A Study on Clinical Applications of Ultra Low Dose CT Scan

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***Abstract* - Computed Tomography contributes a substantial portion of radiation cumulative effective doses within diagnostic radiology, significantly effecting the younger population who have to undergo repeated investigations for various chronic diseases. Ultralow dose CT scan protocols are emerging as one of the various strategies to manage the radiation doses during medical imaging in various clinical settings. By reducing long-term risks, enabling frequent follow-ups with minimal radiation, and facilitating rapid diagnosis in emergency situations, ULDCT optimizes diagnostic imaging while safeguarding patient safety. Additionally, its role in supporting research on radiation dose reduction strategies underscores its importance in advancing both clinical practice and patient care.**

Key Words: Ultra Low Dose Computed Tomography (ULDCT),Computed tomography (CT), Low-dose (LD), Signal to noise ratio (SNR) and Contrast to noise ratio (CNR).

I. INTRODUCTION

Computed tomography is a widely employed imaging modality because of its diverse clinical applications. Along with the numerous advantages, CT scans are also contributing to a substantial amount of effective radiation doses to the patients [1]. The radiation dose from CT comprises a substantial portion of cumulative effective doses within diagnostic radiology significantly effecting younger population who have to undergo repeated investigations for chronic diseases. There are various methods of radiation doses reduction in medical imaging. One of the emerging strategy involves implementation of low-dose and ultralow-dose CT protocols. These protocols along with the utilization of innovative image reconstruction algorithms based on artificial intelligence helps in reduction of patient dose up to 80% as compared to standard dose protocols [2].

During the COVID-19 pandemic, ensuring radiation protection and dose optimization for chest X-rays and CT scans was paramount. While CT scans deliver higher doses and may be necessary for diagnosing and monitoring COVID-19, healthcare providers must carefully justify their use and prioritize minimizing radiation exposure, especially for vulnerable populations such as younger patients and pregnant individuals. Similarly, although chest X-rays offer lower radiation doses, adherence to ALARA Principles is still essential to minimize unnecessary exposure. Ultra-low dose CT imaging emerges as a valuable tool, particularly in pediatric imaging, follow- up studies, and screening programs [2, 3]. By reducing long-term risks, enabling frequent follow-ups with minimal radiation, and facilitating rapid diagnosis in emergency situations, ULDCT optimizes diagnostic imaging while safeguarding patient safety. Additionally, its role in supporting research on radiation dose reduction strategies underscores its importance in advancing both Clinical practice and patient care.

II. REVIEW OF LITERATURE

A review of literature from 2017 to 2024 has been done in this paper to analyze the areas of application of ULDCT. The article authored by Xin Sui in 2017 evaluated ultra-low-dose computed tomography (CT) for pulmonary alveolar proteinosis (PAP), involving 38 patients. Ultra-low-dose CT demonstrated a mean effective radiation dose of only 0.25mSv, approximately to chest radiography. Image noise was significantly reduced with iterative reconstruction (IR), enhancing diagnostic confidence. PAP-specific CT patterns were clearly observed, aiding diagnosis and follow-ups. Quantitative CT measurements correlated strongly with pulmonary function tests (PFTs), particularly mean lung density with diffusion capacity of carbon monoxide (DLCO). Ultra-low-dose CT offers potential for sensitive and objective PAP assessment, with substantially reduced radiation exposure, beneficial for long-term follow-ups, especially in young patients. Limitations include the absence of a control group due to PAP's rarity and the use of low-dose CT as a reference instead of standard CT. Nonetheless, ultra-low-dose CT presents as a valuable option for monitoring PAP progression and treatment response, with implications for other pulmonary diseases [4,10].

The paper authored by G. Widmann. D. Juranek conducted 36 CT datasets using various protocols and reconstruction techniques, showcasing significant dose reductions up to 98.6% while maintaining image quality. Iterative reconstruction techniques, particularly model-based iterative reconstruction (MBIR), showed superior performance in contrast-to-noise ratio (CNR) compared to traditional filtered back projection (FBP). Despite promising results, the study had limitations, including the use of a cadaver head and potential artifacts from surgical implants. Overall, the findings underscored the potential of iterative reconstruction techniques in reducing radiation dose while preserving image quality in CT imaging of orbital soft tissues [5].

Another study conducted by Dominik C Benz evaluated low-dose (LD) and ultra-low-dose (ULD) contrast protocols for coronary CT angiography in 120 patients using a 256-slice CT scanner. LD and ULD protocols were compared, with LD demonstrating comparable significantly different attenuation levels. Visual image quality did not differ among protocols. However, a higher proportion of patients experienced inadequate vessel attenuation with attenuation to normal-dose (ND) protocols, while ULD showed ULD. The LD protocol, with a median volume of 45 ml, proved feasible for current CT scanners, suggesting its viability as an alternative to ND protocols. Nonetheless, ULD protocols remain challenging due to insufficient vessel attenuation, indicating a need for further refinement to enhance their effectiveness in clinical settings [6].

In the study conducted by Fabian Henry Jurgen Elsholtz ULDCT along with deep learning reconstruction was evaluated for diagnosis of renal calculi diagnosis. ULD-DLR showed a stone detection rate of 95.4% and a lesion detection rate of 92.2%. The quality of image on ULD-DLR was comparable to standard low-dose CT (LDCT) and superior to ULD-HIR. ULD-DLR achieved a 77% reduction in radiation dose compared to LDCT, with similar CT values of organs and improved signal-to-noise ratio. The findings suggest that ULDCT with DLR maintains diagnostic accuracy for renal calculi while significantly lowering radiation exposure [7]. According to the study, ULDCT has a lower rate of complications than SDCT and is hence suitable for lung treatments. Additionally, it decreased the total radiation dose from 412 mGy-cm to 34 mGy-cm while maintaining the accuracy of needle insertion [8,9]. Jin S et al. in 2018 did a study involving 82 cancer patients. In this chest scans at 80 kV and abdomen CT scans at 120 kV were conducted. The nodules present in lungs were assessed using two CAD systems, both manually and semi-automatically. Nodules were categorized by size and density, and measurements such as 3D volumes, average diameter, and CT values were compared between the two voltage settings. The study also validated the accuracy and reliability of CAD systems for large nodules [11].

A study by Sun J et.al in 2018 comprised two phases. In the first, 16 low-dose CT dacryocystography scans were reconstructed using MBIR and FBP, showcasing noise reduction by MBIR. Comparison was made with 21 standard-dose paranasal sinus scans using ASIR. In the second phase, 14 pediatric tumor patients underwent follow-up scans with reduced radiation and MBIR. Image noise, CNR of sphenoid, and subjective quality were assessed. CTDIvol, DLP, and effective dose were recorded. MBIR demonstrated noise reduction, maintained image quality, and potentially reduced radiation exposure in both phases [12]. In this article by Widmann et.al utilization of CBCT in implant dentistry presented a spectrum of challenges and opportunities. While its diagnostic capabilities extend beyond traditional radiography, the variation in doses and image quality necessitates optimization and justification before clinical implementation [13].

I Noël PB et al. in 2018 involved 40 scans of thorax-abdomen-pelvis from 20 patients with follow-up of tumor. Each patient was scanned using both standard-dose and a low-dose protocol. The reconstructed images were processed using three different algorithms. The aim was likely to compare image quality and radiation dose reduction across the different protocols and reconstruction methods, which could have implications for optimizing tumor follow-up imaging protocols [14, 16]. J. He et al. involved a novel approach for low-dose CT (LdCT) imaging leveraging deep learning (DL) techniques to enhance model-based iterative reconstruction (MBIR). The proposed method, termed parameterized plug-and-play alternating direction method of multipliers (3pADMM), integrated DL to optimize both the parameterized plug-and-play (3p) prior and related parameters simultaneously, streamlining the process. By training on a large dataset, this framework achieves robust LdCT reconstruction performance. The experiment results using clinical dataset also demonstrated superior noise-induced artifact suppression and edge detail preservation as compared to existing algorithms, showcasing the potential of this DL-based strategy for improving LdCT image quality [15, 17] .Kim et al. examined that artificial intelligence is used in ultra-low dose CT scan to decrease the noise. A convolutional neural network (CNN) is trained with above 18,000 regular dose CT images. They used a simulation tool to get low dose CT images and synthetic noise together. CNN used in ultra-low dose CT scan predict and remove the noise.This deep learning based denoising method resulted in less noise and better image quality as compared to the traditional techniques [18].

Petritsch et al. founded that a tin filtered 100 kV protocol is used in ultra-low dose CT scan to assess the attainable image quality and radiation dose in patients with suspected acute inflammatory paranasal sinus disease[19, 23].Svahn et al. in their comprehensive article explained that how different imaging techniques like standard CT (SD-CT), ultra-low dose CT (ULD-CT), and digital radiography (DR) affects radiation dose in different sized patients [20].

The article by Kroft et al. compared ULDCT and chest x-ray for chest abnormality diagnosing in 200 patients. Ultra-low dose CT gives 100 % diagnostic accuracy and higher confidence levels that leads to more accurate treatment decisions. Discrepancies like false positives or false negatives between these two methods affects the management decisions in 20 % of case. ULD-Ct shows similar radiation exposure to CXR and is more effective. ULD-CT seems hopeful in enhancing chest pathology diagnosis in clinical practice [21, 24]. Zhao et al.'s study in 2019 presented a special computer model called DnCNN-CT that improves the quality of low dose CT images by reducing noise. It was useful for doctors to accurately detect lung diseases like emphysema [22].

Fariba Zarei et al.'s in depth analysis in 2020 evaluated the diagnostic findings of ULDCT for chest as compared to routine CT of Chest. Patients diagnosed with COVID-19 were scanned using routine dose and ultra low dose. Later axial images of both the CT Scans were compared and evaluated by SNR and pixel by pixel noise measurement. It was found that routine chest CT can be replaced by ULD as it provided dose reduction of 94% [25]. Zlatan Alagic et al. in the same year compared the effectiveness of DR and ULD-CT in detecting fractures. ULD-CT showed a statistically advantage over DR in detecting acute fractures and providing additional fracture related findings[26, 30].

Cristina Manera et al. suggested that ultra-low dose computed tomography of the chest without anesthesia is feasible for assessing pulmonary disease in children. It achieved high diagnostic quality with minimal motion artifacts and a mean effective radiation dose of 0.39 mSv, making it a promising technique for pediatric imaging [27, 31].

A study by Kutsi Tuncer et al. examined 98 patients with suspected ankle fracture. Two observers independently evaluated conventional CT and ULDCT image findings. There were no such differences in the quality of image of conventional CT and ULDCT. The effective radiation dose of ULDCT was comparatively lower that conventional CT. Hence, the study evaluated that ULDCT proved to be a reliable tool for fractures of ankle [28]. Robin Z. Cheng et al. reviewed ULD CT scans for ureteral stones and found that they were effective in detecting small and distal stones that might be missed by conventional KUB or ultrasonography [29].

Joël Greffier et al.'s study in 2021 finds similar result in ULD as compared to STD. CNR increase with ULD CT acquisitions as compare to STD CT. Signal to noise ratio (SNR) and Contrast to noise ratio (CNR) observed in normal lungs condition and with pathological condition were almost same, images are readable and we can reduce 88% of radiation dose as compare to STD. ULD CT chest is used full to find normal pathology not efficient for deep of lungs e.g. lungs fibrosis [32,38]. Basien Nicolana et al.'s study examined ULD abdominal CT are useful for bowl obstruction and colitis but for pathologies like as appendicitis STD is preferred[33].
Jordan Chamberlin et al. examined Auto detection of lungs nodules and calcification on coronary artery by

LDCT with help of AI was possible [34,39]. The study conducted by Javid Azadbakht et al. on Chest screening in COVID-19 bring exposure as low as possible for visualization of pneumonia by ULDCT easy. Exposure factor in low dose flow 110kv with 30-140 mA it is very low to STD exposure 120 kV with 320mA [35].Isaac Shiri et al.'s study on Ultra-low-dose chest CT imaging of COVID-19 patients using a deep residual neural network study can reduce 89% of radiation dose, exposure 90kvp with 20-45mA should give 0.66-1.02 mGY radiation, but we cannot able to proper visualized image clearly for deep neural network [36,37].

A study by Gobi et al. in 2022 confirms ultra-low dose CT promising results in detecting pulmonary lesions while minimizing radiation exposure. By use of a third generation Siemens dual-energy CT scanner and a specialized ULD-CT protocol, the study achieved highest diagnostic accuracy with sensitivity of 91% and specificity of 100%. This study evaluates ULD-CT's efficacy in detecting lung lesions associated with COVID-19 [40, 45].Another study by Zarei et al. was conducted at Faghihi Hospital, Iran. This study compares the diagnostic accuracy and quality of image of ULDCT and routine dose CT. ULD-CT shows 94% reduction in radiation exposure, making it a more valuable tool for early detection of COVID-19 related lung lesions [41].

Addala et al. in 2022 focused on ULDCT scan's utility in detecting extremity fractures in trauma patients. This study is conducted at Nimes university Hospital, France found that ULD-CT has better accuracy in detecting fractures as compared to Digital radiography, with higher sensitivity of 93%. Also, ULD-CT identifies fractures that are missed by DR [42]. Kristjansdottir et. al evaluated ULD-CT's efficacy in detecting lung lesions associated with COVID-19. [43, 46].

Zhang et.al explored the combination of ULD-CT with deep learning reconstruction for diagnosing renal calculi while minimizing radiation exposure. The study shows that Ultra-low-dose CT combined with DLR achieved 100% detection rate for stones larger than 3mm. Additionally, ULD-CT combined with DLR shows lower noise levels and Higher SNR as compared to standard CT's [44, 47].The study conducted by Garg et. al in 2023 estimated the effectiveness of ultra-low dose CT in diagnosing acute COVID-19 pneumonia compared to standard-dose CT. Ultra low dose CT showed similar image quality and diagnostic accuracy in detecting COVID-19-related lung abnormalities such as ground glass opacities and linear opacities. It also reduced radiation exposure by 94.38% compared to standard dose CT Overall, ultra-low dose CT proves to be a promising alternative for COVID-19 imaging, offering reliable diagnosis with less radiation risk. It also al discussed that ultra-low dose CT could become a main imaging modality for chest evaluation in low-prevalence non-traumatic emergency department patients. They highlight the need for more research, particularly on cost-effectiveness, as CT is more expensive and time-consuming than chest x-ray [48, 52].

Bayfield et. al explored the use of ultra-low dose CT scans in detecting early lung disease in children with cystic fibrosis. It aims to confirm the effectiveness of this approach compared to low dose CT scans. By implementing spirometer- direct ULDCT scans, the study evaluates structural airway disease using both visual and automated quantitative analysis. The research brings out the importance of accurately identifying early abnormalities to aid in the prevention and management of cystic fibrosis lung disease growth [49, 53].

Karin et. al showed the effectiveness of ultra-low dose CT chest scans in detecting acute COVID-19 pneumonia compared to SDCT scans. It aimed to reduce radiation exposure to patients while maintaining diagnostic quality. Results showed ULDCT submit images with comparable quality to SDCT, with significant reduction in radiation dose (94.38%). ULDCT proven high sensitivity (100%) detecting key COVID-19 imaging features like ground glass opacities (GGOs) and consolidation [50, 54]. Another study by Yan et. al investigated the use of ULDCT reconstructed with an AI iterative reconstruction algorithm in total-body PET/CT imaging. Both phantom and clinical parts were done, comparing ULDCT with AIIR to with hybrid iterative reconstruction. Results showed that ULDCT with AIIR provided comparable image quality to SDCT with HIR, with reduced image noise and high signal-to-noise ratio. However, ULDCT with AIIR could not entirely change SDCT with HIR, but may be suitable for specific circumstances in PET/CT examinations [51].

Kawamoto et. al in 2024 investigated the use of a silver (Ag) filter in low-dose chest CT scans. The filter significantly reduced radiation dose (30% lower) while maintaining image quality. This was achieved by increasing the average energy of the X-rays and reducing image noise. The Ag filter also helped to minimize streak artifacts, especially at very low radiation doses. [55, 60]. A study by Steven Kunz et al. investigated methods for reducing radiation exposure in abdominal CT scans, particularly for diagnosing urinary stones. They compared two techniques: spectral shaping (using a tin filter) and tube voltage modulation (adjusting the voltage of the X-ray beam). The study found that using a tin filter at 100 kVp resulted in the best image quality, even at very low radiation doses (0.5 mGy), compared to other settings [56, 61].

Qing Li et al. paper highlighted a novel deep learning approach, Progressive Cyclical Convolutional Neural Network (PCCNN) in enhancing low-dose CT image quality. Trained on unpaired data, PCCNN leverages noise transfer modeling and progressive refinement to remove noise without compromising diagnostic details. Researchers propose PCCNN, a cutting-edge deep learning method for denoising LDCT images [57].

A study by Mengqiang Xiao et al. investigated the use of ultra-low-dose CT scans for creating 3D printable models of distal radial fractures. They found that the ultra-low-dose CT protocol significantly reduced radiation exposure (by 97.1%) as compared to the standard-dose protocol, while still maintaining sufficient image quality for diagnosing DRFs and creating 3D printed models for preoperative assessment [58].

Yoon JH et al. investigated low-dose computed tomography with deep learning reconstruction for chest scans. The researchers compared this technique to standard-dose CT (RDCT) and low-dose CT with a different reconstruction method (HIR). The study found that LDCT DLR significantly reduced radiation exposure compared to RDCT. It also produced lower image noise and better overall image quality than LDCT HIR [59].

III. DISCUSSION AND CONCLUSION

It is evident from the review of literature that there is a need to modify the current practices because of recent technological improvements. The major dose reduction is also limited to the organs under study. It is important to consider justification and optimization before interpretation and patient management. Also Al software will modify practices such as dose optimization, detection and characterization so there is a need to modify CT practices in order to offer maximum benefits to the patients. Lack of awareness about benefits of ultra-low dose CT over the other diagnostic modalities is still a concern among radiographers in developing countries. The paper examine a number of research on ultra-low-dose computed tomography and its medical uses highlighting the benefits of this technique for lowering radiation exposure while preserving diagnostic precision. ULDCT is a useful choice for patients who require frequent imaging, such as those with pulmonary alveolar proteinosis (PAP), because of its effective radiation dose of approximately 0.25 mSv, which is comparable to standard chest radiography.

Research shows that ULDCT can help diagnose PAP by improving picture clarity using iterative reconstruction approaches. This enhancement facilitates precise tracking of the course of the illness and the effectiveness of treatment, particularly in younger patients. Additionally, computer-aided detection methods improve diagnosis accuracy in lung nodules, which is important in cancer. ULDCT is validated for this purpose. By drastically lowering picture noise, the incorporation of model-based iterative reconstruction (MBIR) enhances ULDCT even further and boosts diagnostic confidence. Cone-beam computed tomography (CBCT) in dentistry provides sophisticated three-dimensional imaging, but it needs to be optimized to efficiently handle different radiation dosages.

Furthermore, ULDCT's diagnostic capabilities are further enhanced with the addition of artificial intelligence (AI) and deep learning algorithms, which improve image quality and reduce noise. In emergency situations, ULDCT is crucial for its remarkable efficacy in identifying fractures, frequently outperforming digital radiography in this regard. ULDCT demonstrated itself to be a dependable imaging technique for evaluating lung abnormalities during the COVID-19 pandemic, preserving diagnostic accuracy while reducing radiation dose. ULDCT's capabilities are being further enhanced by recent breakthroughs including deep learning techniques and sophisticated filtering. Overall, ULDCT shows great promise as a substitute for conventional imaging techniques in a variety of medical applications, providing notable advantages in terms of safety and diagnostic accuracy, especially in situations when patient safety is paramount or frequent imaging is required.

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