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ARTICLE

Enhancing MSCT Image Quality and Equipment Maintenance: Daily Training Essentials for Radiographers at Mzuzu Central Hospital

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ABSTRACT

Objective: In the Radiology Department of Mzuzu Central Hospital (MCH), daily training for radiographers now includes content on Computed Tomography (CT) image quality control and equipment maintenance to ensure the normal, continuous, and stable operation of the 16-slice spiral CT scanner.
Methods: Through comprehensive analysis of relevant equipment, we have identified key parameters that significantly impact CT image quality. Innovative optimization strategies and solutions targeting these parameters have been developed and integrated into daily training programs. Furthermore, starting from an examination of prevalent failure modes observed in CT equipment, we delve into essential maintenance and preservation techniques that CT technologists must master to ensure optimal system performance.
Results: (1) Crucial factors affecting CT image quality include artifacts, noise, partial volume effects, and surrounding gap phenomena, alongside spatial and density resolutions, CT dose, reconstruction algorithms, and human factors during the scanning process. In the daily training for radiographers, emphasis is placed on strictly implementing image quality control measures at every stage of the CT scanning process and skillfully applying advanced scanning and image processing techniques. By doing so, we can provide clinicians with accurate and reliable imaging references for diagnosis and treatment. (2) Strategies for CT equipment maintenance: ① Environmental inspection of the CT room to ensure cleanliness and hygiene. ② Rational and accurate operation, including calibration software proficiency. ③ Regular maintenance and servicing for minimizing machine downtime. ④ Maintenance of the CT X-ray tube. CT technicians can become proficient in equipment maintenance and upkeep techniques through training, which can significantly extend the service life of CT systems and reduce the occurrence of malfunctions.
Conclusion: Through the regular implementation of rigorous CT image quality control training for radiology technicians, coupled with diligent and proactive CT equipment maintenance, we have observed profound and beneficial impacts on improving image quality. The accuracy and fidelity of radiological data ultimately leads to more accurate diagnoses and effective treatments.

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Introduction

In the field of the ever-advancing landscape of medical technology, a myriad of devices and techniques have seamlessly integrated into the diagnostic and therapeutic armamentarium, providing a robust framework for clinical decision-making1-3. Among these innovations, CT scanning has emerged as a pivotal yet nascent modality within the radiological practice of Mzuzu Central Hospital (MCH). Distinguished by its unique imaging principles and examination methodologies, CT scanning starkly diverges from traditional X-ray examinations4,5. Currently, the Neusoft 16-slice spiral CT system, residing in the radiology department of MCH, has seen widespread application in clinical settings. This system furnishes detailed and precise radiological data, underpinning diagnostic accuracy and allowing individualized treatment plans. However, the precision of CT-based diagnoses is not solely reliant on physicians' practical experience and diagnostic acumen; rather, it necessitates the availability of high-quality imaging data6,7. The ongoing refinement and enhancement of CT scanner architecture and performance have further catalyzed the evolution of CT examination techniques. Given this context, it is imperative for radiologic technologists to undergo regular clinical training to comprehensively grasp the complexities of CT operations, strictly adhere to examination protocols, and gain in-depth understanding of the factors influencing CT image quality8-10. This continuous and daily training approach is pivotal for fully harnessing the potential of CT examinations.

CT equipment stands as a cornerstone among large-scale medical imaging devices, indispensable for clinical diagnosis11. Its allure lies in its swift scanning speed, unparalleled image resolution, minimized X-ray dosage, exceptional diagnostic accuracy, and cost-effective pricing. However, as a sophisticated and high-end technology, CT scanners incur substantial maintenance and upkeep costs throughout their lifespan. Consequently, nurturing CT technologists proficient in equipment preservation and maintenance becomes paramount to prolonging the operational lifespan of CT systems, mitigating the risk of malfunctions, and ensuring the safety and reliability of these devices during practical application12-15. This teaching article draws on the daily operational experience of the Neusoft 16-slice spiral CT scanner at MCH to explore targeted training programs for radiology technicians in CT image quality control and equipment maintenance. Subsequent sections delve into the specifics of these daily training initiatives.

Methods

In 2021, the Radiology Department at MCH embarked on a significant undertaking by introducing the inaugural multi-slice spiral CT (MSCT) scanner in the northern region of Malawi. Over the subsequent three years, through accumulated operational experience and meticulous analysis of ancillary equipment, we have gained a comprehensive understanding of the parameters influencing CT image quality. Consequently, optimization strategies and solutions have been incorporated into the daily training regimen for radiographers.

Another core task of our training is to delve deeply into the common fault factors of CT equipment. This endeavor necessitated a delve into the realm of equipment maintenance and preservation techniques, essential competencies that CT technologists must master. Our primary objective was to empower our technicians with the knowledge and skills required to ensure the uninterrupted and optimal functioning of our CT system.

Results

Crucial factors affecting CT image quality include artifacts, noise, partial volume effects, and surrounding gap phenomena, alongside spatial and density resolutions, CT dose, reconstruction algorithms, and human factors during the scanning process. In the daily training for radiographers, emphasis is placed on strictly implementing image quality control measures at every stage of the CT scanning process and skillfully applying advanced scanning and image processing techniques. By doing so, we can provide clinicians with accurate and reliable imaging references for diagnosis and treatment.

Strategies for CT equipment maintenance: ① Environmental inspection of the CT room to ensure cleanliness and hygiene. ② Rational and accurate operation, including calibration software proficiency. ③ Regular maintenance and servicing for minimizing machine downtime. ④ Maintenance of the CT X-ray tube. CT technicians can become proficient in equipment maintenance and upkeep techniques through training, which can significantly extend the service life of CT systems and reduce the occurrence of malfunctions.

By incorporating optimized image quality control and equipment maintenance practices into the daily training of radiographers, we have developed a comprehensive framework to address the challenges associated with CT equipment. This approach not only enhances image performance but also ensures the reliability of diagnostic capabilities, ultimately contributing to improved patient

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care and outcomes.

Discussion

The Fundamental Principles of CT Imaging

CT imaging involves the utilization of X-rays to conduct cross-sectional scanning of pathological regions within the human body. The attenuated X-ray signals emanating from these regions are detected by sensitive detectors, which subsequently convert these signals into electrical impulses. These electrical impulses undergo analog-to-digital conversion and are then processed by a computer, applying specific computational algorithms. Finally, the processed data is visualized through digital-to-analog conversion,.

Analysis and Control Measures for Factors Affecting CT Image Quality

Artifacts

Artifacts refer to elements that do not exist in the actual anatomy but appear in CT images, which degrade image quality. They often manifest as bands, stripes, or rings and can arise from patient-related factors and CT performance-related factors. Common artifacts encountered in CT scans at the Radiology Department of MCH include high-contrast artifacts caused by metallic foreign bodies such as silver clips and dentures; motion artifacts resulting from physiological or involuntary body movements; and fine, solid stripe artifacts stemming from misalignment between the rotational center of the device and the center of the reconstruction matrix.

Upon installation, the MSCT scanner necessitates precise calibration, and regular maintenance throughout its operational lifespan. Prompt attention to any identified issues ensures the machine's continuous and optimal functioning, thereby effectively mitigating artifacts stemming from equipment malfunctions. Furthermore, maintaining an optimal environment within the CT examination room is essential, encompassing appropriate temperature and humidity levels, as well as a stable voltage supply. Moreover, during the examination process, it is crucial to address any instances of accelerated respiration or emotional agitation in patients by administering sedatives as necessary. These measures ensure that patients remain stationary throughout the scanning, significantly reducing the likelihood of artifact formation. By adhering to these practices, the quality and accuracy of radiological imaging are significantly enhanced.

Noise

In the scanning of uniformly scanned materials, the standard deviation of the CT values across pixels is referred to as noise. Noise can be classified into two categories: scanning noise and tissue noise. Scanning noise in MSCT primarily arises from the limited number of photons traversing the human body to the detector, resulting in an uneven distribution across the matrix elements. Tissue noise, on the other hand, stems from the inherent variations in the densities among different tissues within the body, leading to significant fluctuations in CT values within a given tissue range or the manifestation of identical CT values in different tissues. An increase in noise inevitably correlates with a decrease in image quality.

Numerous factors contribute to the generation of noise, including electronic circuit components, detector quality, and detector types, as well as display system noise and rounding errors in reconstruction algorithms. Factors influencing CT noise encompass pixel size, slice thickness, and exposure conditions. Typically, enhancing pixel density can effectively improve spatial resolution while mitigating noise .

Peripheral Space Phenomenon and Partial Volume Effect

The peripheral space phenomenon in MSCT occurs when two adjacent structures with different densities, perpendicular to the scan plane manifesting inaccurate CT values at their interfaces. Specifically, the CT value at the edge of the higher-density structure tends to be underestimated, whereas that of the lower-density structure is overestimated, with indistinct borders between them. This phenomenon is attributed to the overlapping measurements of scan beams at the junction of these two structures.

The partial volume effect in MSCT refers to the fact that the CT value assigned to a voxel represents the average of the CT values of all tissues within that unit volume, rather than the true CT value of each individual tissue. Consequently, lesions smaller than the slice thickness may exhibit biased CT values. For instance, small low-density lesions embedded in high-density tissue may appear with higher CT values, while small high-density lesions in low-density tissue may display lower CT values. This phenomenon is known as the partial volume effect. To mitigate the partial volume effect, proper patient positioning is crucial. Furthermore, reducing the slice thickness during scanning can diminish its influence, as thinner slices lead to a more accurate

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measurement of tissue CT values.

Spatial Resolution and Density Resolution

The CT resolutions arepivotal indicators of image quality and scanner performance, comprises primarily density resolution and spatial resolution. Density resolution pertains to the ability of CT to discern minute variations in the density of adjacent materials within the scanned object, delineating the smallest discernible density difference on the image. Factors influencing density resolution include the size of the object being examined, X-ray dosage, and noise. Enhancing density resolution necessitates an increase in X-ray dosage, which translates to a greater number of photons absorbed by the detector, subsequently elevating the signal-to-noise ratio and relatively mitigating noise. Additionally, larger geometric dimensions of the inspected object facilitate improved density resolution.

Spatial resolution, on the other hand, refers to the smallest spatial geometric length at which adjacent objects can be distinguished on a CT image, essentially signifying the fine structural resolution of the scanned object. Spatial resolution is influenced by various factors, including the width of the detector aperture, the inter-detector distance, the convolution filtering function employed during image reconstruction, pixel size, differences in the absorption coefficients of the inspected material, and system noise. Commonly, spatial resolution is expressed as the diameter of the smallest resolvable circular aperture, with smaller values indicating superior performance. Alternatively, it can be quantified by the number of resolvable line pairs per centimeter, with higher counts being preferable. Given the myriad factors affecting spatial resolution and the inherent limitation of detector aperture size compared to X-ray film grain, the spatial resolution of CT generally does not exceed that of X-ray imaging.

CT Dose

While higher scanning doses in MSCT yield a richer information content and enhanced image clarity, it is imperative to acknowledge the concomitant elevation in radiation levels. The dose administered to the subject must be reasonably minimized while ensuring optimal image quality, necessitating dosage control measures. Insufficient dosage, however, can compromise spatial resolution. Consequently, analyzing dose index distributions and actual clinical image evaluations suggests maintaining the dose index within the range of 20 mGy to 50 mGy, with regular monitoring of the CTDI (Computed Tomography Dose Index). Once the tube voltage is established, the dose index is determined by the mAs (milliampere-seconds) value, closely tied to filtration and field-of-view dimensions. Without altering these conditions, reducing slice thickness enhances both the dose index and spatial resolution, while the converse holds true for increased slice thickness.

Reconstruction Algorithms

CT imagery is inherently digital, with image reconstruction governed by preset digital algorithmic approaches. Commonly employed algorithms include bone, soft tissue, and standard algorithms, each tailored to the specific tissue distribution or anatomical region under examination. Given the intricate relationship between image resolution and the chosen algorithm, a prudent selection is crucial to avoid compromising resolution. Furthermore, volumetric data acquired through spiral scanning enables the reconstruction of images utilizing a diverse array of algorithms.

Human Factors in CT Scanning Processes

In MSCT scanning, various human factors, including those of operators and patients, can potentially impact image quality and control. At the Radiology Department of MCH, for instance, factors such as patients carrying metallic objects, improper scanning positions, suboptimal device parameter settings, motion artifacts during scanning, or inadequate drug dosage and injection rates during contrast-enhanced scans, can all contribute to degraded CT image quality.

To mitigate the effects of human factors, proactive measures must be taken. Before scanning, a thorough review of patient history and the subsequent formulation of a scanning plan are essential to prevent inappropriate scanning parameters. Patients must be instructed to remove all metallic and communication devices to avoid compromising image quality. For patients with impaired consciousness or pediatric cases prone to motion artifacts, assistance with immobilization or sedation is necessary. The selection of contrast agents and their dosage should be individualized based on patient age and anatomical region, with precise control over injection speed and timing. Furthermore, educating patients on the normal reactions associated with contrast enhancement can alleviate anxiety and foster better cooperation during the procedure.

Maintenance and Servicing Strategies for MSCT

Environmental Inspection of the CT Room to Ensure Cleanliness and Hygiene

A comprehensive environmental assessment of the

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CT room is vital prior to initiating the CT system. This includes monitoring and maintaining stable power voltage, ambient temperature within the range of 18°C to 22°C, and humidity between 45% and 60%. Deviations in power voltage can destabilize the CT console and gantry operations, potentially causing irregularities in high-voltage systems and X-ray generation, resulting in degraded image quality. Ensuring that the room temperature remains within optimal ranges is essential, as excessive heat can lead to overheating or burnout of critical components. Excessive humidity levels can also adversely affect hardware performance, introducing image artifacts or degrading image quality. Furthermore, meticulous cleaning and regular disinfection of the CT room are mandatory, with immediate removal of any contaminants such as vomit, bloodstains, or other substances from patients during examinations to prevent potential damage.

Rational and Accurate Operation, Including Calibration Software Proficiency

Rational and accurate operation of the CT system is paramount for optimal image quality. Failure to adequately preheat the tube or insufficient preheating time can compromise image uniformity. Neglecting image calibration, particularly in CT systems based on gas X-ray detector, can introduce significant CT value deviations. Inaccurate patient positioning, scanning with metallic objects on the patient's body, inappropriate scan parameter selection, and concurrent execution of multiple operations can lead to erroneous images, metal artifacts, reduced image resolution, and even system crashes. Therefore, CT technicians must possess a solid foundation in professional theory and operational skills. Daily routines should encompass proper tube conditioning before scanning, proficiency in CT value calibration, air calibration, water phantom calibration, and other software operations. By adhering to these practices, image quality can be significantly enhanced in suboptimal conditions, and maintenance costs can be reduced.

Regular Maintenance and Servicing for Minimizing Machine Downtime

Regular maintenance of expendable components such as the main hard drive, slip ring, and cooling fans is imperative to mitigate equipment failures and ensure continuous operation. Monitoring hard drive capacity and routinely deleting processed patient image data to free up space minimizes the risk of system crashes and enhances operational efficiency. The slip ring should undergo regular cleaning, and carbon brushes should be promptly replaced to maintain uninterrupted power and signal transmission. Additionally, regular cleaning of cooling fans and dust filters using vacuum cleaners maintains optimal airflow, ensuring high-efficiency machine operation and minimizing downtime.

Maintenance of the CT X-ray Tube: Strategies for Prolonged Lifespan and Cost Reduction

The X-ray tube, being the key component of a CT scanner, is expensive to maintain, and implementing strategies for proper use of the X-ray tube can significantly extend its lifespan, thereby reducing operational costs. Maintenance of the X-ray tube involves several key aspects: Firstly, new tubes require specialized training to ensure reliable performance upon installation. Secondly, proper conditioning after startup is vital for prolonging the tube's lifespan. Thirdly, selecting appropriate exposure parameters, such as minimal tube voltage and current while maintaining image quality, minimizes tube wear and reduces patient radiation exposure. Lastly, where feasible, alternating between large and small focal spot exposures during scanning prevents excessive wear on the cathode filament, thereby preserving tube integrity and further extending its lifespan.

Conclusion

In conclusion, the pursuit of high-fidelity imaging data in radiology necessitates an authentic and precise depiction of anatomical structures, which serves as a cornerstone for clinical diagnosis and treatment. To achieve optimal CT image quality, it is paramount to judiciously configure CT equipment parameters and adeptly apply image processing technologies. Furthermore, the implementation of routine quality control measures, coupled with diligent maintenance practices, has a positive impact on enhancing image quality, ultimately underpinning crucial diagnostic and therapeutic endeavors. Therefore, by integrating learning content focused on CT image quality and equipment maintenance into our daily training programs, we have significantly enhanced the accuracy and reliability of radiographic imaging. This benefits both patients and healthcare providers by ensuring more precise diagnoses and effective treatment planning.

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