster acquisition of scan, reduce radiation exposure. Now, Computed tomography imaging is considered fast, detailed, and precise for imaging the body's internal structures. It has become a versatile tool used in various medical fields—such as emergency medicine, oncology, cardiology, neurology, and surgery—playing a vital role in patient care and combining CT with other imaging techniques, such as PET (molecular imaging), is a key aspect of the development of medical imaging.

1.2 Advances in radiation exposure techniques

with advancements in computed tomography and involvement of multi-slice technique this modality developed as fast, detailed, and precise for imaging the cross-sectional imaging of body's internal structures. In the early 2000s, the use of 'Automatic Exposure Control' (AEC)—also known as 'Automatic Tube Current Modulation'—emerged, primarily in Computed Tomography (CT) scanning; this technique was developed to

optimize radiation exposure while maintaining image quality [12]. Older CT machines relied on 'continuous exposure' techniques (such as constant tube current with fixed kVp) throughout the entire scan; this approach did not take into account the patient's size or the extent of X-ray attenuation caused by body tissues [13]. The use of automated exposure control technologies claims to reduce radiation exposure compared to fixed tube current settings [2]. AECs utilize vertical Z-axis modulation and angular X-Y axis rotational modulation. This depends to a significant extent on the noise index values pre-determined by the manufacturer, which are linked to a standard reference figure or reference mAs pre-determined by manufacturers. 'Automatic Exposure Control' (AEC) adjusts the tube current (mA and mAs) as needed, based on this 'reference mAs' (or quality-related reference level) pre-set by the manufacturer [14]. This 'Reference mA' provides consistent exposure if used without automatic modulation. The introduction of AI (Artificial intelligence) Algorithms in radiation exposure control strategies can further improve the automated exposure control techniques [3][4].

1.3 Prime radiation exposure factors in CT

The prime factors influencing radiation exposure in a Computed Tomography (CT) scan are milliamperes (mA), kilovoltage peak (kVp), and exposure time. Among these, mA and time are commonly combined; thus, the most significant factors are 'mAs' and 'kVp'. Kilovoltage peak (kVp) controls the penetrating power of the X-ray beam, while the current in milliamperes (mAs) determines the radiation intensity of the generated X-ray photons. These factors directly influence the way a patient is exposed to radiation and, consequently, the quality of the CT scan image. To reduce patient radiation exposure, scanner manufacturers have incorporated various automated methods and artificial intelligence to optimize the radiation dose. These methods automatically adjust the tube voltage (kVp) and tube current (mAs) and control the radiation dose based on the patient's 'scout image' [5]. At the same time, these techniques maintain the quality of the resulting diagnostic images, and it is claimed that their use leads to a significant reduction in radiation dose.

1.4 Radiation dose management principles

Optimizing the radiation dose helps strike the right balance between obtaining the necessary diagnostic images using minimal radiation and protecting patients from unnecessary radiation exposure. Strategies such as the 'As Low As Reasonably Achievable' (ALARA) principle, new technology, and quality checks are employed to keep radiation doses as low as possible while ensuring the required quality of medical images. Evidence indicates that exposure to radiation levels exceeding certain limits for a prolonged period carries a 1 in 1,000 risk of developing fatal cancer during a person's lifetime [6]. The International Commission on Radiological Protection (ICRP) has established guidelines regarding safe radiation exposure for healthcare workers during their work, but these guidelines do not apply to patients. The recommended safe level is 20 millisieverts per year over a maximum period of five years, provided that radiation exposure in any single year does not exceed 50 millisieverts [7].

1.5 Artificial intelligence (AI) in medical imaging

New developments in medical imaging and artificial intelligence are bringing about revolutionary changes in healthcare. Integrating AI into medical imaging has transformed many aspects of medical care, aiding in the early detection of diseases, accurate diagnosis, personalized treatment plans, and improved patient outcomes. AI has the potential to transform every aspect of the Computed Tomography (CT) process—from the way the patient is positioned on the scanner to the generation of the final images [8]. AI—whether in the form of traditional machine learning or deep learning methods—has potential in reducing radiation dosage in Computed Tomography (CT). AI-based algorithms, can optimize different aspects of CT scans [23]. These include patient positioning, the area to be scanned, and technical settings (such as tube current and voltage). These methods are said to reduce radiation exposure more effectively than using manual constant tube current settings [2] [4].

1.6 Radiation Dose Index and Radiation output

Both manual and automatic methods used to select techniques in Computed Tomography (CT) directly affect the amount of radiation a patient receives; and the 'Dose Index' (CTDI) is a standard method for measuring the radiation output of a CT scanner, regardless of whether parameters are modulated via automatic techniques or constant parameters are selected. Previously, CTDI₁₀₀ (measured using a 100 mm long ionization chamber) and CTDI_w (the average dose across a single slice) were commonly used [24]. However, for modern helical scanners, the CTDI_{vol} value is more commonly used which is actually determined by dividing CTDI_w by the pitch factor [25].

The CT DLP (Dose-Length Product) was measured to determine the total radiation dose output. The DLP value (mGy.cm) is equal to the product of CTDI_{vol} (mGy) and the scan length in centimeters [26]. This is a standard method for measuring the total X-ray radiation emitted or radiation output during a complete CT scan [27].

The amount of radiation emitted by CT scan machines can vary significantly depending on the machine's brand and type. While the specific variation primarily depends on how the manufacturer has designed hardware and configured the machine's software [10,11].

2. Material And Methods

To compare the use of auto-modulated (self-adjusting) parameters with a constant reference value (without auto-modulation), it is essential to understand the primary and secondary aspects of radiation exposure. Determining the radiation dose involves considering key parameters such as 'mAs' and 'kVp,' alongside secondary factors like scan length, pitch, slice thickness, and FOV (field of view). Automated techniques—including Artificial Intelligence (AI)—can be applied at every stage of CT scan imaging, ranging from the precise positioning of the patient to the final stage of image generation [8].

The CT scans were performed using the 'Biograph m' CT scanner manufactured by Siemens Healthcare in Forchheim, Germany; this scanner features 128 slices and utilizes low-dose technology. The manufacturer has also introduced an application named 'AIDAN,' which is based on an Artificial Intelligence (AI) scanner platform and incorporates various AI-based algorithms into these scanners and a specialized CT scanner featuring 'SOMATOM Drive Dual Source' technology, also manufactured by Siemens Healthcare in Germany.

This study included 70 consecutive patients. The average age of the participants was 42 years. The study utilized data obtained from scans performed with specific settings.

This data was derived from CT scans of the head, heart, chest, abdomen and pelvis.

Two different scanning settings were used for these patients.

A.Scans performed with constant, pre-set reference mAs and fixed kVp values without automatic modulation—in accordance with specific clinical scan protocols established by the manufacturer.

B.Scans performed with Real-time adjustment of X-ray tube current and automatic selection of kilovolt peak.

Before the CT scan, each patient's weight and height were measured, and their BMI was calculated.

Subsequently, patients were categorized into different groups based on their BMI: underweight (UW) if their BMI was less than 19.5 kg/m² (a BMI below 16 kg/m² is considered severe underweight or thinness), normal weight (NW) if the BMI was between 20 and 24.9 kg/m², overweight (OW) if the BMI was between 25 and 29.9 kg/m², and obese (OB) if the BMI was 30 kg/m² or higher [10,12,13].

Focus on Prime factors - The primary factors affecting radiation exposure CT scan are mAs and kVp. There is a direct relationship between mAs and the radiation dose received by the patient. If all other factors remain constant, increasing the mAs results in a proportional (1:1) increase in the dose [14,16]. Furthermore, increasing the kVp value leads to an increase in both the average energy of the photons and the total number of photons in the X-ray beam [15].

To determine the impact of 'automatic modulation' versus 'constant uniform radiation exposure' on radiation dose optimization—while focusing on key factors—fixed values for all secondary parameters related to scan protocols (such as scan length, pitch, and FOV) were considered.

Exposure to radiation at levels below 100 kVp results in grainy images, whereas higher kVp levels expose patients to a greater radiation dose. This study evaluates CT scans performed at 100 kVp and 120 kVp to assess the impact of appropriate radiation exposure while maintaining image quality.

Parameter selection- For scans performed with constant reference mAs without automatic modulation, the manufacturer-preset mAs and kVp values were considered; in contrast, automatic exposure control techniques adjust the X-ray tube current based on 'scout' images [5] and—while modulating the X-ray tube current in real-time[18]—also automatically select the required kVp..

'Scout' (localizer) images were acquired using 120 kVp and a maximum tube current of 35 mAs (for scans where automatic modulation was not used); whereas when automatic exposure modulation techniques were employed, the kVp of the scout image was linked to the kVp of the diagnostic scan. The average CTDIvol during 'scout' imaging ranged from 0.05 to 0.08 mGy.

Radiation Intensity and output exposure.

1. Head Scan: Scan data obtained with automatic selection of kVp (energy) and attenuation-based automatic modulation of X-ray tube current, and a scan performed without X-ray tube current modulation using the manufacturer-specified reference tube current at 100 kVp and 120 kVp as constant mAs With a fixed length of 164 mm, a pitch of 0.5, and a 300 mm FOV—under both automatically modulated and constant mAs conditions—the generated X-ray intensity (mAs) and radiation output shown in Figure 1 determine the radiation intensity and output in relation to the patient's BMI.

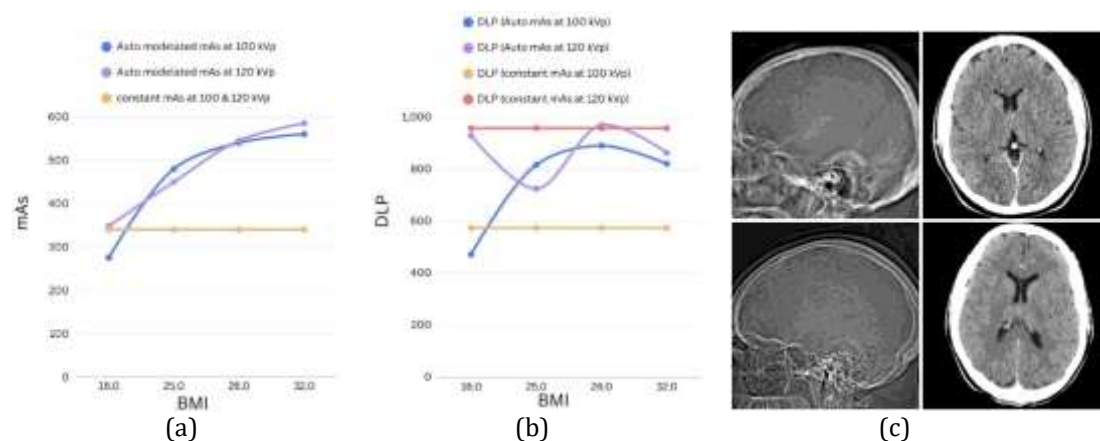


Figure-1. Graphs of Head CT scan showing head scan data: (a) mAs on the y-axis and BMI on the x-axis; (b) DLP on the y-axis and BMI on the x-axis (c) Comparison of scans taken at 100 kVp and 120 kVp.

Figure 1(a) shows a significant difference in DLP at 100 and 120 kVp with constant mAs; conversely, a large difference was observed in the DLP curves—compared to the mAs curves—when using auto-modulated mAs at 100 and 120 kVp. While the mAs curve shows an approximately proportional increase in mAs as BMI rises, this pattern is not observed with the DLP curve.

2. Cardiac Scan: Scan data obtained with automatic selection of kVp (energy) and attenuation-based automatic modulation of X-ray tube current, and a scan performed without X-ray tube current modulation using the manufacturer-specified reference tube current at 100 kVp and 120 kVp as constant mAs With a fixed length of 164 mm, 0.35 pitch, and 780 mm FOV — in both automatically modulated and fixed mAs modes.

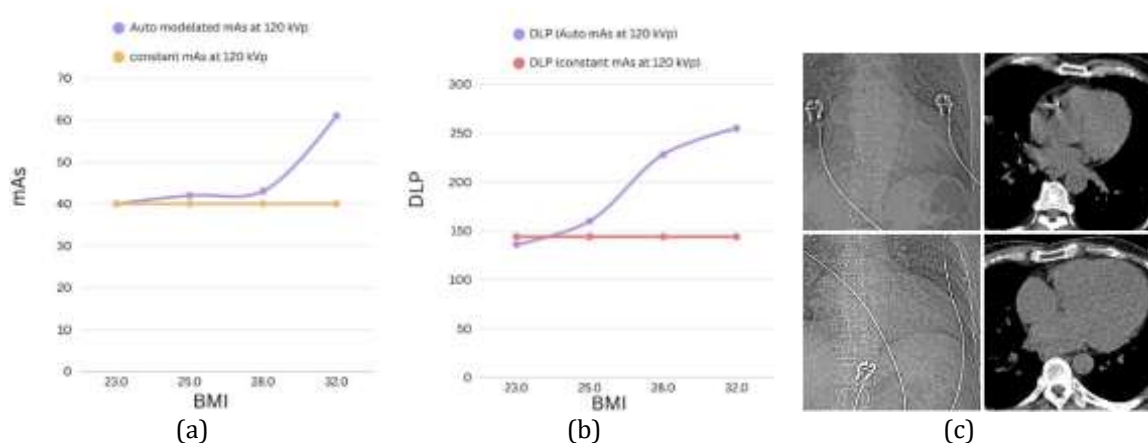


Figure-2. Graphs of Cardiac CT scan showing scan data: (a) mAs on the y-axis and BMI on the x-axis; (b) DLP on the y-axis and BMI on the x-axis (c) Comparison of scans taken at 100 kVp and 120 kVp.

As shown in Figure 2, radiation intensity and output (at 120 kVp) relative to the patient's BMI show an increase in DLP similar to that observed in the mAs curve; however, at a BMI of 28 (Figure 2(b)), the increase in DLP is significantly greater than the increase in mAs, indicating that the nature of DLP is not limited merely to mAs and kVp but is more complex.

3. Chest Scan Chest CT scan: data obtained using automatic selection of kVp (energy) and attenuation-based automatic modulation of X-ray tube current; and scan data obtained without X-ray tube current modulation—using the manufacturer-specified reference tube current as a fixed mAs of 110 mAs at 120 kVp. With a fixed slice thickness of 1.5 mm, a fixed length of 253 mm, a pitch of 1.35, and an FOV (Field of View) of 780 mm — in both automatically modulated and fixed mAs modes.

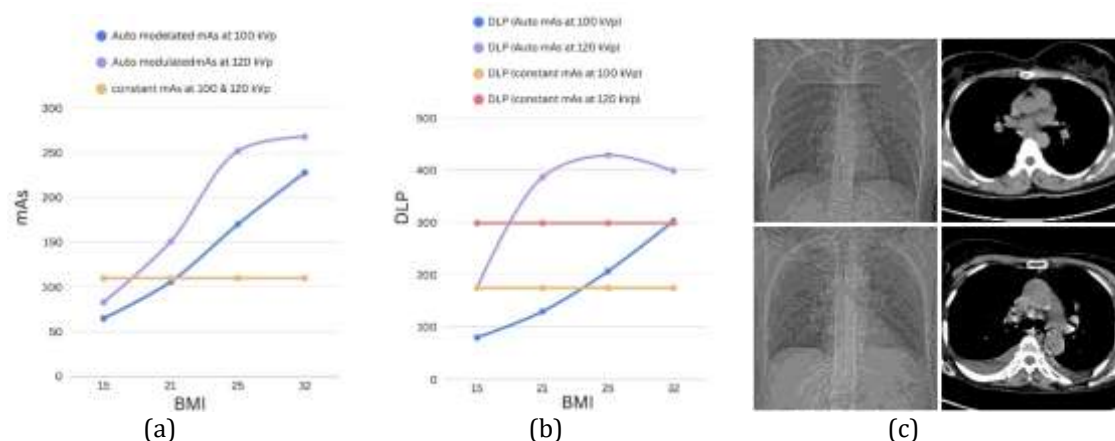


Figure-3. Graphs of Chest CT scan showing scan data: (a) mAs on the y-axis and BMI on the x-axis; (b) DLP on the y-axis and BMI on the x-axis (c) Comparison of scans taken at 100 kVp and 120 kVp.

Figure 3(a) shows a proportional increase in mAs as kVp rises from 100 to 120, whereas the DLP curves in Figure 3(b) exhibit greater variations compared to the mAs curve.

4. Abdomen Scan: Abdominal CT scan data acquired using attenuation-based automatic modulation of X-ray tube current (where kVp selection is also automatic), and scan data acquired without modulation using manufacturer-specified reference tube currents at 100 kVp and 120 kVp (as constant mAs, i.e., 110 mAs). With a fixed length of 400 mm, a pitch of 0.85, and a 780 mm FOV — in both automatically modulated and constant mAs modes.

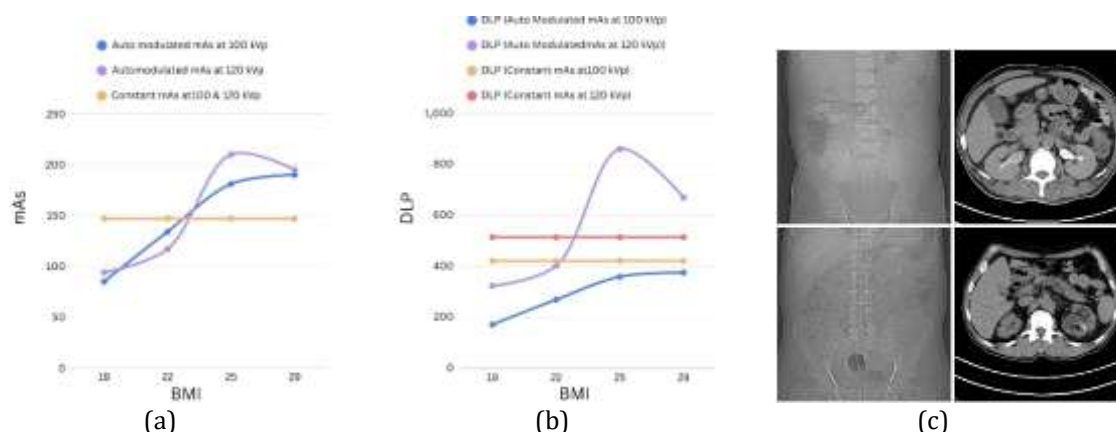


Figure-4. Graphs of Abdomen CT scan showing: (a) mAs on the y-axis and BMI on the x-axis; (b) DLP on the y-axis and BMI on the x-axis (c) Comparison of scans taken at 100 kVp and 120 kVp.

The increase in DLP with rising kVp is clearly evident in the DLP curve shown in Figure 4(b); however, the mAs curves for the auto-selected 100 kVp and 120 kVp settings overlap at several points—a phenomenon not observed in the DLP curves. This indicates that despite the overlap in mAs values, there is a significant increase in the output radiation exposure.

5. Pelvis Scan : This is a CT scan of the pelvis performed using 'attenuation-based automatic modulation' of the X-ray tube current and automatic selection of kVp; it has been compared with scan data acquired at 100 & 120 kVp without X-ray tube current modulation (using the manufacturer-specified reference tube current as a fixed mAs—110 mAs) With a fixed length of 253.5 mm, a pitch of 1.3, and an FOV of 780 mm—in both automatically modulated and fixed mAs modes—and a fixed slice thickness of 2.5 mm.

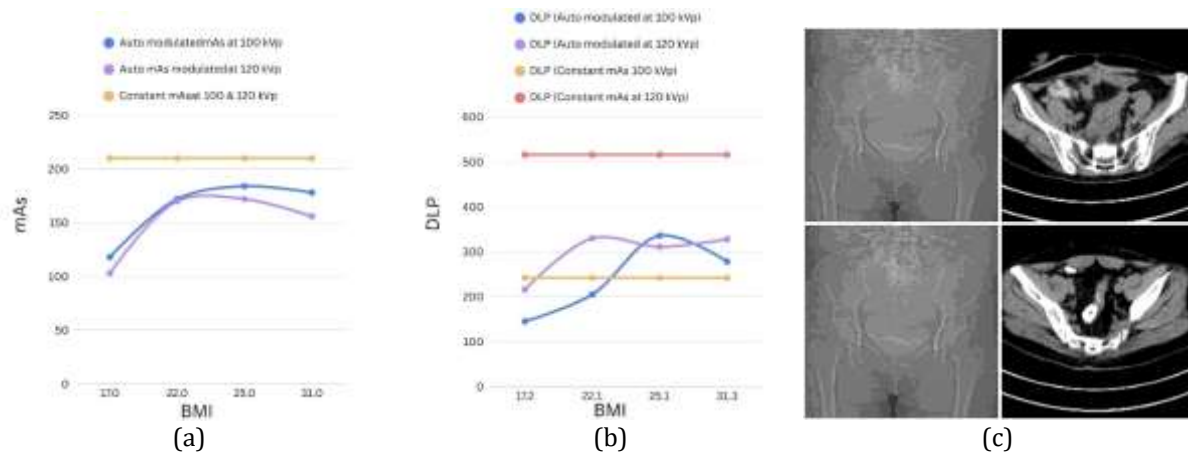


Figure-5. Graphs of Pelvis CT scan showing: (a) mAs on the y-axis and BMI on the x-axis; (b) DLP on the y-axis and BMI on the x-axis (c) Comparison of scans taken at 100 kVp and 120 kVp.

Figure 5 illustrates higher reference X-ray tube levels compared to auto-modulated mAs (modulated using the same reference mAs at both 100 kVp and 120 kVp) during a CT scan of the pelvis; a significant increase in DLP was observed at 120 kVp (without auto modulation), but the auto-modulation of kVp and mAs resulted in a reduction in DLP and, consequently, in output radiation exposure.

Statistical Analysis- Continuous variables were expressed as mean and standard deviation (range), and categorical variables were presented as counts or percentages.

TABLE 1. Mean and Standard deviation.

Group	Scan Type and kVp Defined	BMI (kg/m ²) Mean $\pm$ SD	Tube Current (mAs) Mean $\pm$ SD	CTDIvol (mGy) Mean $\pm$ SD	DLP (mGy·cm) Mean $\pm$ SD	DLP (mGy·cm) Median	DLP (mGy·cm) Range
Group 1	Head CT (100kVp Auto & Constant)	24.75 $\pm$ 6.185	463.75 $\pm$ 130.344	44.00 $\pm$ 11.518	752.25 $\pm$ 188.587	821.00	419
Group 2	Chest CT (100kVp Auto & Constant)	23.50 $\pm$ 7.550	142.25 $\pm$ 71.658	6.50 $\pm$ 3.109	180.00 $\pm$ 97.225	168.50	223
Group 3	Abdomen CT (100kVp Auto & Constant)	23.75 $\pm$ 4.272	147.50 $\pm$ 48.363	6.50 $\pm$ 1.915	295.50 $\pm$ 94.055	316.00	204
Group 4	Pelvis CT (100kVp Auto & Constant)	23.75 $\pm$ 5.852	163.00 $\pm$ 30.397	9.00 $\pm$ 3.367	241.00 $\pm$ 83.479	241.50	191
Group 5	Head CT (120kVp Auto & Constant)	24.975 $\pm$ 6.602	482.00 $\pm$ 105.764	49.25 $\pm$ 5.058	874.00 $\pm$ 107.483	898.50	245
Group 6	Cardiac CT (120kVp Auto & Constant)	27.25 $\pm$ 4.349	46.50 $\pm$ 9.747	11.25 $\pm$ 3.202	194.75 $\pm$ 55.961	194.00	119
Group 7	Chest CT (120kVp Auto & Constant)	25.25 $\pm$ 6.702	188.50 $\pm$ 87.348	9.50 $\pm$ 2.646	347.50 $\pm$ 116.349	393.00	254

Group 8	Abdomen CT (120kVp Auto & Constant)	24.00 ± 3.367	154 ± 57.114	11.73 ± 4.425	565.75 ± 247.1	538	325
Group 9	Pelvis CT (120kVp Auto & Constant)	24.75 ± 5.058	150.25 ± 32.294	11.25 ± 2.217	296.25 ± 54.175	319.50	114

TABLE 2. 100 kVp vs 120kVp.

Parameter	120 kVp	100 kVp	p-value
DLP (mGy·cm)	455.65 ± 107	360.43 ± 146	0.0438

TABLE 3. Brain Auto modulated mAs vs constant mAs at 100 kVp (Fixed energy)

Parameter	Auto modulated mAs	Constant mAs	p-value
CTDLvol	48.50 (27-52)	33(33-33)	0.219
DLP (mGy·cm)	821(474-893)	576(576-576)	0.219

An increase in kVp leads to a significant rise in radiation output. In an evaluation of CT scans performed at 100 kVp—comparing scans without mAs modulation to those with auto-modulated mAs—no significant reduction in radiation dose was found ($p > 0.5$); whereas a significant reduction in radiation dose was observed in CT scans performed at 100 kVp compared to those at 120 kVp ($p < 0.04$).

3. Result

An increase in kVp leads to a substantial rise in radiation output. This significant increase in radiation output is more evident in scans performed at a fixed reference tube current without automatic modulation. For head CT scans, the average effective radiation output increased from 576 mGy.cm at 100 kVp to 960 mGy.cm at 120 kVp without automatic modulation; whereas with automatic modulation of mAs and kVp, the average effective radiation output rose from 752.25 mGy.cm at 100 kVp to 874 mGy.cm at 120 kVp. For chest CT scans, the average effective radiation output without automatic modulation increased from 175 mGy.cm at 100 kVp to 299 mGy.cm at 120 kVp, while with automatic modulation of mAs and kVp, it rose from 180 mGy.cm at 100 kVp to 347 mGy.cm at 120 kVp. In abdominal CT scans, the average effective radiation output without automatic modulation ranged from 423 mGy.cm at 100 kVp to 516 mGy.cm at 120 kVp, whereas automatic modulation of mAs and kVp increased this average effective radiation output from 295.50 mGy.cm at 100 kVp to 565.75 mGy.cm at 120 kVp. In the case of pelvic CT scans, the average effective radiation output without automatic modulation ranged from 242 mGy.cm at 100 kVp to 425 mGy.cm at 120 kVp; whereas automatic modulation of mAs and kVp resulted in an average effective radiation output ranging from 241 mGy.cm at 100 kVp to 296 mGy.cm at 120 kVp.

4. Discussion

Radiation output changes significantly with variations in kVp, and the amount of radiation emitted by CT scan machines can vary considerably depending on the machine's brand [11,19]. Considered fast, detailed, and precise method of imaging the body's internal structures Computed tomography imaging become a versatile tool used in various medical fields—such as emergency medicine, oncology, cardiology, neurology, and surgery—playing a vital role in patient care and combining CT with other imaging techniques, such as PET (molecular imaging), is a key aspect of the development of medical imaging. In light of these advancements, future considerations regarding computed tomography and the adverse effects associated with ionizing radiation underscore the importance of optimizing radiation doses.

Automatic exposure control modulates the X-ray tube by using the manufacturer-preset reference tube current as a baseline and adjusts radiation exposure based on 'scout' images [20]. In the absence of automatic modulation, the radiation dose remains constant due to the fixed reference X-ray tube current and fixed kVp. This level remains steady throughout the entire scan, regardless of whether thinner or thicker parts of the body are being imaged. However, automatic exposure control modulation relies significantly on the reference tube current [21,22], and this reference tube current varies among different manufacturers. Manufacturers are also incorporating AI (Artificial Intelligence) to enhance the precision of radiation exposure modulation via automatic exposure control. The modulation of radiation exposure through automatic exposure control also varies from manufacturer to manufacturer, due to variation in reference X-Ray tube current along with difference in hardware and software configuration as there is no universal standard.

5. Conclusion

Output radiation exposure changes significantly with variations in kVp; when kVp is increased from 100 kVp to 120 kVp, the output radiation exposure rises substantially, and increasing it to 140 kVp can lead to a further increase. Radiation exposure varies through automatic exposure control based on body structure, as determined by 'scout' images. Furthermore, the output intensity of different imaging units varies from manufacturer to manufacturer in the absence of any universal standard. Imaging Units with automatically modulated radiation exposure rely on a reference X-ray tube current predefined by the manufacturer; establishing universal standards for the radiation output of computed tomography requires advanced technology—such as AI (Artificial Intelligence)—beyond conventional physics-based automatic exposure control.

6. Limitations

this study focus only on prime factors affecting radiation exposure. When advanced artificial intelligence-based algorithms are used to reconstruct final output images of computed tomography, there are certain limitations in assessing how well they perform. The number of patients considered in this study were limited in number and that is another limitation of this study, and the results could have been better if data from a larger number of patients had been considered.

References

1. Lifeng Yu†, Xin Liu, Shuai Leng, James M Kofler, Juan C Ramirez-Giraldo, Mingliang Qu, Jodie Christner, Joel G Fletcher, and Cynthia H McCollough Department of Radiology, Mayo Clinic, 200 First Street SW, Rochester, MN 55905, USA.
2. McCollough CH, Bruesewitz MR, Kofler JM Jr. CT dose reduction and dose management tools: overview of available options. *Radiographic*. 2006;26: 503–512.
3. Sun J, Li H, Wang B, Li J, Li M, Zhou Z, et al. Application of a deep learning image reconstruction (DLIR) algorithm in head CT imaging for children to improve image quality and lesion detection. *BMC Med Imag* 2021;21(1). <https://doi.org/10.1186/s12880-021-00637-w>.
4. NagayamaY, Iwashita K, Maruyama N, Uetani H, Goto M, Sakabe D, et al. Deep learning-based reconstruction can improve the image quality of low radiation dose head CT. *EurRadiol* 2023;33(5). <https://doi.org/10.1007/s00330-023-09559-3>.
5. Yusuke Inoue, Kazunori Nagahara, Hiroko Kudo, Hiroyasu Itoh Department of Diagnostic Radiology, Kitasato University School of Medicine, Sagami-hara, Kanagawa 252-0374, Japan *Am J Nucl Med Mol Imaging* 2018;8(2):143-152 www.ajnmml.us /ISSN:2160 8407/ajnmml0076225.
6. Radhika Bhanot, Zeeshan B. M. Hameed, Milap Shah, Patrick Julieb-Jones, Andreas Skolarikos, Bhaskar Somani, Steps to Minimize Radiation Exposure During All Parts of the Endourological Journey *Current Urology Reports* (2022) 23:255–259 <https://doi.org/10.1007/s11934-022-01102-z>.
7. Vano E. Occupational radiation protection of health workers in imaging. *Radiat Prot Dosimetry*. 2015;164(1–2):126–9. <https://doi.org/10.1093/rpd/ncu354>. Epub 2014 Dec 4 PMID: 25480840.
8. C.H. McCollough, S. Leng. Use of artificial intelligence in computed tomography dose optimization. CT Clinical Innovation Center, Department of Radiology, Mayo Clinic, Rochester, MN, USA, ICRP 2019 Proceedings.
9. International Commission on Radiological Protection. The 2007 recon emendations of the international commission on radiological protection. ICRP publication 103. *Ann ICRP*. 2007;37:1–332.
10. Obesity, BMI, and Health: A Critical Review Frank Q. Nuttall, MD, PhD, Minneapolis VAMedical Center, One Veterans Dr 111G, Minneapolis, MN 55417 (Nutta001@umn.edu)
11. International variation in radiation dose for computed tomography examinations 2019 Jan Rebecca Smith-Bindman et al, Yifei Wang 2, Philip Chu 2, Robert Chung 3, Andrew J Einstein 4, Jonathan Balcombe 5, Mary Cocker 6, PMID: PMC6314083 PMID: 30602590.
12. Stephen D. Osborne et al Automatic Exposure Control During Computed Tomography Scans of the Head: Effects on Dose and Image Quality (2019). *Electronic Theses and Dissertations*. Paper 3658. <https://dc.etsu.edu/etd/3658>.
13. Stephen P Power, Fiachra Moloney, et al Computed tomography and patient risk: Facts, perceptions and uncertainties *World J Radiol* 2016 December 28; 8(12): 902-915 ISSN 1949-8470.
14. Christopher P. Favazza, PhD, Lifeng Yu et al Automatic Exposure Control Systems Designed to Maintain Constant Image Noise *J Computer Assist Tomography*. 2015; 39(3): 437–442. doi:10.1097/RCT.0000000000000221.
15. Yu L, Li H, Fletcher JG, et al. Automatic selection of tube potential for radiation dose reduction in CT: a general strategy. *Med Phys*. 2010; 37:234–243.
16. Erickson, B.J., Korfiatis, P., Akkus, Z., et al., 2017. Machine learning for medical imaging. *Radiographics* 37, 505–515.
17. Franck C and Bacher K. Influence of localizer and scan direction on the dose-reducing effect of automatic

- tube current modulation in computed tomography. *Radiat Prot Dosimetry* 2016; 169: 136-142.
18. Söderberg M. Overview, practical tips and potential pitfalls of using automatic exposure control in ct: siemens CARE dose 4D. *Radiat Prot Dosimetry* 2016; 169: 84-91.
 19. [19] Saltybaeva, N., Schmidt, B., Wimmer, A., et al., 2018. Precise and automatic patient positioning in computed tomography: avatar modeling of the patient surface using a 3-dimensional camera. *Invest. Radiol.* 53, 641–646.
 20. Greffier J, Durand Q, Frandon J, Si-Mohamed S, Loisy M, de Oliveira F, et al. Improved image quality and dose reduction in abdominal CT with deep learning reconstruction algorithm: a phantom study. *EurRadiol* 2022;33(1). <https://doi.org/10.1007/s00330-022-09003-y>.
 21. Yu, L., Shiung, M.M., Jondal, D., et al., 2012. Development and validation of a practical lower-dose-simulation tool for optimizing computed tomography scan protocols. *J. Comput. Assist. Tomogr.* 36, 477–487.
 22. Favazza, C.P., Ferrero, A., Yu, L., et al., 2017. Use of a channelized Hotelling observer to assess CT image quality and optimize dose reduction for iteratively reconstructed images. *J. Med. Imaging (Bellingham)* 4, 031213.
 23. Willeminck M, Noël P. The evolution of image reconstruction for CT from filtered back projection to artificial intelligence. *Eur Radiol.* 2018;29(5):2185–2195.
 24. Thibault J, Sauer K, Bouman C, Hsieh J. A three-dimensional statistical approach to improved image quality for multislice helical CT. *Med Phys.* 2007;34(11):4526–4544.
 25. Akagi M, Nakamura Y, Higaki T, et al. Deep learning reconstruction improves image quality of abdominal ultra-high-resolution CT. *Eur Radiol.* 2019;29(11):6163–6171.
 26. White paper Automatic landmarking and parsing of human anatomy (ALPHA) for innovative and smart MI applications Siemens Healthineers.
 27. Singh S, Shaw M, Kaur H, Sonik B, Singh P, Jagtap J. Relevance Of Automatic Techniques Including Artificial Intelligence On Radiation Dose Optimization In Computed Tomography. *Int J Drug Deliv Technol.* 2026;16(53s): 636-647. DOI: 10.25258/ijddt.16.53s.114