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بجامعة المرقب

العدد السادس والعشرين
يناير 2025م

هيئـــة التحريـر

- المجلة ترحب بما يرد عليها من أبحاث وعلى استعداد لنشرها بعد التحكيم .
- المجلة تحترم كل الاحترام آراء المحكمين وتعمل بمقتضاها .
- كافة الآراء والأفكار المنشورة تعبر عن آراء أصحابها ولا تتحمل المجلة تبعاتها .
- يتحمل الباحث مسؤولية الأمانة العلمية وهو المسؤول عما ينشر له .
- البحوث المقدمة للنشر لا ترد لأصحابها نشرت أو لم تنشر .

ضوابط النشر:

يشترط في البحوث العلمية المقدمة للنشر أن يراعى فيها ما يأتي :

- أصول البحث العلمي وقواعده .
- ألا تكون المادة العلمية قد سبق نشرها أو كانت جزءا من رسالة علمية .
- يرفق بالبحث تزكية لغوية وفق أنموذج معد .
- تعدل البحوث المقبولة وتصحح وفق ما يراه المحكمون .
- التزام الباحث بالضوابط التي وضعتها المجلة من عدد الصفحات ، ونوع الخط ورقمه ، والفترات الزمنية الممنوحة للتعديل ، وما يستجد من ضوابط تضعها المجلة مستقبلا .

تنبيهات :

- للمجلة الحق في تعديل البحث أو طلب تعديله أو رفضه .
- يخضع البحث في النشر لأولويات المجلة وسياستها .
- البحوث المنشورة تعبر عن وجهة نظر أصحابها ، ولا تعبر عن وجهة نظر المجلة .

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A Review of mAs Optimization Strategies in CT Imaging: Maximizing Quality and Minimizing Dose simultaneously

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Abstract:

Milliampere-seconds mAs, a product of tube current (mA) and the scan time (seconds), plays a fundamental role in determining the radiation dose delivered to patients. Increasing mAs generally improves signal-to-noise ratio (SNR) in images, enhancing image quality by reducing noise and improving the clarity of fine details. However, this comes at the cost of increasing the radiation dose, which must be carefully balanced to avoid unnecessary exposure. Conversely, reducing mAs might result in increasing the noise of radiology image and minimising contrast with spatial resolution, potentially compromising diagnostic accuracy. Computed tomography is a cornerstone of modern medical imaging, offering unparalleled anatomical details. Nevertheless, its widespread use necessitates cautious consideration of dose optimization. Milliampere-seconds significantly influences image quality. This review examines the complex interplay between mAs, image quality metrics (noise, spatial resolution and contrast resolution besides radiation dose), integrating findings from recent studies and emphasizing strategies for mAs optimization. The impact of various techniques, including iterative reconstruction and automatic exposure control, will be discussed in the framework of both achieving diagnostically acceptable images and minimizing patient effective dose. An analysis of relevant studies exploring various approaches to mAs optimization and the resulting image quality tradeoffs will be presented. Emphasizing the optimization of exposure factors (mAs) allows healthcare providers to deliver superior patient care while reducing the possible risks from radiation doses.

Keywords: Milliampere-seconds, Dose Optimization, Image Quality, Computed tomography

Introduction:

CT transforms medical diagnostics by giving detailed cross-sectional images of patient's body. This advancement enables the picturing of intricate anatomical structures, that makes it becomes indispensable for diagnosing a varied range of medical conditions. However, this capability exceeds that of conventional radiography. With the global increase in CT, there are urgent need for strategies to reasonable radiation risks while maintaining diagnostic accuracy (Brenner, et al 2007).

The reason behind increasing patients whom undergoing CT scan is the accuracy it provides. It's now become a routine to use CT scan in clinical situations such as emergency, outpatient, and general practice thus they are increasingly becoming an essential component of health. Likewise, the capability to quickly acquire accurate pictures led to better outcomes for patients through timely detection and diagnosis of diseases, better planning of operative intervention and better follow up of diseases' management (Smith 2020).

It is critical to understand the relationship which exists among mAs, image contrast and effective dose. More mAs would result to picture being clearer but the radiation would be higher, whilst the opposite is true with lower mAs settings (Jones et al., 2019). For instance, Tan et al. (2023). demonstrated that a CT scanning protocol using 180 mAs was more effective in reducing radiation dose compared to protocols using 100 mAs and 280 mAs. In addition, Mehnert et al. (2023) explored the effectiveness of lower mAs settings on diagnostic image contrast in forensic age estimation. Their study found that while lower mAs settings (40, 30, and 23 mAs) achieved high diagnostic quality, they still resulted in higher doses than those obtained at one hundred kV. This indicates that while lower mAs is effective, careful consideration must be given to the specific clinical context and diagnostic requirements. Synthetic CT techniques have also been investigated as a means to simulate lower dose protocols. Wang & Pelc, (2011) demonstrated that to add noise to original scan projections, could effectively simulate lower mAs settings while still providing sufficient image quality for diagnoses. This approach may offer a pathway to reduce radiation in clinical settings. The pediatric population is particularly sensitive to radiation, making the optimization of mAs settings in this group crucial. Tada et al. (2017) found that a low-dose protocol (80 kV, 150 mAs) for temporal bone images in children improved image quality compared to higher kV settings. This suggests that tailored protocols for specific patient demographics can yield better outcomes. Singh and Sukkala (2021) conducted good phantom study that revealed the direct impact of mAs, concluding that reducing mAs to 50 in multislice low-dose CT scans resulted in minimal effects on image contrast for slice thicknesses of 4 mm. Kubo et al. (2016) demonstrated that a low-dose chest CT protocol (50 mAs) could be effectively used for comprehensive assessments of intrathoracic abnormalities, indicating that lower mAs settings can still meet clinical diagnostic requirements. This is further supported by findings from Kim et al. (2016) who emphasized that standard tube voltage (120 kVp) produced better quality images than lower voltages, reinforcing optimization importance of both mAs and kVp settings. Yi et al. (2017) found that using a 100-mA for multidetector CT scans met clinical diagnostic requirements while significantly reducing patient effective dose compared to conventional higher doses. This aligns with findings from Mohan, (2021), who reported substantial reductions in radiation exposure when mAs was decreased. Zhou et al, (2023) demonstrated that ultra-low-dose spectral-detector CT could accurately quantify pulmonary nodules, suggesting that innovative technologies can facilitate further reductions in radiation effective dose without compromising diagnostic capabilities. This review identifies the different approaches taken to guarantee that a balance has been reached, therefore, achieving and maintaining quality images while also providing safety to the patients. Furthermore, we hope to give a thorough review of where the field is currently standing and future insight by reviewing the CT dosimetry principles.

1. The Impact of mAs on Image contrast and Radiation effective dose

Milliampere-second is a fundamental parameter in CT. Higher mAs settings typically produce better image by enhancing the signal-to-noise ratio (SNR) and reducing image noise. However, this increase in image contrast is accompanied by a proportional increase in radiation effective dose, raising concerns about patient safety (McNitt-Gray, 2006). Conversely, lower mAs settings lead to decreased image quality, characterized by increased noise and reduced contrast resolution, potentially compromising diagnostic accuracy. Striking the right balance in mAs settings is critical, as overexposure lead to unnecessary radiation risks while underexposure may result in inadequate diagnostic information (Ludwig & Reza, 2012). Lowering the mAs reduces radiation dose, nevertheless, this can compromise image quality by increasing image noise, results in introducing artifacts (Brenner & Hall, 2007; Reid et al., 2010; Zarb et al., 2024).

The complex balance between mAs, image quality metrics spatial resolution, contrast, noise and radiation dose in CT is a critical aspect of modern radiology. Achieving high diagnostic effectiveness while minimizing ionizing radiation to patient requires a deep understanding of the interplay among these factors. (Zarb, et al. 2024). Figure (1) illustrates how noise, uniformity, and dose change with increasing mA at 80, 100, and 120 kV. It shows that noise decreases and uniformity improves with higher mA, but this comes with increased radiation dose. These results highlight the importance of selecting appropriate mA levels based on clinical requirements and patient safety considerations. (Diab et al.2023).

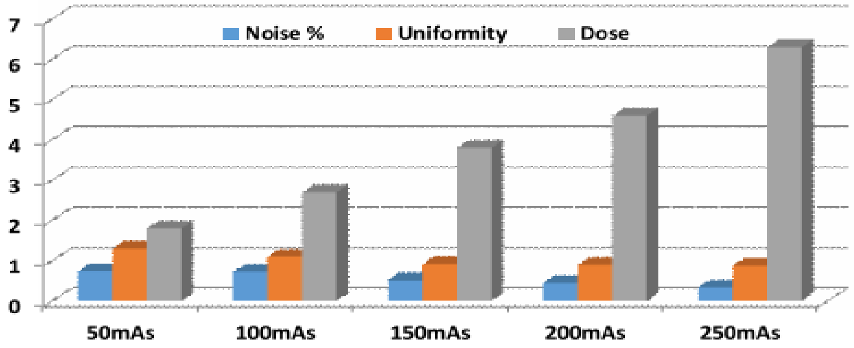

Figure 1: Dependence of uniformity, noise and dose values on different mA at 80 kV. Diab et al.2023

Image Noise

Image noise decreases as the square root of the milliampere-seconds (mAs) increases. Higher mAs reduces noise, resulting in a clearer image (Bushberg et al., 2011). However, excessive mAs can lead to unnecessary radiation effective dose without significant improvements in diagnostic quality. Figure 2 shows how noise varies with changes in tube voltage (kV) and current (mA). At lower kV and mA settings (e.g., 80 kV, 50 mAs), the noise is higher, whereas increasing these parameters reduces noise. The figure emphasizes the tradeoff between radiation dose and noise, illustrating the importance of optimizing kV and mA to achieve diagnosable image quality while minimizing radiation. (Diab et al.2023). Radiographers must balance images quality and patients' dose by selecting the lowest mAs that provides diagnostically acceptable images. This requires understanding the specific clinical task and the patient's condition (Bushberg et al., 2012).

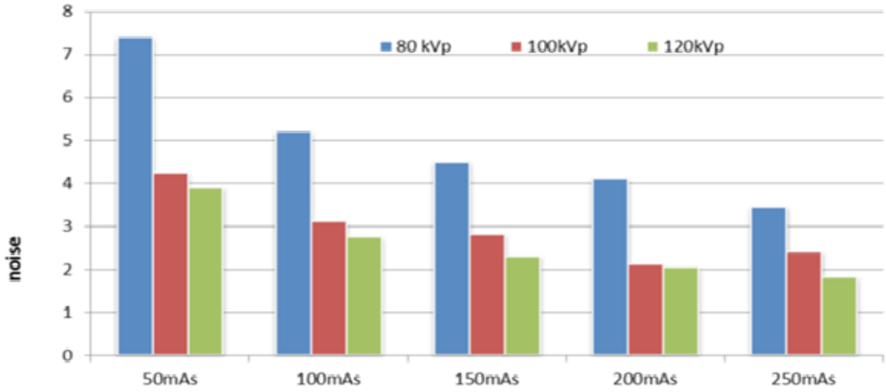

Figure 2: Noise values at 80, 100 and 120 kV and 50, 100,150,200and 250 mA. Diab et al. 2023

Spatial Resolution

Spatial resolution is largely unaffected by mAs, because Spatial resolution depends on geometric factors like focal spot size and detector characteristics (Lin and Alessio., 2009) (Alsleem and Davidson 2012).

2. Strategies for mAs Optimization:

mAs is crucial in defining radiation effective dose and contrast of CT scans images. Reducing mAs without losing important diagnostic information requires combination of better hardware, improved image processing, and well-developed protocols.

Effective mAs optimization involves selecting optimum exposure parameters and utilizing advanced technologies to balance image contrast quality and effective absorbed dose. Many studies and protocols aim to reduce the radiation exposure during CT imaging without compromising diagnostic quality. Application of mAs reduction plays a central role in these efforts. Iterative reconstruction (IR) techniques and automatic exposure control (AEC) are two advanced methods that have shown promise in optimizing mAs. These techniques enable the use of lower mAs settings while still producing high-quality images. AEC systems dynamically adjust the mAs. (Kalra et al., 2004; Solomon & Samei, 2019).

Iterative Reconstruction (IR):

IR is a sophisticated image reconstruction algorithm used in CT that has revolutionized the field by significantly reducing image noise and radiation dose. Unlike traditional filtered back projection (FBP), IR iteratively refines the image by comparing it to measured data and making continuous adjustments until the two align (Kim et al.2014).

Iterative processes that involve forward and backward projections, statistical modeling, and noise reduction techniques. As a result, IR can produce clearer and more detailed images, which are essential for accurate diagnosis. Studies have shown that IR can enhance the visibility of low-contrast structures and reduce streak artifacts, leading to better overall image quality (Solomon & Samei, 2019).

IR algorithms process raw CT data to reduce noise and artifacts. A critical benefit of IR is its potential to lower the radiation dose required for CT scans. By enhancing image quality at lower dose levels, IR allows for substantial dose reductions. Research has demonstrated that IR can achieve dose reductions of 25-40% in comparison to to traditional FBP methods (Reid et al., 2010). Hur et al. (2012) reported that using an 80-kVp CT with iterative reconstruction improved image quality compared to standard filtered back projection (FBP) reconstruction, suggesting that these algorithms can effectively lower radiation doses without sacrificing diagnostic efficacy. Hsieh et al, (2013) in evaluation of the significant advancements of CT image reconstruction during the past of two decades. It discusses three main areas of algorithmic development: analytical, model-based iterative, and application-specific reconstructions. Joshi et al. (2023) study demonstrated the feasibility of lower mAs protocols (80kVp, 200 mAs) while achieving a significant dose reduction, although accompanied by a moderate noise increase that does not compromise diagnostic efficacy.

Another study done by Seeram, (2023) for dose decreasing and optimization strategies resulted in Practical guidelines for implementing reduction of dose in clinical. The IR application extends to various clinical settings, including cardiac, abdominal, and paediatric imaging. In cardiac CT, for example, IR helps reduce motion artifacts and improve the visualization of coronary arteries. In abdominal imaging, IR enhances the detection of small lesions and improves tissue contrast. Paediatric imaging benefits significantly from IR due to its ability to maintain image quality at reduced doses, thus ensuring patient safety (Huda & Samei, 2008).

Automatic Exposure Control (AEC):

AEC systems automatically adjust exposure parameters to maintain consistent image quality across varying patient sizes and anatomical regions. Thereby optimizing image quality and reducing unnecessary exposure. However, it's crucial to understand the principles governing AEC operation and apply them properly to avoid potential mistakes, such as improper positioning or selection of incorrect detectors, which can lead to suboptimal exposures (Jerrold et al 2011).

AEC systems typically use ionization chambers or phototimers to measure the radiation. This process helps maintain a consistent signal-to-noise ratio across different patient sizes and densities, leading to more uniform image quality (kalra et al.,2004).
Muhogora et al. (2009) indicated that the limited implementation of AEC in developing countries may represent a substantial opportunity to improve dose management. AEC enables patient-specific dose adjustment, directly reducing overall radiation exposure.
Zarb et al. (2011) point out that the functionality and efficiency of AEC algorithms can vary among manufacturers. Proper patient positioning and alignment with the AEC detectors are crucial to achieving optimal results. Additionally, continuous advancements in AEC technology are being made to further enhance dose optimization and quality of the image (Bushberg et al.,2011).

kVp Optimization

Although not directly linked to mAs, kVp significantly influences noise of the image and absorbed dose. Lower kVp increases noise, requiring higher mAs (or other compensating parameters) to maintain adequate image quality, creating a complexity in the optimization process. Zarb et al. (2011) illustrated the need for simultaneous optimization of both kVp and mAs, recognizing the interdependence of these parameters in achieving optimal dose and image quality profiles.

Adaptive Protocols

Protocols adjusted for patients (based on size, composition, and aria of interest) minimize dose. This strategy, mentioned in Panakkal et al. (2020), allows lowering mAs without significantly compromising the quality for clinical purposes. The work by Panakkal et al (2020). further highlights regional differences in CT procedures, focusing on higher effective doses for abdomen and chest CT exams and offering adaptive protocol techniques to lower overall radiation. Availability and functionality of IR algorithms, AEC, and advanced image processing tools vary across institutions, directly influencing the feasibility of dose optimization approaches (Muhogora et al. 2009; Zarb et al. 2011).
Rueckert and McCollough (2010) review strategies for optimizing CT protocols for cardiac scans, emphasizing a need for customized mAs settings. Kaza et al. (2014) also stress the importance of optimizing mAs in abdominal CT, particularly in high-contrast regions such as the liver and kidneys.
In addition, techniques such as prospective ECG gating and retrospective gating in cardiac CT also help in reducing mAs, as they limit unnecessary exposure by synchronizing the scan with the cardiac cycle (Rueckert & McCollough, 2010).
Recent advancements in CT imaging technology have provided new ways to optimize mAs settings. For instance, advancements in detector technology and computational algorithms have improved the efficiency of data acquisition, allowing for lower mAs settings without sacrificing image quality. Solomon et al. (2020) discusses these advancements and their implications for performance optimization in CT imaging. The use of advanced reconstruction techniques and real-time imaging adjustments also contributes to achieving optimal mAs settings.

3. Assessing Image Quality and Patient Dose

The impact of mAs (milliampere-seconds) on image quality can differ depending on which body part being scanned. For instance, abdominal CT scans require higher mAs to maintain image clarity, as the abdomen contains larger and denser tissues. (Ardi et al. 2020)
Kaza et al. (2014) stressed importance of new methods to reduce abdominal dose in CT, while Rueckert and McCollough (2010) show how cardiac CT scans use lower mAs settings to deal with the heart's motion and the need for fast imaging. Image quality is often measured

using metrics like the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). Lower mAs settings usually lead to more noise in the image, which can lower the image quality. Zarb et al. (2011) look into tools that help balance mAs and other settings to reduce noise while keeping the image clear. These tools are essential in medical practice to make sure CT images are good enough for accurate diagnosis, especially in areas like cancer and heart disease.

Measuring the radiation dose which patient receives is crucial for optimizing mAs. Important parameters include:

CTDIw (Computed Tomography Dose Index, weighted)

This measures the average radiation dose within a standardized phantom (a model). Muhogora et al. (2009) discuss its use for comparing different CT systems and evaluating their dose profiles, though it does not provide a patient-specific dose value.

DLP (Dose Length Product)

This measures the total radiation dose delivered along the scan length, providing a more clinically relevant measure than CTDIw alone. Muhogora et al. (2009) found cases where DLP exceeded established thresholds, highlighting the importance of optimized scan length in dose control.

Effective Dose

Effective dose, which quantifies the biological risk during radiation exposure, was directly related to the mAs (Martin, 2013). This considers different tissue sensitivities to radiation. Converting from DLP to effective dose requires region-specific factors to estimate cancer risk per scan accurately (Panakkal et al., 2020). Correct application of these factors is necessary to reflect tissue radiosensitivity properly. Panakkal et al. (2020) offer insights into estimating radiation risks for common clinical CT procedures. Studies by McNitt-Gray (2006) and Muhogora et al. (2009) discuss safety concerns related to mAs in clinical practice and the status of managing the dose properly. Especially in children, is a key goal in optimizing mAs settings.

Conclusion:

This review summaries findings from multiple studies showing how different techniques can help reduce radiation effective dose and maintain diagnostic quality of the images.

In conclusion, Iterative reconstruction and automatic exposure techniques are two advanced methods that have shown great promise in optimizing mAs (tube current) for computed tomography. Iterative reconstruction improves image quality by reducing noise and artifacts, enabling high-quality images at lower radiation doses. This method iteratively refines images, enhancing clarity while reducing the need for higher radiation exposure. Conversely, automatic exposure control adjusts the mAs in real-time based on the patient's anatomy and density, ensuring optimal image quality with the minimal necessary dose. Together, IR and AEC represent the best applications to minimize patient dose while maintaining image quality, balancing patient safety and diagnostic efficacy. Continuous research is necessary to improve these optimization techniques, ultimately leading to reduce radiation exposure for patients while keeping clinical effectiveness high. Effective CT optimization balances diagnostic image quality with patient safety, dropping radiation exposure through advanced technologies and targeted protocols.

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