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Artikel Asli /*Original Article*

Contrast-Limited Adaptive Histogram Equalisation (CLAHE) as Post Processing Method for Hip Joint Phantom Imaging

Penyamaan Histogram Adaptif Terhad Kontras (CLAHE) sebagai Kaedah Pascapemprosesan untuk Pengimejan Fantom Sendi Pinggul

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ABSTRACT

This work aims to quantitatively analyse diagnostic images and improve the quality via post-processing technique. Metal hip joint phantom images were utilised, with ImageJ as a tool for post-processing and a tool in analysing medical images. Contrast Limited Adaptive Histogram Equalisation (CLAHE) method was performed on metal hip phantom images. Contrast noise ratio (CNR) were calculated for images after CLAHE methods were performed. Data was statistically analysed using SPSS Statistics 20. For all the images, there were negative correlation between noise and kVp adjustment while positive correlation was observed on CNR when mAs was adjusted. The CLAHE method showed an improvement in contrast, though it was not statistically significant (mean CNR difference = 0.011). This suggests potential for enhancing diagnostic image quality using post-processing methods.

Keywords: metal hip joint phantom, image quality, CLAHE, post-processing

ABSTRAK

Kajian ini bertujuan untuk menganalisis imej diagnostik secara kuantitatif dan meningkatkan kualitinya melalui teknik pascapemprosesan. Imej fantom sendi pinggul berlogam telah digunakan, dengan perisian ImageJ sebagai alat pascapemprosesan serta analisis imej perubatan. Kaedah Penyamaan Histogram Adaptif Terhad Kontras (CLAHE) telah diaplikasikan pada imej fantom sendi pinggul berlogam. Nisbah hingar kontras (CNR) dikira bagi imej selepas kaedah CLAHE dilaksanakan. Data dianalisis secara statistik menggunakan SPSS Statistics 20. Bagi semua imej, terdapat korelasi negatif antara hingar dan pelarasan kVp, manakala korelasi positif diperhatikan pada CNR apabila mAs dilaraskan. Kaedah CLAHE menunjukkan peningkatan dalam kontras, namun perbezaannya tidak signifikan secara statistik (perbezaan min CNR = 0.011). Dapatan ini mencadangkan potensi penggunaan kaedah pascapemprosesan dalam meningkatkan kualiti imej diagnostik.

Kata Kunci: fantom sendi pinggul berlogam, kualiti imej, CLAHE, pascapemprosesan

INTRODUCTION

In diagnosing abnormalities or diseases in patients, medical imaging techniques such as general X-rays, computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and ultrasound (US) are commonly employed (Abhisheka et al. 2024). The interpretation and analysis of these images play a crucial role in ensuring accurate diagnosis and effective treatment. Medical image processing is often utilised to enhance the clarity and interpretability of medical images, which may involve improving visualisation through image enhancement, (Rifai et al. 2024) or extracting relevant information, either manually or through automated techniques. Contrast-limited adaptive histogram equalisation (CLAHE) can be applied to medical images to enhance contrast, addressing common issues such as noise and intensity inhomogeneity (Mahmoudi et al. 2022). By enhancing visualisation and extracting critical diagnostic information, post-processing plays a vital role in ensuring precise and reliable medical assessments.

Medical image analysis can be categorised into quantitative and qualitative approaches. Quantitative analysis involves objective measurements and calculations, such as assessing contrast, noise levels, contrast-to-noise ratio (CNR), and signal-to-noise ratio (SNR), (Hokamura et al. 2024) along with various other metrics related to pixel intensity and image quality. These numerical evaluations help in standardising image assessment, ensuring consistency, and facilitating comparisons across different imaging modalities. On the other hand, qualitative analysis relies on subjective interpretation by radiologists or medical professionals to assess image clarity (Li et al. 2024), anatomical structures, and pathological findings. When image quality is suboptimal, various image enhancement techniques, such as noise reduction, contrast adjustment, and edge enhancement, can be applied to improve the diagnostic value. These enhancements help in better visualisation of critical structures, allowing for more accurate detection and characterisation of abnormalities, ultimately supporting more effective diagnosis and treatment planning.

Post-processing in diagnostic imaging refers to the enhancement and analysis of medical images after acquisition to improve their interpretability and diagnostic accuracy. This process involves various techniques such as contrast adjustment, noise reduction, edge enhancement, and reconstruction algorithms (Hussain et al. 2024) to optimise image quality. Advanced methods, including 3D reconstruction, further aid in detecting abnormalities and improving clinical decision-making. Post-processing is particularly essential in modalities like CT, MRI, and PET, where raw images may require refinement to highlight specific anatomical structures or pathological findings. In this study, CLAHE is applied to analyse hip phantom images using ImageJ version 1.51j8. The effectiveness of contrast enhancement is then evaluated on the processed images following the application of CLAHE.

MATERIALS AND METHODS

In this study, all metal hip phantom images were converted to 8-bit format. A total of nine images were acquired using different kVp and mAs settings. The metal hip joint phantom was constructed using white cement to simulate human bone, stainless steel to represent the metal implant, and Perspex along with water, as their densities closely match human tissues. The images were captured at 40, 70, and 100 kVp, which are commonly used parameters for metal hip joint imaging. The selection of materials was based on their density, with white cement having a density of 2.33 g/cm³, closely resembling human bone. Perspex, with a density of 1.19 g/cm³, closely matches soft tissue density as referenced in ICRU-44. Water, with a density of 1.0 g/cm³, was used as a tissue-equivalent material. Table 1 lists the different acquisition parameters and images of hip joint phantom.

ImageJ version 1.51j8 was used for image post-processing. The region of interest (ROI) was selected to determine pixel intensity. The mean and standard deviation calculated from each ROI were recorded. The histogram and pixel data of the entire image were obtained using ImageJ. Pixel data for specific areas of interest were also measured with the software. All these measurements were conducted by the same operator to ensure consistency. ImageJ plugins were utilised for image enhancement, specifically contrast-limited adaptive histogram equalization (CLAHE). Figure 1 illustrates the example of histogram in ImageJ.

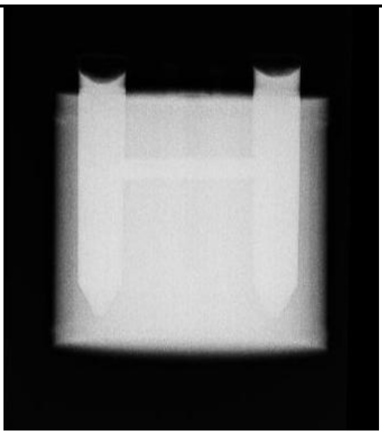
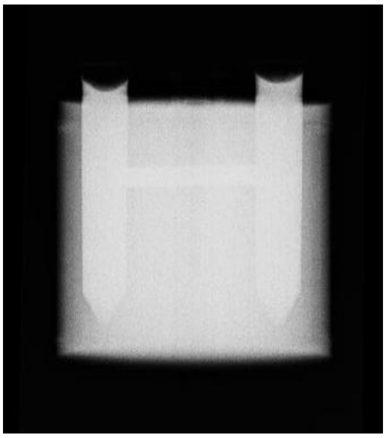
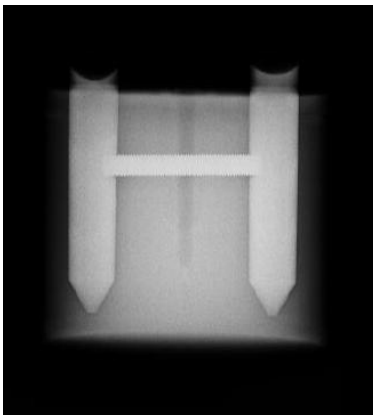
RESULTS AND DISCUSSION

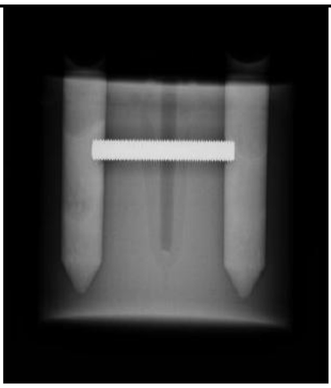
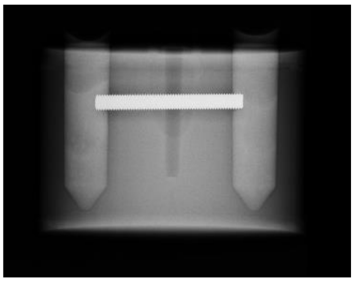
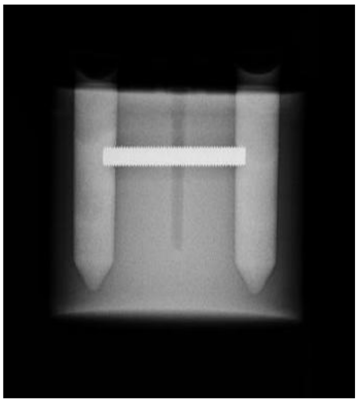
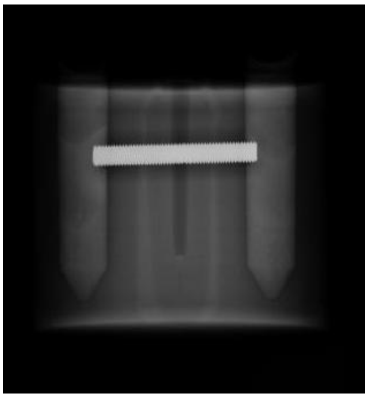
The acquisition parameters utilised for metal hip joint phantom were 40, 70, and 100 kVp, along with 10, 50, and 80 mAs. The image quality parameters analysed in this study included noise and contrast-to-noise ratio (CNR). Table 2 presents the noise and CNR values for the original hip phantom images. Figure 2 depicts the relationship between noise and kVp at a constant mAs, while Figure 3 illustrates the variation of CNR with mAs at a constant kVp for the hip phantom images.

The results indicate that at a constant kVp, an increase in mAs led to a corresponding increase in CNR. A positive correlation was observed, as determined through Pearson correlation analysis using SPSS, as illustrated in Figure 4. This finding aligns with previous research, which similarly reported that higher technical factor settings contribute to an increase in CNR values in medical images (Pauwels et al. 2014). CLAHE was employed as a post-processing technique to enhance contrast in hip phantom images. This study evaluated image quality by calculating contrast and CNR. Figure 5 presents the raw hip phantom images alongside those processed with CLAHE. Table 3 summarises the contrast values prior to enhancement, while Table 4 provides the contrast values after applying CLAHE. A paired sample t-test was conducted to compare the mean contrast values before and after applying CLAHE. The analysis revealed a mean difference of 0.011.

While the tabulated data indicated an increase in contrast, the results from the paired sample t-test using SPSS showed that this increase was not statistically significant, likely due to the limited sample size. Nevertheless, CLAHE proved to be an acceptable method for enhancing the bone-metal contrast, as qualitative assessment demonstrated noticeable improvement in image contrast, despite the lack of statistical significance. Previous study reported that CLAHE-enhanced images exhibit finer details, making them more suitable for diagnostic purposes (Mansour & Gaheen 2024)..

TABLE 1 List of different acquisition parameters and images of hip joint phantom.

No.	Images	kVp	mAs
1		40	10
2		40	50
3		40	80

4		70	10
5		70	50
6		70	80
7		100	10

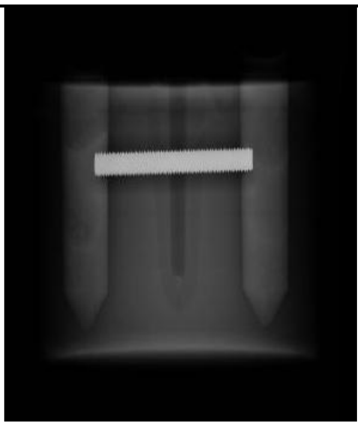
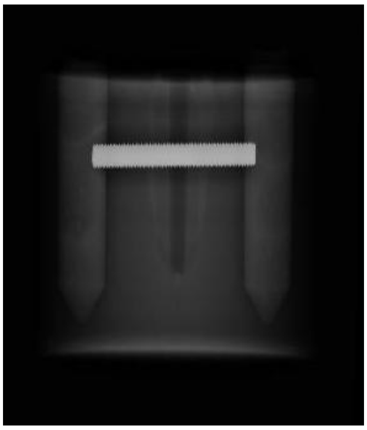
8		100	50
9		100	80

TABLE 2 Noise and CNR for the original hip phantom images.

No	kVp	mAs	Noise	Contrast to noise ratio
1	40	10	74.385	0.912
2	40	50	74.615	0.483
3	40	80	56.821	0.246
4	70	10	41.848	1.335
5	70	50	51.146	0.536
6	70	80	47.477	2.707
7	100	10	26.345	1.263
8	100	50	24.280	0.511
9	100	80	20.447	0.514

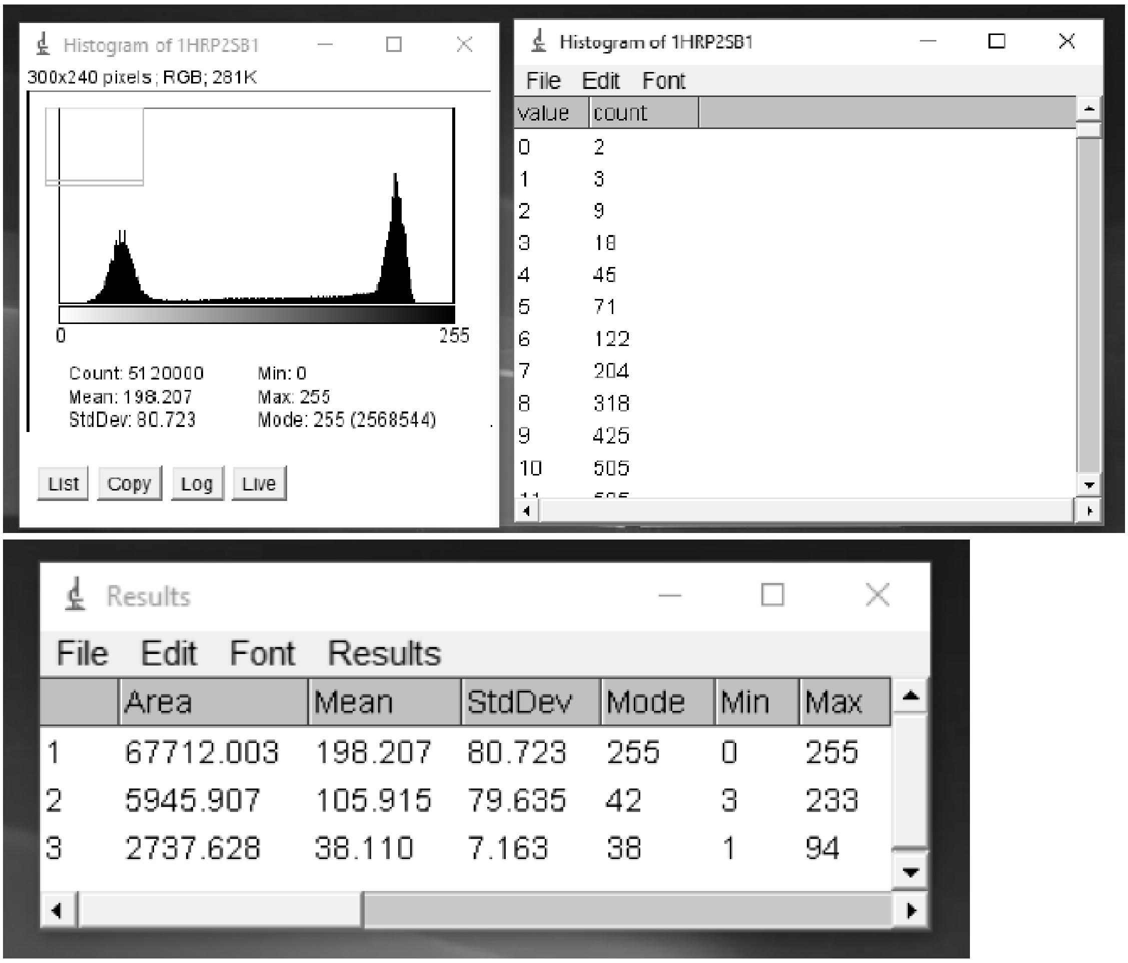


FIGURE 1 ImageJ Display of Pixel Intensity and Histogram.

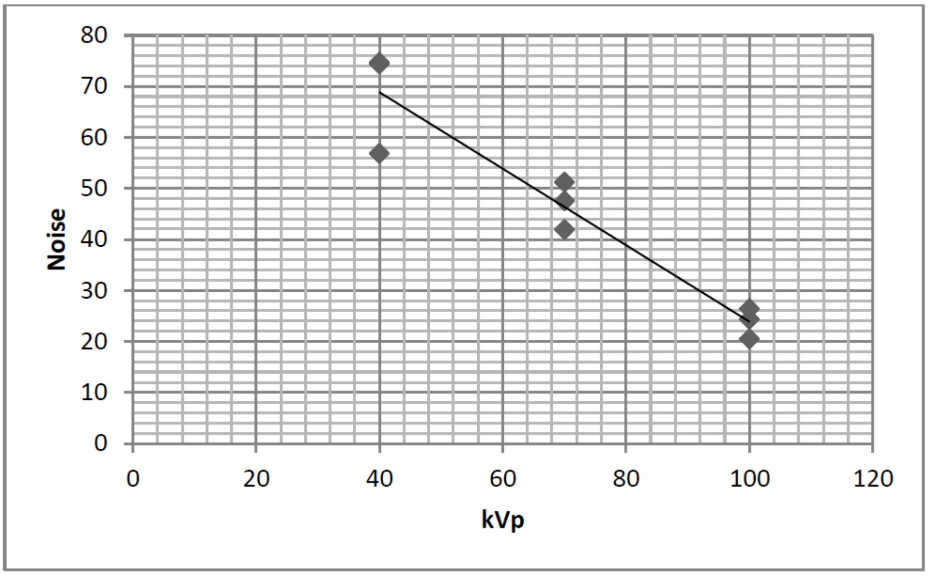


FIGURE 2 Noise versus kVp at constant mAs in original hip phantom images

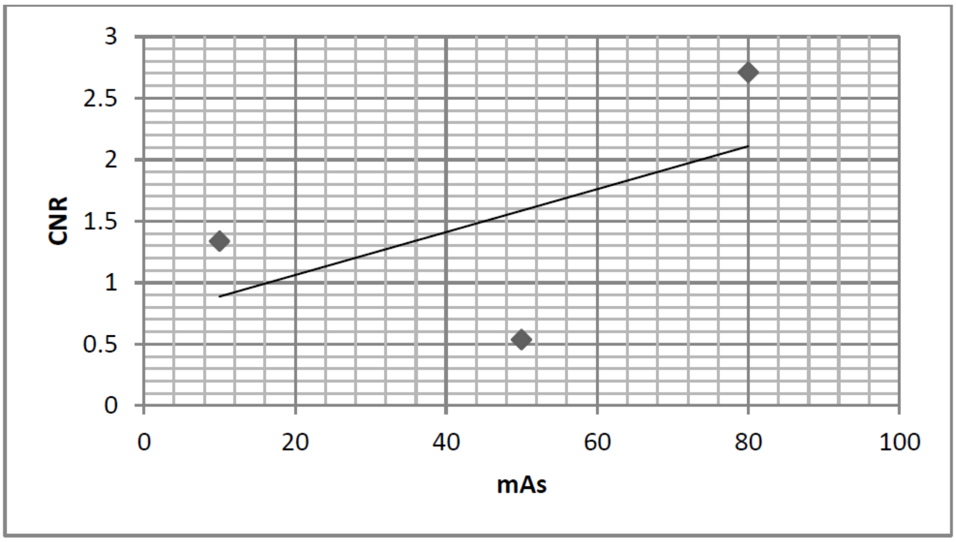


FIGURE 3 CNR versus mAs at constant kVp of original hip phantom images

		mAs	CNR
mAs	Pearson Correlation	1	.558
	Sig. (1-tailed)		.311
	N	3	3
CNR	Pearson Correlation	.558	1
	Sig. (1-tailed)	.311	
	N	3	3

FIGURE 4 Pearson correlation of image's CNR with mAs at constant kVp

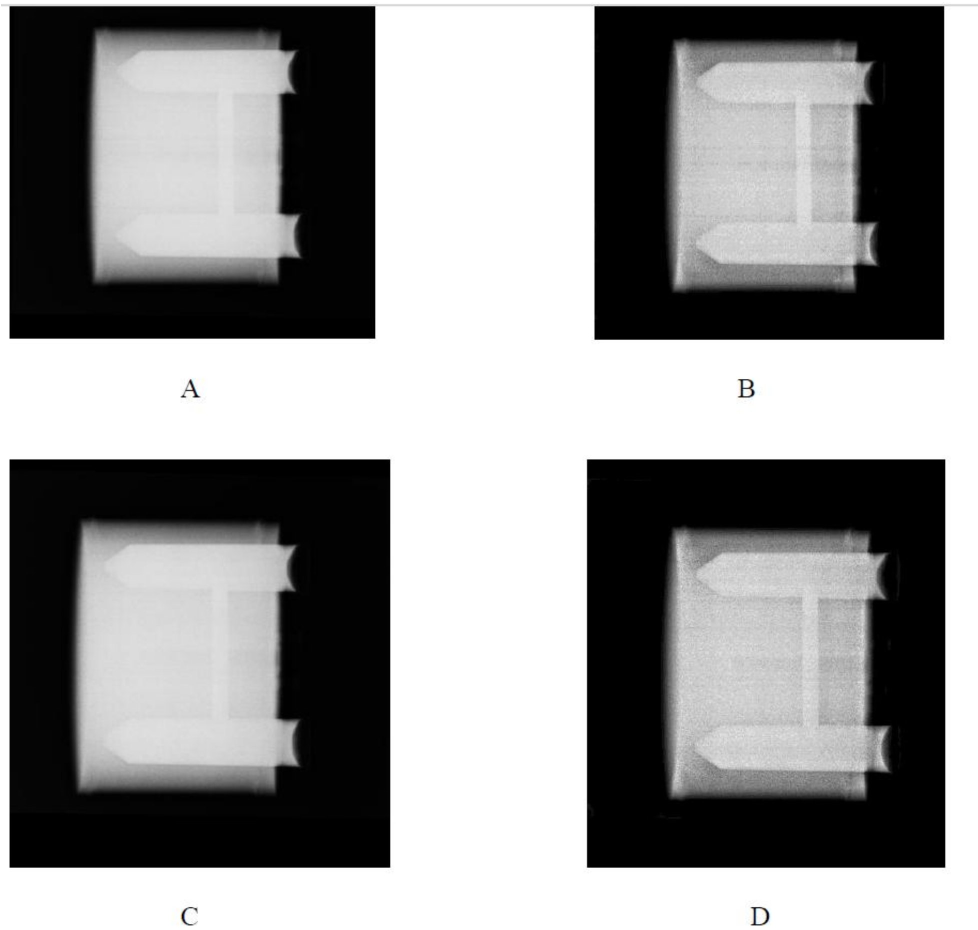


FIGURE 5 (A) The raw image of hip phantom (40kVp, 10mAs), (B) is the image after CLAHE, (C) is the raw image of hip phantom (40kVp, 50mAs), (D) is the image after CLAHE

TABLE 3 Contrast value before enhancement with CLAHE.

Image	Contrast (bone - steel)	ROI selection	Contrast (soft tissue - air)	ROI selection
A	0.006	Image 1 & 5	0.035	Image 3 & 7
C	0.012	Image 2 & 6	0.001	Image 4 & 8

TABLE 4 Contrast value after enhancement with CLAHE

Image	Contrast (bone - steel)	ROI selection	Contrast (soft tissue - air)	ROI selection
B	0.014	Image 1 & 5	0.006	Image 3 & 7
D	0.028	Image 2 & 6	0.049	Image 4 & 8

Previous research by (Acharya et al. 2018) demonstrated that CLAHE enhances images by processing small tiles (8 × 8 pixels) and utilising bilinear interpolation to blend neighbouring tiles, thereby eliminating boundaries, equalising intensity, and improving contrast. Similarly, other studies have also reported that CLAHE effectively enhances image contrast. Previous studies have demonstrated the effectiveness of CLAHE in assigning displayed intensity levels, particularly in chest CT scans (Mahmoudi et al. 2022). Various histogram techniques can be utilised to enhance radiograph contrast, helping to overcome challenges faced by physicians during image analysis. These techniques offer valuable tools for physicians and medical professionals across multiple specialties beyond radiology. Additionally, exploring alternative image enhancement algorithms and evaluating existing methods through current research on different types of medical images can further improve diagnostic accuracy.

CONCLUSION

In conclusion, the image quality of hip phantom images was enhanced in this study. For metal hip joint images, the mean difference before and after histogram equalisation was 0.011. This finding highlights the potential of post-processing techniques in improving the overall quality of diagnostic images, suggesting possible value in clinical applications for better visualisation of structures affected by metal implants without the need for additional radiation dose.

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REFERENCE

Abhisheka, B., Biswas, S.K., Purkayastha, B., Das, D. & Escargueil, A. 2024. Recent trend in medical imaging modalities and their applications in disease diagnosis: a review. *Multimed. Tools Appl.* 83, 43035–43070.

Acharya, U.R., Koh, J.E.W., Hagiwara, Y., Tan, J.H., Gertych, A., Vijayananthan, A., Yaakup, N.A., Abdullah, B.J.J., Bin Mohd Fabell, M.K. & Yeong, C.H. 2018. Automated diagnosis of focal liver lesions using bidirectional empirical mode decomposition features. *Comput. Biol. Med*. 94: 11–18.

Hokamura, M., Uetani, H., Nakaura, T., Matsuo, K., Morita, K., Nagayama, Y., Kidoh, M., Yamashita, Y., Ueda, M. & Mukasa, A. 2024. Exploring the impact of super-resolution deep learning on MR angiography image quality. *Neuroradiology* 66: 217–226.

Hussain, D., Abbas, N. & Khan, J. 2024. Recent Breakthroughs in PET-CT Multimodality Imaging: Innovations and Clinical Impact. *Bioeng.* (Basel, Switzerland) 11.

Li, S., Qiao, P., Wang, L., Ning, M., Yuan, L., Zheng, Y. & Chen, J. 2024. An Organ-Aware Diagnosis Framework for Radiology Report Generation. *IEEE Trans. Med. Imaging* 43: 4253–4265.

Mahmoudi, R., Benameur, N., Mabrouk, R., Mohammed, M., Zapirain, B. & Bedoui, M.H. 2022. A Deep Learning-Based Diagnosis System for COVID-19 Detection and Pneumonia Screening Using CT Imaging. *Appl. Sci.* 12: 4825.

Mansour, A. & Gaheen, M. 2024. *Enhancement of radiographs using the HE and CLAHE techniques*. المجلة العلمية لكلية التربية النوعية جامعة دمياط 2024, 45–61

Pauwels, R., Silkosessak, O., Jacobs, R., Bogaerts, R., Bosmans, H. & Panmekiate, S. 2014. A pragmatic approach to determine the optimal kVp in cone beam CT: balancing contrast-to-noise ratio and radiation dose. *Dentomaxillofac. Radiol*. 43: 20140059.

Rifai, A.M., Raharjo, S., Utami, E. & Ariatmanto, D. 2024. Analysis for diagnosis of pneumonia symptoms using chest X-ray based on MobileNetV2 models with image enhancement using white balance and contrast limited adaptive histogram equalization (CLAHE). *Biomed. Signal Process. Control* 90:105857