



Evaluation of Digital Image Enhancement Methods for MRI Visualization of Small Uterine Fibroids: An Inter-Reader Agreement Study

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Abstract Magnetic Resonance Imaging (MRI) is a crucial imaging modality for evaluating gynecological pelvic disorders particularly those affecting the uterus, such as uterine fibroids. However, visualizing small uterine fibroids (less than 3 cm in diameter) can be challenging due to poor lesion conspicuity, image noise and low local contrast. This study evaluated the impact of digital image enhancement techniques on the visibility of small uterine fibroids in MRI images. The study included three patients with uterine fibroids smaller than 3 cm, utilizing 81 selected images from MRI sequences. These images were processed using Gaussian filtering followed by three independent enhancement methods: Laplacian edge sharpening, Contrast Limited Adaptive Histogram Equalization (CLAHE) and Discrete Wavelet Transform (DWT). Three experienced radiologists independently evaluated both the original and the corresponding enhanced images using a visual rating scale ranging from 1 lowest to 10 highest, where higher scores indicated improved lesion visibility. Inter-rater agreement and reliability were assessed using the Intraclass Correlation Coefficient (ICC) and weighted Cohen's kappa, while repeated-measures analysis was employed to account for the repetitive nature of the evaluations. The results demonstrated a generally good-to-high level of inter-rater agreement and reliability, with Intraclass Correlation Coefficient (ICC) values ranging from 0.717 to 0.887. Weighted Kappa values also indicated moderate-to-high agreement between pairs of raters. Repeated-measures analysis revealed statistically significant differences in ratings based on the rater and the imaging sequence, whereas the interaction between the rater and the imaging sequence was not statistically significant. These findings suggest that digital image enhancement may improve the visibility and prominence of small uterine fibroids on MRI scans. However, given that the study included only three patients and did not employ an independent diagnostic reference standard, these results are preliminary and should not be interpreted as evidence of improved diagnostic accuracy.

Key Words MRI, Uterine Fibroid, Edges Sharpen, Wavelet Transform, Contrast Enhancement

INTRODUCTION

Medical imaging has seen tremendous improvement in the last few decades thanks to the progress made in medical technologies and digital image processes. The progress made on this front has helped improve the quality and accuracy of diagnostic imaging, which allows doctors to better diagnose, manage and treat many diseases. Thus, nowadays medical imaging plays a critical role in medicine and is employed in detection, diagnostic and clinical management of diseases [1].

Magnetic Resonance Imaging (MRI) is one of the most sophisticated medical imaging methods as it yields very good contrast for soft tissue and very high-resolution images

without any use of ionizing radiation. Therefore, MRI is a safer imaging modality than Computed Tomography (CT) for radiation exposure and is the preferred choice of imaging modality for the evaluation of many soft tissue or neurologic cases [2]. MRI uses nuclear magnetic resonance-or the human body's reaction to a strong magnetic field that would align protons in the nuclei of the hydrogen atoms in the tissues. These protons are altered by exposure to pulses of radio waves, taking in energy and altering their direction. On return to their original orientation, they send signals which are received and reconstructed by the machine to produce a high-resolution diagnostic picture [3].

MRI is now one of the most important imaging modalities applied to the assessment of disease in the female genital tract where it can provide accurate diagnostic information regarding anatomy of the uterus, ovary and surrounding tissue [4]. As a diagnostic tool, MR imaging is known for providing an important diagnostic advantage, because images of a few specific levels of a region can be obtained across the entire pelvic region with a high degree of contrast between soft-tissue and bone. This is especially noted during the diagnosis of MRI of uterine fibroids.

Uterine fibroids are one of the most common benign tumors in women of fertile age. They have been found to occur in as many as 70% of females at some time in their lives. They develop from the smooth muscle tissue of the uterine lining and can be either one or many and may occur anywhere inside the uterus. They may also come in various forms such as intramural, submucosal or subserosal fibroids. Some uterine fibroids may cause no symptoms but some can cause other health issues such as pelvic pain, heavy periods and fertility problems, so early and accurate identification and diagnosis of potentially problematic conditions is important [5].

An imaging technique known as magnetic resonance imaging (MRI) is considered to be the best method available for fibroid evaluation and may provide information about the fibroid's size, location and histological composition. Apart from this, it can also aid in identifying the normal tissues surrounding the tumour and the relations that the tumour has with the other extracellular tissues, which are essential for the right planning of the therapy [6].

Despite the great progress made in the techniques of magnetic resonance imaging (MRI), small uterine fibroids can still be difficult to diagnose in some instances, especially very small tumors. This can be related to the fact that many small uterine lesions are poorly visualized in their images due to either poor contrast between the tumor and the surrounding uterine tissue, image noise or the partial volume effect resulting in low image clarity of very small lesions in radiographic images [7,8].

Over the last few years, there has been considerable progress in medical imaging and it's primarily been fuelled by the incorporation of Artificial Intelligence (AI) into medical image analysis. By leveraging sophisticated image processing algorithms and extracting diagnostic information, AI algorithms can enhance image quality, particularly in medical imaging and provide more accurate diagnoses with the assistance of advanced tools. With the help of advanced tools and algorithms, AI can analyze and generate accurate diagnoses by enhancing image quality, particularly in medical imagery, while using sophisticated image processing algorithms and extracting diagnostic information. Medical imaging applications of AI include automated tumor detection, medical image analysis, image quality improvement and medical image diagnostic decision support for doctors [9].

Another vital application of medical image processing is image enhancement and image sharpening, which plays a

critical role in increasing contrast and resolving fine details in the image and hence aiding the physicians with better diagnosis capability [10].

MATLAB is among the most popular tools when it comes to medical image processing. It offers advanced software environment, with ease and efficiency of application of image enhancement algorithms and image analysis. In addition, there are special libraries for performing digital image processing [11].

In this study, the focus is on determining the effectiveness of the methodologies applied in image enhancement used to enhance the MRI images of small-sized uterine fibroids and on the scores of agreements among radiologists on the interpretation of the processed MRI images, where the use of image enhancement in making a radiological diagnosis is of paramount importance to enhance the quality of the MRI images.

Problem Statement

Although there has been progress in Magnetic Resonance Imaging (MRI) techniques, it remains a significant challenge in clinical practice to detect small uterine fibroids with high certainty. This is because the boundaries of small tumours can be difficult to distinguish and may be obscured by limited size, factors such as low contrast between the tumour and the normal uterine muscle and noise effects [7,8]. In addition, differences in uterine tissue contrast versus differences in radiologist experiences can cause discrepancies in the MRI interpretation, potentially influencing the accuracy of imaging diagnostics and clinical decision-making.

Research Gap

Despite the continued development of MRI image-enhancement techniques to improve image quality and highlight fine anatomical details, several approaches have been investigated, including Contrast Limited Adaptive Histogram Equalization (CLAHE) for local contrast enhancement [12], Discrete Wavelet Transform (DWT) for multi-resolution analysis and detail enhancement while preserving relevant image structures [13] and image-sharpening techniques. However, many previous studies have evaluated individual enhancement methods or focused on a limited number of MRI sequences, which may not fully reflect the variety of sequences used in the assessment of small uterine fibroids.

In addition, previous studies have often relied on objective image-quality measures such as Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM) to evaluate image-processing performance [14]. Although these measures are useful for quantifying changes in image characteristics, they do not necessarily reflect how radiologists perceive lesion visibility or image interpretability. Differences in imaging protocols, patient characteristics and the need for evaluation by experienced readers also remain important considerations when image-processing methods are applied to medical imaging [15].

Thus, there is a need to evaluate digital image enhancement methods based on assessments by experienced radiologists comparing the same MRI images before and after processing particularly in cases of small uterine fibroids that may be difficult to detect visually. This study addresses this research gap by applying various image processing techniques and evaluating their impact on lesion clarity across multiple MRI sequences, utilizing standardized assessment criteria adopted by radiologists and analyzing inter-rater agreement.

Novelty and Study Contribution

This study evaluates a multi-stage digital image-processing workflow designed to improve the visualization of small uterine fibroids on MRI. The workflow combines several established image-processing methods, including Gaussian filtering for noise reduction, Discrete Wavelet Transform (DWT) for multi-resolution image representation, Contrast Limited Adaptive Histogram Equalization (CLAHE) for local contrast enhancement and Laplacian-based edge sharpening for enhancement of structural boundaries and fine details [12,13].

Unlike studies that primarily assess enhancement using objective digital image-quality metrics such as PSNR and SSIM [14], the present study focuses on radiologist-based visual assessment of the processed images. The original image was displayed first, followed by the corresponding enhanced image; radiologists assigned a score ranging from 1 minimum to 10 maximum to indicate the level of improvement observed in the visibility of the lesion. This assessment was conducted using multiple MRI sequences standardly employed for evaluating uterine fibroids.

Data from the three independent radiologists were analyzed using weighted Cohen's kappa and the Intraclass Correlation Coefficient (ICC) to assess inter-rater agreement and reliability; repeated-measures analysis was also utilized to account for the repetitive nature of the radiologists' assessments.

Significance of the Study

This work is important because it is intended to assess the clinical utility of the image enhancement techniques used with MRI and not just through image quality computation.

Better visualization of small or small numbers of uterine fibroids may help the radiologist detect subtle lesions and help boost confidence during the interpretation of these images. This study examines the change in radiologists' interpretations before and after enhancement, to determine if there are clinically significant differences in MRI interpretation using digital image processing.

In addition, the statistical analysis of the reliability of the interpretation by the different readers allows objective measurement of inter-reader agreement, resulting in repeatability of the radiological interpretation. This validation can help in the evolution of future computer-aided diagnostic methods and medical imaging applications.

Objectives of the Study

The objectives of this study are:

- To develop a multi-stage MRI image enhancement framework combining Gaussian filtering, Discrete Wavelet Transform (DWT), Contrast Limited Adaptive Histogram Equalization (CLAHE) and Laplacian sharpening for improving the visualization of small uterine fibroids
- To evaluate the effect of the proposed enhancement framework on MRI image interpretation across different clinical imaging sequences
- 3.To compare radiologists' assessments of original and enhanced MRI images to determine whether image enhancement improves the visibility of small uterine fibroids
- Assessing inter-reader agreement and the reliability of radiologists' evaluations of contrast-enhanced MRI images (using weighted Cohen's kappa and the Intraclass Correlation Coefficient (ICC))
- Determining whether radiologists' evaluations differ based on the reader and the MRI sequence and assessing the reader-sequence interaction using repeated measures analysis

METHODS

This is a retrospective observational imaging study design which was used to compare the effect of using digital image enhancement in MRI image of small uterine fibroids. Ethical approval was obtained from the relevant ethics committee (Approval No. 837, dated 30/06/2025) and the name of the institution has been blinded for peer review.

Original MRI images were compared with images enhanced by use of digital image processes to learn how diagnostic tasks performed by radiologists may be affected by the various types of image process.

This study also sought to assess the level of agreement and reliability among radiologists when interpreting enhanced medical images, using statistical measures that include weighted Cohen's kappa and the Intraclass Correlation Coefficient (ICC).

Study Population

In this study we chose for three patients that we found that we had small uterine fibroids measuring less than 3 cm. Nine routine MRI sequences were included for each patient and three representative images were selected from each sequence, resulting in 27 images per patient and a total dataset of 81 MRI images. The selected images were processed using the proposed image enhancement framework and subsequently evaluated by three independent radiologists. Small uterine fibroids were specifically selected because they are often difficult to detect on MRI, making them suitable for evaluating the effectiveness of digital image enhancement techniques in improving image quality and diagnostic interpretation.

Table 1: MRI Protocol and Sequence Parameters

Parameter	STAIR	T1WI- GAD	T1WI- TSE	T2W-TSE	DWI, ADC
TR	2521	628	378	3500	4010
TE	80	10	7.0	80	68
FOV	380	300	400	400	375
Slice thickness	5 mm	5 mm	5 mm	5 mm	5 mm
Number of slices	18	40	18	18	40
Scan time	2.11 sec	5.36 sec	1.85 sec	3.9 sec	1.12 sec
SNR	1.00	1.00	1.00	1.00	1.00

Table 2: MRI Image Preprocessing Steps

Step	Technique	MATLAB Function	Cropping	Implementation Parameters	Purpose
1	Gaussian Filtering	imgaussfilt()	-	Kernel size = 5×5; $\sigma = 1.0$	Reduces image noise and unwanted high-frequency variations
2A	Edge Sharpening	imsharpen()	70 pixels from each side	Radius = 2; Amount = 1.5	Enhances lesion boundaries and fine structural details
2B	CLAHE	adapthisteq()	70 pixels from each side	NumTiles = [8 8]; ClipLimit = 0.01	Enhances local contrast and improves visibility of local details
2C	Haar-DWT	dwt2()/idwt2()	40-pixel border followed by subsequent cropping	Haar wavelet; first-level 2-D decomposition; LL approximation subband normalized using mat2gray	Provides multi-resolution image representation and enhances relevant image details
3	Resizing	imresize()	-	224×224 pixels; bilinear interpolation	Standardizes image dimensions
4	Saving	imwrite()	-	PNG format	Stores processed images separately

MRI Protocol

Analyses of various series of MRI scans were performed for each patient. The sequences were chosen because of their relevance to the evaluation of uterine diseases and uterine fibroids.

The sequences included were:

- Axial and sagittal T1 weighted images
- Axial and sagittal views on T1 with gadolinium
- Axial and sagittal T2 weighted
- STIR coronal
- DWI and ADC axial

The sequences are the ones standard in MRI commonly used to assess uterine fibroids that deliver multiple diagnostic information on the tissue properties and pathological changes (Table 1).

Image Processing

The MRI images were processed using MATLAB R2024a. The processing started with the original MRI images, followed by Gaussian filtering to reduce image noise and unwanted variations in the images.

Following the filtering stage, three image enhancement methods were applied separately: Contrast-Limited Adaptive Histogram Equalization (CLAHE), Laplacian edge sharpening and Discrete Wavelet Transform (DWT). These methods were implemented independently to allow for the evaluation of each technique's specific impact: CLAHE was used to improve local contrast; Laplacian edge sharpening served to enhance image edges and fine structural details; and DWT was employed to represent the image at various scales and enhance relevant details.

After processing, each enhanced image was resized to the required dimensions and saved separately for further assessment by the radiologists. The same procedure was followed for all selected MRI images included in the study.

To minimize potential image distortion, cropping and resizing operations were performed consistently, preserving the uterine region and the targeted small fibroid. Enhancement techniques were employed to improve image contrast and highlight structural details without intentionally altering the lesion's anatomical characteristics. Both the original and processed images represented the same anatomical regions and were subsequently evaluated by three experienced radiologists. Furthermore, the MATLAB functions and parameters used at each processing stage are listed in Table 2 to provide sufficient detail for result reproducibility.

The following pre-processing techniques are cropping of the area to be analyzed, edge sharpening, contrast enhancement and Discrete wavelet transform. Figure 1 shows the preprocessing sequence details such as, (a) The sagittal T1-TSE Gad enhanced MRI image, (b) Coronal STIR image and (c) Axial ADC images.

Methodology Flowchart

The general overview of pre-processing of MRI images is shown in Figure 2. This process starts from the original MRI image and then involves various steps to enhance the image such as applying Gaussian filter, applying contrast enhancement (CLAHE), applying Laplacian filter, Discrete Wavelet Transform, resizing image and then saving the processed image.

The preprocessing techniques used in this study are summarized in Table 2. Every step makes the MRI image better and better, so that features can be extracted and lesions found in the image even more precisely.

Image Enhancement Algorithm

This method of image enhancement is performed in the process presented here and consists of three steps: Discrete Wavelet Transform (DWT), Constrained Adaptive Contrast Equation (CLAHE) and Laplace's technique used to enhance

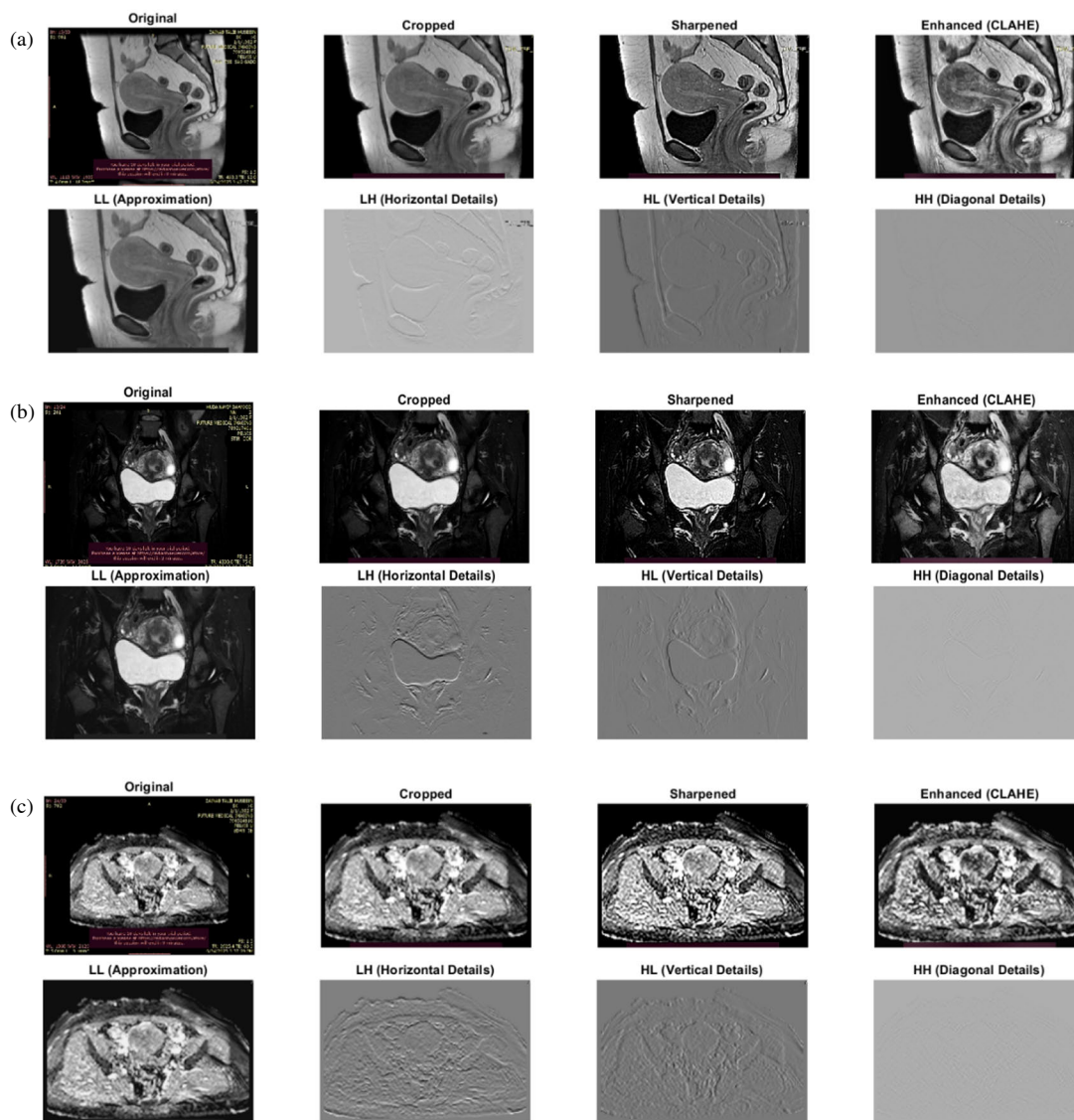


Figure 1: Pelvis MRI image with sequential preprocessing such as, (a) Sagittal T1-TSE Gad enhanced image, (b) Coronal STIR image and (c) Axial ADC image, including Cropped image showing attention to the uterine area, Edge Sharpening image and Contrasted with Enhanced image showing better visualization of uterine tissue

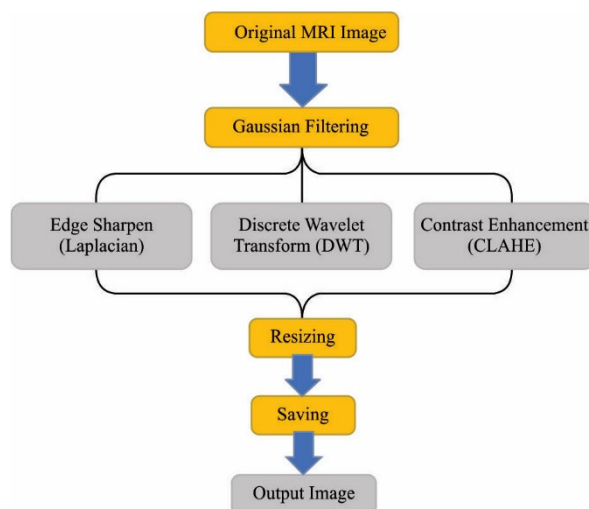


Figure 2: Flowchart

Table 3: Algorithm 1: MRI Image Enhancement Using CLAHE and Laplacian

Description	Steps
Load MRI image dataset	1
Apply Gaussian filtering to reduce noise	2
Apply CLAHE for contrast enhancement	3
Apply DWT for multi-scale decomposition and detail enhancement	4
Apply Laplacian filter for edge sharpening	5
Resize images to standard input size	6
Save enhanced images	7
Output processed MRI images	8

the clearness of the images as well as the images boundaries where lesions are discovered. The algorithm proposed is expressed in terms of the following steps in Algorithm 1 (Table 3).

The Discrete Wavelet Transform (DWT) was applied to provide a multi-resolution representation of Magnetic Resonance Imaging (MRI) images and to enhance the representation of relevant image details. The Haar wavelet was used to perform a first-level 2D decomposition; the DWT decomposed each image into four sub-bands-three detail sub-bands (LH, HL and HH) and one approximation sub-band (LL)-representing distinct spatial and frequency components.

The DWT was implemented in the MATLAB R2024a environment using the 'dwt2()' function. This function performs 2D wavelet decomposition by applying separable low-pass and high-pass filtering operations followed by down-sampling, thereby generating the approximation and detail sub-bands [16].

In this study, the approximation sub-band (LL) was selected for further processing, as it retains the essential low-frequency structural information of the MRI image. The selected LL sub-band underwent normalization using the 'mat2gray ()' function in MATLAB and was subsequently resized to 224×224 pixels. These procedures were uniformly applied to the selected MRI images prior to their presentation for evaluation by a radiologist. Wavelet-based image processing has been investigated in previous MRI studies as a means of improving image representation and the extraction of relevant image features. Therefore, wavelet transform was used to emphasize diagnostically relevant high-frequency information prior to deep learning classification.

The Laplacian filter was applied to emphasize the fast varying part of the image intensity at edges that represent structures, to improve the boundaries of lesions. The discrete Laplacian operator acts on the image brightness function to find its second derivative in the spatial domain and in this way emphasises fine details and shows discontinuities in structure. The Laplacian filter was made using the fspecial (laplacian) function of the Image Processing Toolbox in MATLAB package and applied to the image to achieve more definition of the edges. It has been seen by recent studies that boundary enhancement and structural distinction is better attained whereas using the Laplacian, in particular in MRI

lesion analysis [17]. This parameter improves the morphology of fibroids with abrupt changes of light intensities at the margins.

Application of CLAHE: MRI images contain low-contrast areas; hence, the image was passed through CLAHE, which helps in improving the local contrast while avoiding noise amplification. CLAHE enhances the visual quality of the local details of a given image, by equalizing the histogram distribution of the details contained in "small" context areas (tiles) while jointly restricting the amplification of noise in each tile. For MATLAB, the implementation of CLAHE was done by utilizing the Image Processing Toolbox (adapthisteq function). It segments the image into many small regions (tiles), performs adaptive histogram equalization on each region and sets a clip limit to clip out the excessive contrast enhancement before combining the regions by bilinear interpolation [11]. While CLAHE has the same frequency distribution clipping properties as the original equation, the range of clipping is limited. Recent medical imaging studies show that CLAHE affects the stability of the radiographic qualities and boosts the strength of classification in MRI datasets [18]. However, to make the difference in histological regions between normal uterine muscle and fibrotic areas, CLAHE has been added.

Image Evaluation

Three experienced radiologists independently evaluated the selected MRI images. To minimize potential bias, each radiologist performed the assessment independently without access to the assessments or scores provided by the other readers. For each selected image, the original, unprocessed image was displayed first, followed by its corresponding digitally enhanced version. After viewing both images, each radiologist rated the overall improvement on a scale of 1 to 10, applying the same evaluation criteria across all images and MRI sequences. A score of 1 indicated minimal to no improvement, 5 indicated moderate improvement and 10 indicated excellent improvement in the visualization of the lesion and relevant anatomical details, with intermediate scores reflecting levels between these points. The same display order and evaluation procedures were maintained throughout the assessment. Scores were recorded separately for each image and MRI sequence and subsequently used to evaluate inter-reader agreement and the perceived impact of digital image enhancement.

Statistical Analysis

Statistical analysis was performed to assess the level of agreement among the readers (three radiologists) and the observed effect of digital image enhancement. Weighted Cohen's kappa coefficients were used to evaluate pairwise agreement between radiologists, given that the visual assessment scale was ordinal (ranging from 1 to 10). The Intraclass Correlation Coefficient (ICC) was also used to assess the overall reliability of the ratings; specifically, a two-way random-effects model based on absolute agreement [ICC (2,1)] was employed. Additionally, a repeated-measures analysis was conducted to account for the repeated assessments performed by the radiologists, treating both the reader and the MRI sequence as within-subject factors and examining the interaction between them. Since the selected MRI images (totaling 81) were derived from only three patients, the observations were not considered independent at the patient level. Statistical significance was assessed at the $\alpha = 0.05$ level and the results were considered exploratory due to the small sample size at the patient level.

RESULTS AND DISCUSSION

Evaluating the performance of image readers in interpreting MRI images after enhancement using artificial intelligence techniques, as shown in Table 4.

The three-reader assessment for patient Zainab showed a high level of inter-reader agreement in the evaluation of the

enhanced MRI images. The weighted Cohen's kappa values were 0.798 for R1 vs. R2, 0.847 for R1 vs. R3 and 0.806 for R2 vs. R3, indicating substantial to excellent agreement among the individual reader pairs. The overall Intraclass Correlation Coefficient (ICC) was 0.833 (95% CI: 0.563-0.926), indicating excellent overall inter-reader reliability. The findings suggest that the three radiologists showed, a high level of consistency in their visual assessment of the enhanced MRI images for this patient.

Figure 3 shows Pairwise inter-reader agreement for patient Zainab based on weighted Cohen's kappa: (a) Reader 1 vs. Reader 2, (b) Reader 1 vs. Reader 3 and (c) Reader 2 vs. Reader 3.

From the data in Table 5, it can be seen that there is a varying level of agreement among the readers about the case of patient Huda.

The three-reader assessment for patient Huda showed a generally good level of inter-reader agreement in the evaluation of the enhanced MRI images. The weighted Cohen's kappa values were 0.667 for R1 vs. R2, 0.538 for R1 vs. R3 and 0.880 for R2 vs. R3, indicating moderate to excellent agreement among the individual reader pairs. The highest agreement was observed between R2 and R3 (weighted $\kappa = 0.880$), while the lowest agreement was observed between R1 and R3 (weighted $\kappa = 0.538$). The overall Intraclass Correlation Coefficient (ICC) was 0.717 (95% CI: 0.360-0.867), indicating good overall inter-reader

Table 4: Statistical Evaluation of Inter-Reader Agreement in Enhanced image MRI Interpretation for Patient Zainab

Comparison	Weighted Cohen's Kappa	95% CI
R1 versus R2	0.798	0.411-0.930
R1 versus R3	0.847	0.534-0.970
R2 versus R3	0.806	0.571-0.943
Overall ICC (2,1)	0.833	0.563-0.926

Table 5: Statistical Evaluation of Inter-Reader Agreement in Enhanced MRI image Interpretation for Patient Huda

Comparison	Weighted Cohen's Kappa	95% CI
R1 versus R2	0.667	0.372-1.000
R1 versus R3	0.538	0.000-0.780
R2 versus R3	0.880	0.372-1.000
Overall ICC (2,1)	0.717	0.360-0.867

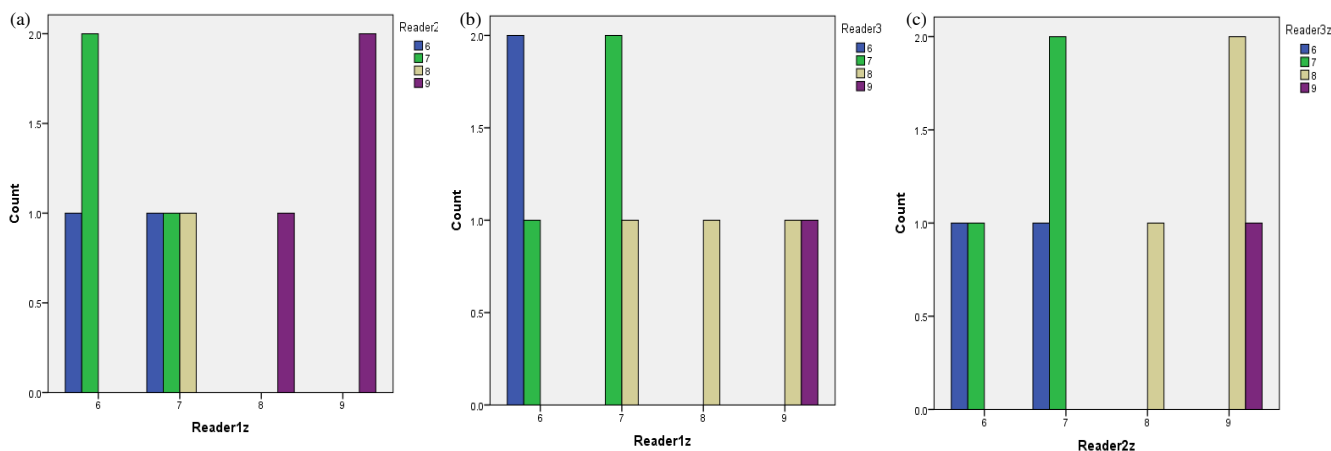


Figure 3(a-c): (a) Agreement between Reader 1 and Reader 2, (b) Agreement between Reader 1 and Reader 3 and (c) Agreement between Reader 2 and Reader 3

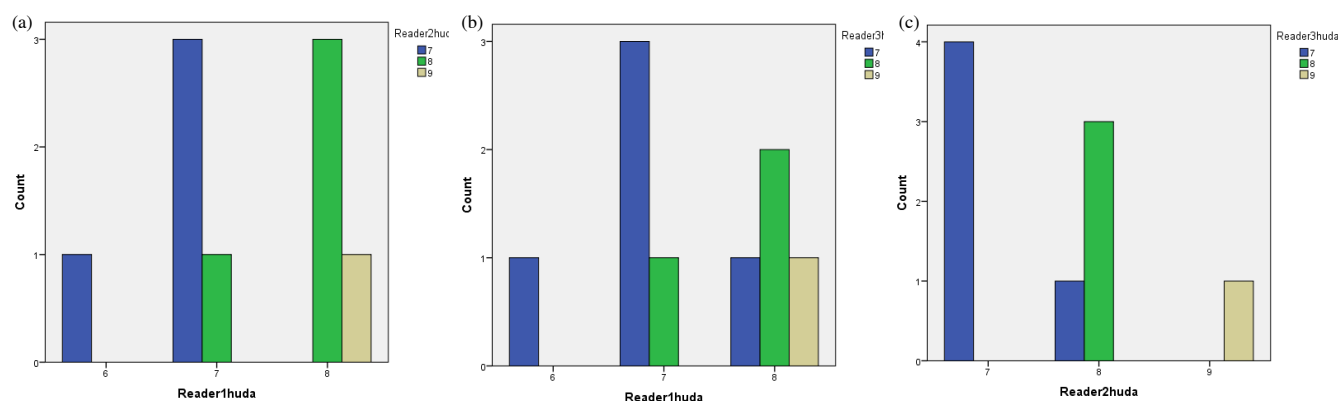


Figure 4(a-c): (a) Agreement between Reader 1 and Reader 2, (b) Agreement between Reader 1 and Reader 3 and (c) Agreement between Reader 2 and Reader 3

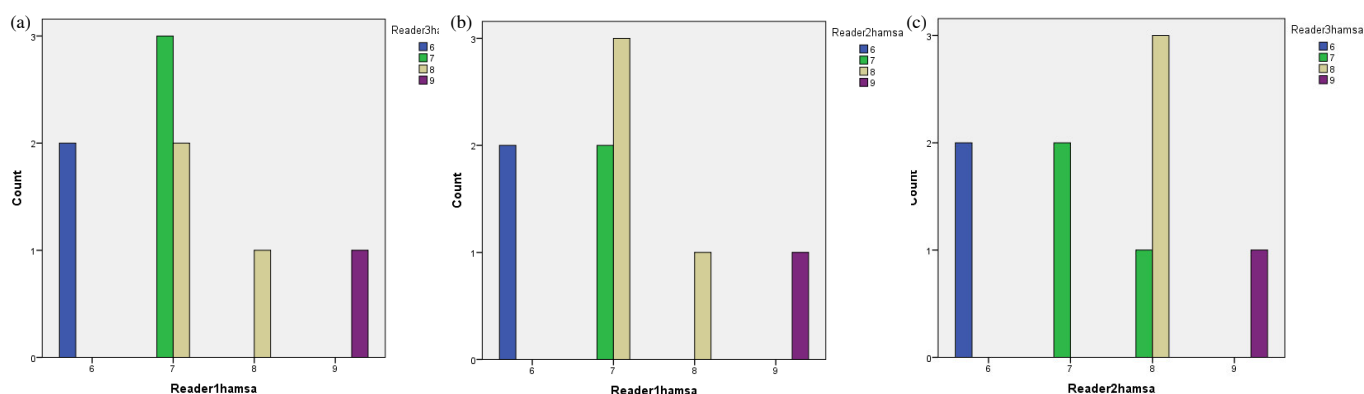


Figure 5(a-c): (a) Agreement between Reader 1 and Reader 2, (b) Agreement between Reader 1 and Reader 3 and (c) Agreement between Reader 2 and Reader 3

Table 6: Statistical Evaluation of Inter-Reader Agreement in Enhanced MRI image Interpretation for Patient Hamsa

Comparison	Weighted Cohen's Kappa	95% CI
R1 versus R2	0.814	0.341-1.000
R1 versus R3	0.870	0.400-1.000
R2 versus R3	0.939	0.630-1.000
Overall ICC (2,1)	0.887	0.538-1.000

reliability. These findings suggest that the three radiologists showed generally consistent visual assessment of the enhanced MRI images, although some variation was observed between individual reader pairs.

Figure 4 shows Pairwise inter-reader agreement for patient Zainab based on weighted Cohen's kappa: (a) Reader 1 vs. Reader 2, (b) Reader 1 vs. Reader 3 and (c) Reader 2 vs. Reader 3.

Inter-reader agreement is found to be higher for Patient Hamsa from Table 6 as compared to the previous case.

The three-reader assessment for patient Hamsa demonstrated a high level of inter-reader agreement in the evaluation of the enhanced MRI images. The weighted Cohen's kappa values were 0.814 for R1 vs. R2, 0.870 for R1 vs. R3 and 0.939 for R2 vs. R3, indicating substantial to excellent agreement among the individual reader pairs. The highest agreement was observed between R2 and R3 (weighted $\kappa = 0.939$), while the agreement between R1 and

Table 7: Repeated-Measures Analysis of Radiologist Assessment Scores

Effect	F	df	p-value
Reader	61.00	2, 4	0.001
MRI Sequence	14.42	8, 16	<0.001
ReaderxMRI Sequence	1.60	16, 32	0.126

R2 was also strong (weighted $\kappa = 0.814$). The overall Intraclass Correlation Coefficient (ICC) was 0.887 (95% CI: 0.538-1.000), indicating excellent overall inter-reader reliability. These findings demonstrate a high level of consistency among the three radiologists in their visual assessment of the enhanced MRI images for this patient.

Figure 5 shows pairwise inter-reader agreement for patient Zainab based on weighted Cohen's kappa: (a) Reader 1 vs. Reader 2, (b) Reader 1 vs. Reader 3 and (c) Reader 2 vs. Reader 3.

The repeated-measures analysis showed a statistically significant difference among the three radiologists ($F = 61.00$, $df = 2, 4$, $p = 0.001$) and across the MRI sequences ($F = 14.42$, $df = 8, 16$, $p < 0.001$) (Table 7). The reader-by-sequence interaction was not statistically significant ($F = 1.60$, $df = 16, 32$, $p = 0.126$). These findings indicate that the ratings varied according to reader and MRI sequence, while the pattern of reader differences did not significantly depend on the MRI sequence.

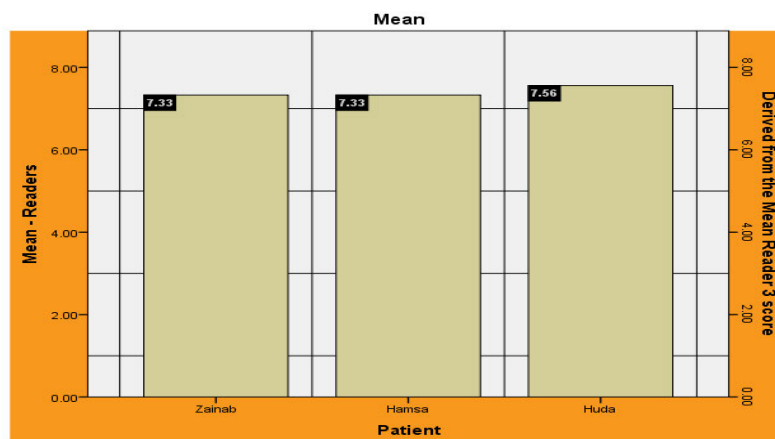


Figure 6: Mean Performance Improvement Scores of Radiologists Across the Three Patients

Figure 6 illustrates the average improvement scores assigned by the three radiologists to the enhanced MRI images of the three patients; higher scores indicate a greater perceived improvement in image clarity.

The findings of the present study show that digital image processing techniques can increase the quality of MRI images and their detection of small fibroids in particular.

The application of advanced digital processing method (DWT-CLAHE - LAPLACE) techniques for sharpening and contrast enhancement has been revealed, which has improved the images and radiologist's diagnostic skill due to the fine outlines of the lesions in the tissues.

The Discrete Wavelet Transform (DWT) also played an important role in improving MRI image quality by decomposing images into multiple frequency components, enabling effective noise suppression while preserving anatomical boundaries and fine structural details. This multi-resolution analysis enhanced the visualization of small uterine fibroids without compromising the original anatomical information. Similar findings have been reported in previous studies, which demonstrated that wavelet-based enhancement improves image resolution, preserves diagnostically important features and supports more accurate medical image interpretation [13,19].

Classical Adaptive Histogram Equalization (AHE) may over amplify noise in fairly uniform portions of MRI. CLAHE does this with a clip applied before computing the cdf associated with the histogram at a specified value, canceling out over energizing of useless noise. Research has shown that CLAHE enhances performance for CAD applications including Convolutional Neural Networks (CNNs), which are used to detect key features, such as in Alzheimers or tumor detection scenarios.

Citing the accuracy in lesion size, the Laplacian method could be the most precise and reliable method for ensuring the quality of the input MRI data. The accuracy and reliability of multiple thickness and lesion size measurement methods has also been investigated in medical MRI data, with performance varying depending on the image processing method used [20-22].

The inter-reader agreement results showed variation among the three patients. For Zainab, the weighted Cohen's kappa values ranged from 0.798 to 0.847, with an ICC of 0.833. For Huda, the weighted kappa values ranged from 0.538 to 0.880, with an ICC of 0.717. For Hamsa, the weighted kappa values ranged from 0.814 to 0.939, with an ICC of 0.887. These findings indicate generally good to high inter-reader agreement and reliability, although some differences were observed between individual reader pairs. Previous studies have similarly reported that radiologist experience and image quality can influence the consistency of medical image interpretation [23].

The repeated-measures analysis also showed differences in the assessment scores according to radiologist and MRI sequence, whereas the reader-by-sequence interaction was not statistically significant. These findings suggest that the ratings varied across readers and MRI sequences, while the pattern of reader differences was relatively consistent across the sequences.

The present findings should be interpreted as evidence of perceived improvement in image visualization and inter-reader reliability, rather than as evidence of improved diagnostic accuracy. The study did not include an independent diagnostic reference standard and therefore it cannot determine whether image enhancement improves the true detection of uterine fibroids. Similarly, the findings cannot be used to demonstrate a reduction in diagnostic errors or establish clinical effectiveness.

Previous research has reported potential applications of image-processing and artificial intelligence methods in medical imaging and decision-support systems [10,24]. However, these studies provide broader context for the potential development of computer-assisted imaging approaches and should not be interpreted as evidence that the present study validated an AI-based diagnostic system. Further challenges related to data quality, dataset size, validation, interpretability and transparency remain important considerations for future clinical applications [25].

Overall, the present study provides preliminary evidence that digital image enhancement may improve the

perceived visualization of small uterine fibroids on MRI. Larger studies with more patients, independent diagnostic reference standards and external validation are required to determine whether these improvements in visual assessment translate into measurable clinical or diagnostic benefit.

CONCLUSIONS

The results of this study indicate that digital image processing techniques can enhance the perceived visual quality and visibility of small uterine fibroids in Magnetic Resonance Imaging (MRI) scans. The processed images demonstrated improved visual representation of lesion details, as assessed by three experienced radiologists.

Analysis of inter-reader agreement revealed a good-to-high level of consensus and reliability among the radiologists, although some variation was observed between individual readers and across different MRI sequences.

Nevertheless, these findings should be considered preliminary, given that the study included only three patients and did not employ an independent diagnostic reference standard. Consequently, the current study does not confirm improvements in diagnostic accuracy or reductions in medical error rates. Further studies involving larger patient cohorts, independent diagnostic reference standards and external validation are required to determine the clinical value of these image enhancement techniques.

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