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Protection of Radiosensitive Organs with Diagnosable Image Maximizing Radiation Protection for Radiosensitive Organs during CT

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Abstract:- The primary objective of this investigation is to comprehensively evaluate potential strategies to mitigate the risk of radiation-induced ailments stemming from the excessive exposure of radiosensitive organs such as the eyes, thyroid, breast, and gonads during CT scans, without compromising diagnostic image quality. In the methodology, a thorough examination and synthesis of existing literature were conducted, encompassing various studies and their respective findings. By scrutinizing the results and conclusions of these studies, the aim was to identify optimal approaches for minimizing the risk of radiation-related diseases associated with the overexposure of radiosensitive organs.

The culmination of this analysis revealed a range of methods tailored to protect specific radiosensitive organs. Notably, for safeguarding the eye lens, gantry tilting emerged as the most efficacious technique. However, circumstances may arise where gantry tilting is impractical; in such cases, the utilization of silicon rubber shielding combined with tube current modulation was deemed viable. Furthermore, for other radiosensitive organs, such as the thyroid, breast, and gonads, the implementation of tube current modulation, supplemented by ADMIRE 3, was identified as a significantly effective measure. In conclusion, this study underscores the importance of adopting targeted strategies to mitigate radiation risks while preserving diagnostic image quality during CT scans. By leveraging techniques such as gantry tilting, silicon rubber shielding, and tube current modulation with ADMIRE 3, healthcare practitioners can enhance patient safety and minimize the likelihood of radiation-induced health complications. Additionally, ensuring the authenticity of these findings, plagiarism was rigorously checked to maintain the integrity of the research.

Keywords:- *SODAR, Gantry Tilting, Radiological Staff Training, Tube Current Modulation, ADMIRE.*

I. INTRODUCTION

October 1st, 1971 marked the major breakthrough in the history of medical science as it was the day when Sir Godfrey Newbold Hounsfield unravel many anatomical and physiological mysteries of the human body without opening it up by constructing **EMI Scanner** which was later known as **Computed Tomography scanner, or CT scanner**[1] With the help of EMI scanner, the world's first scan was done of the brain at Atkinson Morley in Wimbledon England[2]. Over 3 million CT scans were performed in the U.S. within a decade. By 2005, the number crosses 68 billion all over the world.

With the advancement in the medico-technical era, the time required to acquire the scan and collect information gradually reduces. It took 30 minutes to acquire the first brain scan, and about 2.5 hours were taken to process the data. Initially, only axial images were acquired, so it was named Computed Axial Tomography scanner. But in the present time, it is just a matter of seconds to acquire the scan and the image can be displayed in any plain. Because of this, all medical branches become CT dependent a lot. Whether it's a suspected infract or bleed, hemorrhage or headache, seizures or sinusitis, lung infection or pleural effusion, pancreatitis or abdominal bleed, liver abscess or cholelithiasis, a CT scan is a must performing test to initiate the treatment because of its higher resolution picture quality. Not only for initiation of treatment but for the continuous follow-up to check the status update about the diseases and patient condition; a CT scan is performed multiple times.

A. Cancer risk from CT

CT scan becomes the major modality for the diagnosis of cancer. On the other hand, determining the risk of cancer is also associated with it and has become a major controversy in the present time. BEIR (Biological Effects of Ionizing Radiation) published an outline model in 2006 stating that there would be some cancer risk associated with low doses of radiation encounter greater than 50mSv[3]. Costello et al. (2013) reviewed few studies showing the damage to the DNA as a harmful effect of radiation at low doses. In various laboratory experiments, hormonesis does occur. American Journal of Roentgenology (AJR) also

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issued a statement commenting on recognizing the harm caused due to low doses of CT radiation [3]. The U.S. Food and drug administration also compared the natural incidence of fatal cancer in the U.S. with a CT radiation dose of 10mSv which was similar to BEIR report. Pearce et al. (2014) also documented the relative risk of leukemia among the children increased three times who had received accumulative radiation exposure of a minimum of 30 mSv [4]. This major concern about the risk of cancer from radiation exposure derived from the studies performed on people who live miles away from the epicenter of the Hiroshima and Nagasaki tragedy emerging symptoms of cancer. Their distance from the epicenter of the atomic bomb concluded as multiple radiation exposures from the CT scanner. Multiple epidemiologic studies had published concerning the increasing number of patients by Pearce et al.

B. Risk of Cataract

In the new guidelines of ICRP 103, the annual radiation dose of the eye lens is reduced to 50mSv as the eyes lens is considered as the most radiosensitive organ in the human body. The eye lens is enlisted as the most radiosensitive tissue in the human body by ICRP, resulting in the development of cataracts and lens opacities [5]. Due to overexposure to eye lenses, there is a great possibility of radiation-induced cataracts or lens opacification without a threshold dose [6,7]. The ionizing radiation that emerges from CT doesn't only cause cancer but can be the reason for cataracts. A study showed that the risk of leukemia almost got tripled in children after their cumulative dose reaches to 50mGy. Because of these kinds of results, ICRP has updated and changed the threshold or equivalent dose limit values of the eye from 2-8 Gy to 0.50 Gy[7]. In 2012, *Yuan et al.* performed a survey on the patient who underwent head and neck CT examinations and get cataracts from 2000-2009 and he also concluded that there is a possibility of cataracts due to repeated CT examination [8].

Taking all those reports into consideration that had been published previously, the requirement and use of effective techniques and equipment is very important to avoid drastic results due to radiation in whole-body CT examination. Only reducing the radiation dose is not the only goal to achieve but getting a good and diagnosable image quality is also very important.

II. METHODOLOGY

This retrospective qualitative review, focused on assessing methods to safeguard radiosensitive organs like the eyes, thyroid, breast, and gonads. Thirty articles were scrutinized to determine effective techniques while maintaining image quality. Selection criteria included articles from reputable journals, excluding those not cited in databases like Scopus or PubMed and those unrelated to organ protection techniques. The study's design entailed summarizing results from literature, aiming to identify optimal approaches for radiation reduction.

III. RESULT & DISCUSSION

There are various organs in the human body such as the eyes, thyroid, breast, and gonads that need to be protected while performing any CT examination. After studying and going through 30 articles, it is seen that different techniques can be used to protect particular radiosensitive organs which provide greater protection with maintaining image quality and avoid any type of artifact. After going through previous studies, the eye considered as most sensitive study organ in the human body, and lots of techniques is suggested by various authors during head and face CT examinations to reduce radiation dose such as shielding, tube current modulation, tube voltage adaptation, iterative reconstruction, etc. All these techniques not only help in protecting eye lenses but other radiosensitive organs as well.

A. Gantry Tilt

In terms of protecting the lens of the eyes from direct exposure, the most applicable method in the practical field is gantry tilt to protect the eyes from the occurrence of cataracts due to over-exposure or accumulative exposure dose from all other examinations [6]. It is easily achievable. But in the case of trauma patients, we can't apply it as its major drawback is a little time-consuming and cause beam hardening artifact at the posterior fossa of the brain and base of the skull as well. This artifact causes degradation of image quality and due to tilting, there is a possibility of anatomical atrophy. The study performed by Nikupaavo et al and Lai CWK et al in 2015 both said that gantry tilt surely provides 92% of radiation protection to the lens of the eyes [7,9]. But in the case of other radiosensitive organs, gantry tilt doesn't pay off.

B. Shielding

For the protection of any organ, the first thing that comes to our mind is shielding. But in terms of shielding, lead shields seem to be the only option that comes into our minds. There are various types of shields that have been used in different types of studies by various authors such as bismuth shields, tungsten functional paper, and saba shielding which provide better image quality with fewer artifacts compared to a lead shield. But the result of these three shielding techniques in terms of protecting the lens of the eyes from exposure with diagnostic able image quality is different. But there is no particular study available that compares shields. According to *Jia Wang*, bismuth shields provide 26.4% of measured dose reduction compared to the initial reference scan10. *H. Kosaka et al* used tungsten functional paper as a shield for eyes lens but get a 17.8% of radiation dose reduction [11]. But *Y. Irdawaati* noted a 700% increase in CT number [12]. But by increasing the distance between eyes and TFP, the CT number can be maintained and image quality stays diagnostic able. But if we used a Saba shield made up 0.13mm thickness of zing and bismuth manufactured by *V. Saba.* it provides a dose reduction of 42% [13]. A silicon rubber lead shield was developed and tested by *Y. Irdawati et al* in 2019 whose lead percentage varies from 0-5%. The author also tried to increase the distance between the shield and eyes to check its effectiveness and gets around 50% of depletion in the exposure to the lens of the eyes recorded by the dosimeters placed at the eye's region [12].

C. Tube Current Modulation

Tube current modulation is a technique that is widely used in modern CT scanners. It works similarly as an Automatic Exposure Control switch in a conventional radiographic system. TCM changes the flow of current to the X-ray tube so that the quantity of production of xrays also gets varies which helps in reducing the amount of exposure to the organ. After studying a few articles, it appeared that multiple means could modulate tube currents. *Automatic Tube Current Modulation, organ-based tube current modulation, global tube current reduction, and SODAR (Specific-organ dose adaptation and reduction protocol)* are a few examples of CT software studied in articles.

➢ *Automatic Tube Current Modulation*

Automatic tube current modulation is one of the easiest methods to modulate the tube current in modern CT scanners. It works on the mechanism to obtain a target image quality for varying local patient attenuation throughout the scan [14]. The applied amount of ATCM during a scan is adjusted with the help of an operator-controlled image quality reference parameter. From attenuation characteristics of the patient recorded during the topogram, the CT scanner priorly determines the amount of tube current to be applied at different locations during acquisition. ATCM also accounted for patient attenuation characteristics for different projection angles during each rotation for angular modulation. Sometimes, previously acquired data of characterize attenuation during half or whole revolution is also used during ATCM to modulate the tube current angularly. When *Haji-Momenian et al* studied automatic tube current modulation using DLP and Monte-Carlo stimulated organ-based calculation for various CT examinations such as *unenhanced head CT, unenhanced chest CT, unenhanced abdominopelvic CT, pulmonary CTA* as well as *contrast CT* examinations on 16-MDCT and 64-MDCT; he concluded that there was about 19-39% of estimated dose reduction is recorded compared to reference scan in unenhanced CT head, for CT chest, about 15 % of dose reduction was recorded[15]. *Sookeng et al* performed a study in 2016 on CT head examination to compare signal-to-noise ratio and dose to lens of the eye and concluded that there was about 60% of dose reduction [16].

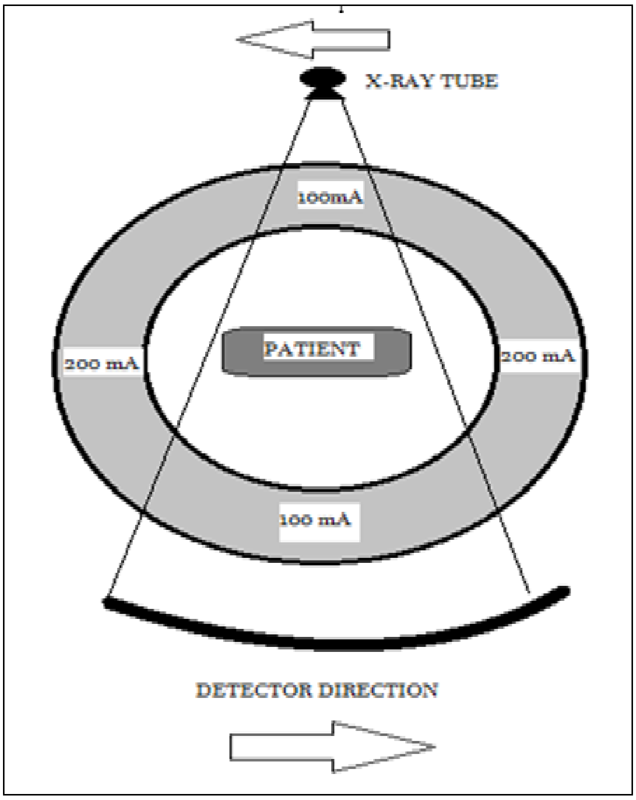

Fig 1: Automatic Tube Current Modulation

➢ *Organ-Based Tube Current Modulation*

Organ-based tube current modulation is an organ-specified tube current reduction module that reduces the tube current when the X-ray tube reaches the anterior aspect of the human body to a specific degree of the region during scanning. And when it crosses the radiosensitive organ, to maintain the image quality and CT number, the tube current gets increased to the rest of the posterior part of the scanning area. The total current and exposure time product over 360 degrees of revolution during organ-based TCM is equal to the amount of exposure performed without using organ-based tube current modulation [17]. During performing the CT head examination, by using the SODAR protocol, *Reimann et al* recorded about 46-59% of dose reduction to the eyes lens without compromising any image quality [18]. But when *Karmazyn et al.* studied the impact of body mass index on the result of using tube current modulation longitudinally in pediatric patients, the author stated that in patients whose body weight is less than 20 kg achieve around 11% of dose reduction [19]. The patient whose body weight lies between 60-100kg got 30% of dose reduction. On average, he recorded around 19% of overall dose reduction in pediatric patients. In the end, the author concluded that automatic tube current modulation is not much effective in pediatric patients with smaller body sizes.

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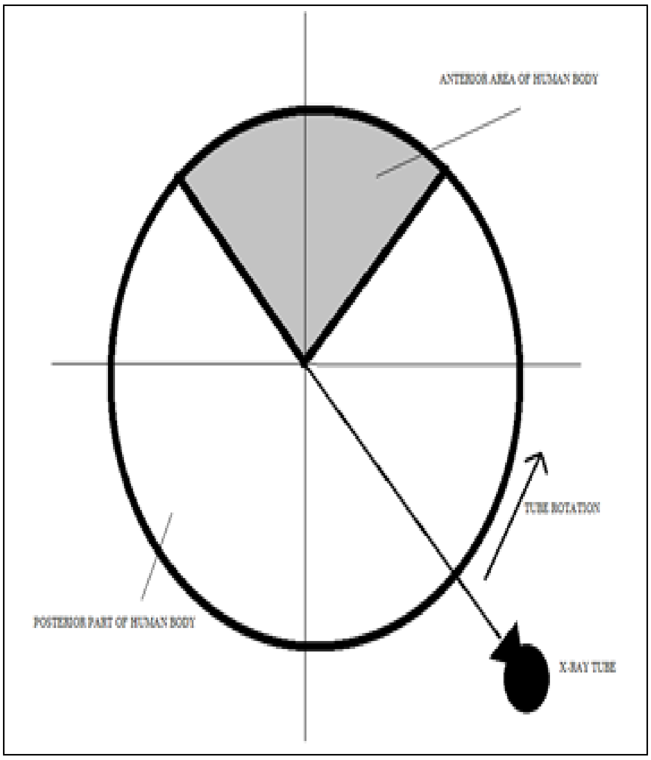

Fig 2: Organ bases TCM

➢ *Automatic Tube Voltage Adaptation*

Automatic tube voltage adaptation is an algorithmic tool that selects and modulates the voltage (70-140kV) based on the topogram on the bases of attenuation along the z-axis. This tool itself selects the voltage range at each scanning location that meets the prescribed image quality requirement. On the basis of the selected scanning range and amount of radiation dose, the curve of tube voltage modulation is calculated. But when sometimes the tube voltage range exceeded the system limit, the algorithm repeated the calculation maintaining the tube potential and acquiring the optimal image quality with a lower radiation dose. As in tube current modulation, tube current changes according to the region of exposure, in TVA the selected voltage remains the same throughout the whole CT investigation. After selecting the optimal values of kilovoltage, tube current, and CTDI vol, the software displayed the values before acquiring the scan so that any changes can be done to avoid repeating the scan. After using this software, *Mayer et al* concluded that there was about 35% of dose reduction in the CT chest, and a 42% of dose reduction in the CT abdomen compared to prior scanning. To evaluate the dose reduction, the author measured the drastic reduction in HU value in the images and when the images were being evaluated by the radiologists, they don't point out a major loss of information [20].

Due to tube current modulation and tube voltage modulation, beam hardening artifact is seen at the base of the skull in CT head examinations. So, *Lin et al* performed a study in 2017 that compared the result of a fixed tube current scan with a bismuth-antimony shield with a topogram-based tube current modulation scanning on an anthropomorphic phantom evaluating the image quality on the bases of SNR and CNR. Lin found about a 21.6% of the increase in SNR and 7.2% of CNR while using topogram-based tube current modulation. After combining topogram-based tube current modulation with barium sulfate or bismuth-antimony shield, there was a deduction of 12.2% to 27.2% of radiation dose delivered to the lens of the eye [21]. *Kosaka et al* also performed a study in 2019 on tube current modulation with using a tungsten functional paper shield and get a dose reduction of about 27.7% [11]. *Li et al* tested XCARE software for tube current modulation on CT chest examination on 560 female patients to calculate the amount of exposure to breast tissues and image quality in the detection of anomalies. On the basis of *p*-values, the author stated that using XCARE surely reduces the radiation exposure to breast tissues but keeps similar image quality as he received without using XCARE software [22].

Gervaise et al. also tested the impact of body mass index on the usage of tube current modulation, adaptive statistical iterative reconstruction, and tube voltage adaption on the diagnosis of Renal Colic and concluded that body mass index helps the modules to select the accurate factors to get better image quality mainly in case of obese and over-weight patients [23]. *Israel et al.* also performs an investigation to check the changes in automatic exposure control factors due to patient size during thoracic, pelvic, and abdominal CT examinations and concluded that with the increase in body weight, exposure quantity also increased which causes the increment in radiation exposure. Patients with body weight between 60-100 kgs received 3 times more radiation even with automatic tube current modulation [24]. But *Spaminato et al.* stated that a patient's body size does not impact the CT dosimetry calculation on theoretical as well as on practical grounds [25]. She said that CT dosimetry calculation is based on CTDIvol and DLP.

D. Iterative Reconstruction Algorithm

After using tube voltage adaptation or tube current modulation to reduce the production of x-ray so that radiosensitive organs can be protected, it costs in terms of degraded image quality. So, in that situation, post-processing comes into play. At present time, most of the scanners work on an iterative reconstruction algorithm. But ADMIRE and SAFIRE were mostly tested with tube voltage adaptation. *Schmid et al* tested the impact of ADMIRE & SAFIRE with TVA in head and neck CT examinations in 2017[26]. He tested both iterative reconstruction methods on 103 patients separately to evaluate their effect on image quality. The author further divides iterative reconstruction methods on the bases of their strength levels. He also used FBP algorithm for comparison also. He concluded that ADMIRE 3 with TVA provides 7.5% of lower exposure with 14.4% of less production of image noise than SAFIRE [21]. In 2018, *Ellman et al* also tested ADMIRE in abdominal CT to the amount of dose reduction. He compared the effect of ADMIRE strength 3 and 5 and he also said that after combining ADMIRE 3 with FBP in abdominal CT examination, there was about 30% of reduction in the exposure [26]. As per *Higaki et al* study published in 2018, his concern with the increase in the possibility of carcinogenic risk of 0.34-1.30% from abdominal CT examination, he stated after comparing previous studies on automatic exposure control, tube current modulation, iterative reconstruction algorithm; 20-40% of radiation exposure can be reduced by iterative reconstruction [28].

In 2014, H *Brodoefel et al* tried to check the effect of using iterative reconstruction with noise efficient detector design in CT head investigation and recorded a dose reduction of about 50% compared to the reference standard in terms of CTDI[29].

E. Knowledge & Attitude of Patients toward Radiation

No matter what type of technique is introduced in the market, it is useless unless it was requested. So education about the modality and knowledge about the drastic effects of radiation of the patient is very much important. *Takakuwa et al* perform a questionary survey on the patients who requested for CT examination to know about their knowledge related to the post-effects of radiation on their body and what changes in their decision happen when they get educated as well. It had been seen that only 34% of patients were well educated about the effects of radiation and out of which 74% of patients prioritize the diagnosis and treatment over the post-effects. While about 68% percent of patients let their physician decide whether to take the risk or not. But sex, body mass index, or perseverance of illness does not affect their decision [27].

F. Radiological Staff Training

With time, there is new advancement happening in the field of medical imaging and new techniques keep on introducing. The modality is controlled by the radiation technologist and if radiation technologists are not properly educated about the techniques which can be used to protect the radiosensitive organs then there is no use of the techniques. To test the importance of radiation technologists in reducing radiation exposure to radiosensitive organs with the proper usage of techniques, *Paolicchi et al.* perform a study on radiation technologists. He compares the repeated scans, visualization of posterior fossa structure in CT head examination, grey matter differentiation, subjective image quality in terms of artifacts, grey matter conspiracy, and contrast-to-noise ratio before and after intensive training of radiation imaging technologists. After the training, it was seen that CTDI and DLP get reduced significantly. Not only that, tube current-time value and tube voltage also reduced impressively in CT head examinations of pediatric patients [30]. On the other hand, to avoid exposure to organs that are not required for diagnosis, proper communication between physicians and radiation technologists also helps a lot [31]. *Hricak et al.* tried to establish a proper channel of communication between physicians and radiation technologists on hospital premises and it provides much better results in terms of less radiation exposure to radiosensitive organs and gets much better image quality and scans related to pathology [32]. During CT examination, posture is very important. Proper body posture not only provides better image quality in terms of diagnosis able data but also protects radiation-sensitive organs. As it already has been cleared that the eyes are the most radiosensitive organ of the human body, if we do not have a shield with us to protect the eye lens, we still can protect the eye lens by proper positioning during CT head and neck examination and get about 89% of dose reduction as well. A proper posture not only protects the eyes lens but reduces exposure to the median brain, pituitary gland, globes, and salivary gland by 59%, 52%, 66%, and 29% respectively [33].

IV. SUMMARY AND CONCLUSION

After going through all these articles that have been published in high-index journals, it is clear that radiation exposure is very dangerous for radiosensitive organs and it's the radiation imaging officer's duty to try every possible option to protect these organs such as the eyes, the thyroid, the breast, the gonads. And it is only possible after proper practice and education about protection techniques and their use. Patients should also get educated about the post-effects of the tests or procedure he is going to get. Proper communication between radiation technician and physician also help to achieve the goal of protecting radio-sensitive organs with image quality up to the mark. Medical imaging modality is filled with multiple techniques which can protect radiosensitive organs but after studying these techniques at after going through all the results received by the authors that tested these techniques on phantom and patients; it can be said that by combining silicon-rubber shields with TCM and Gantry tilting, the maximum protection to the lens of the eyes that keep the exposure in limited range with proper image quality can be provided. For other organs, SODAR protocol, and organ-based TCM can keep exposure factors under the limit. Iterative reconstruction algorithms control the image quality that displays on the monitor after processing and it has been seen that ADMIRE 3 provides optimum image quality with lower exposure.

REFERENCES

[1]. History of computed tomography - Wikipedia. (2007, May 7). History of Computed Tomography - Wikipedia. Retrieved November 20, 2022, from https://en.wikipedia.org/w/index.php?title=History_of_computed_tomography&oldid=1048274109
[2]. Half A Century In CT: How Computed Tomography Has Evolved — ISCT. (2016, October 7). ISCT. Retrieved November 20, 2022, from https://www.isct.org/computed-tomography-blog/2017/2/10/half-a-century-in-ct-how-computed-tomography-has-evolved
[3]. Costello, J. E., Cecava, N. D., Tucker, J. E., & Bau, J. L. (2013). Ct radiation dose: Current controversies and dose reduction strategies. American Journal of Roentgenology, 201(6), 1283–1290. https://doi.org/10.2214/AJR.12.9720.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24MAY839

[4]. Pearce, M. S., Salotti, J. A., Little, M. P., McHugh, K., Lee, C., Kim, K. P., Howe, N. L., Ronckers, C. M., Rajaraman, P., Craft, A. W., Parker, L., & Berrington De González, A. (2012). Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: A retrospective cohort study. The Lancet, 380(9840), 499–505. https://doi.org/10.1016/S0140-6736(12)60815-0

[5]. [No authors listed]. The 2007 Recommendations of the International Commission on Radiological Protection: ICRP publication 103. Ann ICRP

[6]. Poon, R., & Badawy, M. K. (2019). Radiation dose and risk to the lens of the eye during CT examinations of the brain. Journal of Medical Imaging and Radiation Oncology, 63(6), 786–794. https://doi.org/10.1111/1754-9485.12950

[7]. Nikupaavo, U., Kaasalainen, T., Reijonen, V., Ahonen, S.-M., & Kortesniemi, M. (2015). Lens dose in routine head ct: Comparison of different optimization methods with anthropomorphic phantoms. American Journal of Roentgenology, 204(1), 117–123. https://doi.org/10.2214/AJR.14.12763

[8]. Yuan, M.-K., Tsai, D.-C., Chang, S.-C., Yuan, M.-C., Chang, S.-J., Chen, H.-W., & Leu, H.-B. (2013). The risk of cataract associated with repeated head and neck ct studies: A nationwide population-based study. American Journal of Roentgenology, 201(3), 626–630. https://doi.org/10.2214/AJR.12.9652

[9]. Lai, C. W.-K., Cheung, H.-Y., Chan, T.-P., & Wong, T. H. (2015). Reducing the radiation dose to the eye lens region during CT brain examination: The potential beneficial effect of the combined use of bolus and a bismuth shield. Radioprotection, 50(3), 195–201. https://doi.org/10.1051/radiopro/2015003

[10]. Wang, J., Duan, X., Christner, J. A., Leng, S., Grant, K. L., & McCollough, C. H. (2012). Bismuth shielding, organ-based tube current modulation, and global reduction of tube current for dose reduction to the eye at head ct. Radiology, 262(1), 191–198. https://doi.org/10.1148/radiol.11110470

[11]. Kosaka, H., Monzen, H., Amano, M., Tamura, M., Hattori, S., Kono, Y., & Nishimura, Y. (2020). Radiation dose reduction to the eye lens in head CT using tungsten functional paper and organ-based tube current modulation. European Journal of Radiology, 124, 108814. https://doi.org/10.1016/j.ejrad.2020.108814

[12]. Irdawati, Y., Sutanto, H., Anam, C., Fujibuchi, T., Zahroh, F., & Dougherty, G. (2019). Development of a novel artifact-free eye shield based on silicon rubber-lead composition in the CT examination of the head. Journal of Radiological Protection, 39(4), 991–1005. https://doi.org/10.1088/1361-6498/ab2f3e

[13]. Saba, V., Valizadeh, A., Barkhordari, M., Shuraki, J. K., & Zahedinia, M. (2021). In-plane Saba shielding for dose reduction to the eye at head CT. Physica Medica, 92, S128. https://doi.org/10.1016/S1120-1797(22)00274-5

[14]. Merzan, D., Nowik, P., Poludniowski, G., & Bujila, R. (2017). Evaluating the impact of scan settings on automatic tube current modulation in CT using a novel phantom. The British Journal of Radiology, 90(1069), 20160308. https://doi.org/10.1259/bjr.20160308

[15]. Haji-Momenian, S., Ellenbogen, A., Khati, N., Taffel, M., Earls, J., Miller, G., & Zeman, R. K. (2018). Comparing dose-length product–based and monte carlo simulation organ–based calculations of effective dose in 16- and 64-mdct examinations using automatic tube current modulation. American Journal of Roentgenology, 210(3), 583–592. https://doi.org/10.2214/AJR.17.18294

[16]. Sookpeng, S., Butdee, C. Signal-to-noise ratio and dose to the lens of the eye for computed tomography examination of the brain using an automatic tube current modulation system. Emerg Radiol 24, 233–239 (2017). https://doi.org/10.1007/s10140-016-1470-6

[17]. Duan, X., Wang, J., Christner, J. A., Leng, S., Grant, K. L., & McCollough, C. H. (2011). Dose reduction to anterior surfaces with organ-based tube-current modulation: Evaluation of performance in a phantom study. American Journal of Roentgenology, 197(3), 689–695. https://doi.org/10.2214/AJR.10.6061

[18]. Reimann, A. J., Davison, C., Bjarnason, T., Yogesh, T., Kryzmyk, K., Mayo, J., & Nicolaou, S. (2012). Organ-based computed tomographic (Ct) radiation dose reduction to the lenses: Impact on image quality for ct of the head. Journal of Computer Assisted Tomography, 36(3), 334–338. https://doi.org/10.1097/RCT.0b013e318251ec61

[19]. Karmazyn, B., Ai, H., Liang, Y., Klahr, P., Eckert, G. J., & Jennings, S. G. (2015). Effect of body size on dose reduction with longitudinal tube current modulation in pediatric patients. American Journal of Roentgenology, 204(4), 861–864. https://doi.org/10.2214/AJR.14.12762

[20]. Mayer, C., Meyer, M., Fink, C., Schmidt, B., Sedlmair, M., Schoenberg, S. O., & Henzler, T. (2014). Potential for radiation dose savings in abdominal and chest ct using automatic tube voltage selection in combination with automatic tube current modulation. American Journal of Roentgenology, 203(2), 292–299. https://doi.org/10.2214/AJR.13.11628

[21]. Lin, M.-F., Chen, C.-Y., Lee, Y.-H., Li, C.-W., Gerweck, L. E., Wang, H., & Chan, W. P. (2019). Topogram-based tube current modulation of head computed tomography for optimizing image quality while protecting the eye lens with shielding. Acta Radiologica, 60(1), 61–67. https://doi.org/10.1177/0284185118770894

[22]. Li, C., Qi, L., Zhang, Y., Gao, F., Jin, X., Zhang, L., Tang, H., & Li, M. (2020). Image quality and clinical usefulness of automatic tube current modulation technology in female chest computed tomography screening. Medicine, 99(33), e21719. https://doi.org/10.1097/MD.0000000000021719
[23]. Gervaise, A., Naulet, P., Beuret, F., Henry, C., Pernin, M., Portron, Y., & Lapierre-Combes, M. (2014). Low-dose ct with automatic tube current modulation, adaptive statistical iterative reconstruction, and low tube voltage for the diagnosis of renal colic: Impact of body mass index. American Journal of Roentgenology, 202(3), 553–560. https://doi.org/10.2214/AJR.13.11350
[24]. Israel, G. M., Cicchiello, L., Brink, J., & Huda, W. (2010). Patient size and radiation exposure in thoracic, pelvic, and abdominal ct examinations performed with automatic exposure control. American Journal of Roentgenology, 195(6), 1342–1346. https://doi.org/10.2214/AJR.09.3331
[25]. Spampinato, S., Gueli, A. M., Milone, P., & Raffaele, L. A. (2018). Dosimetric changes with computed tomography automatic tube-current modulation techniques. Radiological Physics and Technology, 11(2), 184–191. https://doi.org/10.1007/s12194-018-0454-5
[26]. Schmid, A. I., Uder, M., & Lell, M. M. (2017). Reaching for better image quality and lower radiation dose in head and neck CT: Advanced modeled and sinogram-affirmed iterative reconstruction in combination with tube voltage adaptation. Dentomaxillofacial Radiology, 46(1), 20160131. https://doi.org/10.1259/dmfr.20160131
[27]. Ellmann, S., Kammerer, F., Allmendinger, T., Hammon, M., Janka, R., Lell, M., Uder, M., & Kramer, M. (2018). Advanced modeled iterative reconstruction (Admire) facilitates radiation dose reduction in abdominal ct. Academic Radiology, 25(10),1277–1284. https://doi.org/10.1016/j.acra.2018.01.014
[28]. Higaki, T., Nakamura, Y., Fukumoto, W., Honda, Y., Tatsugami, F., & Awai, K. (2019). Clinical application of radiation dose reduction at abdominal CT. European Journal of Radiology, 111, 68–75. https://doi.org/10.1016/j.ejrad.2018.12.018
[29]. Brodoefel, H., Bender, B., Schabel, C., Fenchel, M., Ernemann, U., & Korn, A. (2015). Potential of combining iterative reconstruction with noise efficient detector design: Aggressive dose reduction in head CT. The British Journal of Radiology, 88(1050), 20140404. https://doi.org/10.1259/bjr.20140404
[30]. Takakuwa, K. M., Estepa, A. T., & Shofer, F. S. (2010). Knowledge and attitudes of emergency department patients regarding radiation risk of ct: Effects of age, sex, race, education, insurance, body mass index, pain, and seriousness of illness. American Journal of Roentgenology, 195(5), 1151–1158. https://doi.org/10.2214/AJR.09.3847
[31]. Paolicchi, F., Faggioni, L., Bastiani, L., Molinaro, S., Puglioli, M., Caramella, D., & Bartolozzi, C. (2014). Optimizing the balance between radiation dose and image quality in pediatric head ct: Findings before and after intensive radiologic staff training. American Journal of Roentgenology, 202(6), 1309–1315. https://doi.org/10.2214/AJR.13.11741
[32]. Hricak, H., Brenner, D. J., Adelstein, S. J., Frush, D. P., Hall, E. J., Howell, R. W., McCollough, C. H., Mettler, F. A., Pearce, M. S., Suleiman, O. H., Thrall, J. H., & Wagner, L. K. (2011). Managing radiation use in medical imaging: A multifaceted challenge. Radiology, 258(3), 889–905. https://doi.org/10.1148/radiol.10101157
[33]. Mosher, E. G., Butman, J. A., Folio, L. R., Biassou, N. M., & Lee, C. (2018). Lens dose reduction by patient posture modification during neck ct. American Journal of Roentgenology, 210(5), 1111–1117. https://doi.org/10.2214/AJR.17.18261