ENHANCEMENT TECHNIQUES FOR ABDOMINAL ORGANS' MAGNETIC RESONANCE IMAGING

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ABSTRACT

Medical images which carry important information about the human body most times appear with low visual quality; hence, it is often strenuous to detect and extract adequate information from them. Information extracted can lead to right or wrong diagnosis and prognosis. To obtain optimum images for accurate diagnosis therefore, these images must pass through an enhancement process which consists of a series of methods that aim at improving their visual assessment. Magnetic Resonance Imaging (MRI) produces most of the important medical images of which the raw data acquired can be corrupted by several types of noise and artefacts. This paper aims at improving the quality of abdominal MR images in the spatial domain. The method began with the application of the median filter for the noise reduction. Thereafter, the filtered image was further enhanced with Histogram Equalization (HE), Contrast Limited Adaptive Histogram Equalization (CLAHE), and a proposed technique; the Power Law Transformed Adaptive Histogram Equalization (PLTAHE). A sharpening effect was applied using the unsharp mask filter for the result. The results of the applied techniques were compared side by side for the best enhancement effect, and an objective assessment was carried out on by evaluating the Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM) values of the images. A subjective assessment was also carried out with a radiologist who gave a better perception to the effects of the enhancement techniques on the samples studied. The results of the study showed that the proposed technique Power Law Transformed Adaptive Histogram Equalization produced the best contrast for the analysed MR images.

KEYWORDS: Enhancement, MRI, HE, CLAHE, PLATHE.

1. INTRODUCTION

Medical imaging offers a promising way and guarantee for major advances in science and medical diagnosis as higher precision images are being produced. Computer-aided diagnosis is presently a fundamental part of the early detection, diagnosis, and treatment of malignancies such as cancer of internal organs. The challenge is to viably process and analyse the images in order to effectively extract, and interpret the information contained to gain understanding and useful knowledge about the structure and function of the affected damaged organs (Dougherty, 2011).

Magnetic Resonance Imaging (MRI) has become an imperative non-invasive imaging modality as it gives excellent contrast between soft tissues (Lauterbur, 1973). Most times these images appear with poor visual representation due to the presence of noise and artefacts from the image acquisition system. Therefore, the need to pre-process these images by filtering and improving the visual quality is fundamental for further processing. This study applies the selective attributes of a class of digital filters with computer vision to preferentially extract and enhance the images of the particular organ being investigated from its background or overlying noise contents (Saleh et al. 2011; Solomon et al. 2011; Xu et al. 2009). The enhancement techniques were implemented in the spatial domain that deals with the direct manipulation of image pixels.

2. MATERIALS AND METHODS

2.1 Materials

A series of random patients affected by symptomatic cancers of the liver, kidney, and spleen were considered. Six (6) scanned abdominal MR samples were selected from the sample size for this study. The images highlighting, the liver (Erickson, et al. 2016), kidney (National Cancer Institute Clinical Proteomic Tumor Analysis Consortium (CPTAC). 2018). and spleen (Erickson, et al. 2016) were obtained from The Cancer Imaging Archive (TCIA) public access (Clark *et al.*, 2013) hosted by the University of Arkansas for Medical Sciences (UAMS), and Jos University Teaching Hospital (JUTH).

2.2 Methods

The enhancement techniques were applied on six (6) sample slices out of the sample size acquired from TCIA database and JUTH. Before the implementation of the enhancement techniques, all samples were anonymised. To begin the enhancement process, noise reduction was carried out on each of the acquired images by utilizing the median filtering method. For this study, three (3) enhancement techniques; Histogram Equalization (HE), Contrast Limited Adaptive Histogram Equalization (CLAHE), (Saleh, Ahmed, & Nordin, 2011; Solomon & Breckon, 2011; Xu, Liu, & Chen, 2009) and the proposed technique; Power Law Transformed Adaptive Histogram Equalization (PLTAHE) were implemented and compared with each other to select the best method to be utilized. In addition, the samples obtained at TCIA were also compared side by side with that obtained at JUTH. Further in processing the images, a sharpening effect was applied on the enhanced images using the unsharp masking technique (UMT).

2.2.1 Median Filter (MF)

The median filter eliminates unwanted elements of noise present in the images. Images used in the medical field are sometimes contaminated by a type of noise called salt and pepper noise. This noise manifests as minute variations in the grayscale representation of the image. The median filter has an advantage of removing impulse noises, in such a way that, the image sharpness is not altered. The MF is one of the most commonly used filtering techniques as it provides excellent noise-reduction (Aparna, Jatti, & Bharadwaj, 2015). In MATLAB, the median filtering was carried out by utilizing an in-built function called 'medfilt2' which is a two-dimensional (2-D) filter. The size of the window can be selected, and the smaller the window, the faster the median filtering operation. Each pixel's value was compared to its neighbour and replaced by the median value of the number of pixels detected by the window size. It essentially detects if or not the pixel is a representation of its surroundings.

2.2.2 Histogram Equalization (HE)

Histogram modeling techniques (i.e. histogram equalization) provide a refined technique for adjusting the dynamic range and contrast of an image by modifying the image with the end goal that its intensity histogram has the desired shape (Solomon & Breckon, 2011). Histogram modeling operators may utilize non-direct and non-monotonic transfer functions to map between pixel intensity values in the input and output images. Histogram equalization utilizes a monotonic, non-linear mapping which re-allots the intensity values of pixels in the input image such that the output image contains a uniform distribution of intensities. An in-built function 'histeq' in MATLAB is used to match a flat histogram with 64 bins by default.

2.2.3 Contrast Limited Adaptive Histogram Equalization (CLAHE)

Contrast Limited Adaptive Histogram Equalization (CLAHE) is a technique utilized for improving the local contrast of images. It is a generalization of ordinary histogram equalization and adaptive histogram equalization (Saleh et al., 2011). CLAHE does not operate on the whole image, just like the ordinary Histogram Equalization (HE), it rather works on small areas in images, named tiles (Solomon & Breckon, 2011). Each tile contrast is enhanced, so that the histogram of the output area roughly matches the histogram determined by the distribution parameter. The adjacent tiles are then combined using bilinear interpolation to eliminate artificially induced boundaries. The contrast, particularly in homogeneous regions, can be limited to avoid amplifying any unwanted information like noise which could exist in the images. In MATLAB, CLAHE has an inbuilt function called 'adapthisteq'.

For this, the clip limit, number of tiles, number of bins, distribution parameter all needs to be specified. The value of each parameter was determined by multiple tests of each anatomy as the clip limit is dependent on the organ analysed. The contrast of each tile is enhanced, so that the output image's histogram looks like the histogram determined by the distribution parameter.

2.2.4 Power Law Transformed Adaptive Histogram Equalization (PLTAHE)

This paper proposes the Power Law Transformed Adaptive Histogram Equalization (PLTAHE) technique developed by the authors which applies a function of the power law gamma correction as well as tiles enhancement via the adaptive histogram equalization (Akintunde, 2019). The transformation function depicts that a change in the input gray level (r) would have a corresponding change on the output gray level (s) (Vimal & Thiruvikraman, 2012):

$$s = cr^{\gamma} \qquad Eq.(1)$$

Where γ is the gamma value, c and γ are positive constants.
Therefore Eq. (1) can be written as:

$$I_{output}(i,j) = c\left(I_{input}(i,j)\right)^{\gamma} \qquad Eq.(2)$$

Where i, j are the horizontal and vertical axes of the image element.
When the output pixel equals the input pixel value (i.e.$\gamma = 1$, $s = r$), this balances the contrast of the mid-value regions. When the output pixel equals the square of the input pixel (i.e. $\gamma > 1$, $s = r^2$), it enhances the contrast of high-value portions of the image at the expense of low-value regions. When the output pixel equals the square root of the input pixel value (i.e. $\gamma < 1$, $s = r^{1/2}$), this enhances the contrast of low-value portions of the image at the expense of high-value regions. The value of gamma correction is selected based on the sample analysed. The constant c performs range scaling on the images. Generally, the PLTAHE technique filters excessive noise and enhances contrast contained in each tile and a set value for gamma (γ) correction was fixed which is saved for each tile.

3. RESULTS

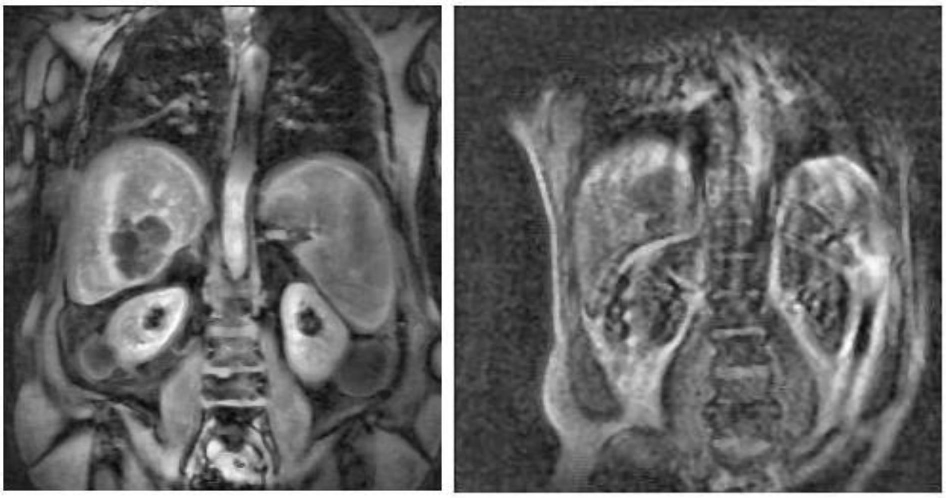
The outcome of the application of the various enhancement techniques on the studied organs (liver, kidney, and spleen) were presented in Fig. (1) – Fig. (15). The samples from TCIA and JUTH were compared side by side. The image quality metrics used to assess the enhancement techniques were presented in Table (1) and Table (2). While the charts showing a comparison of the metrics were presented in Fig. (16) – Fig. (21). Following the objective assessment summarised in table (1) and table (2) as well as Fig. (16)- Fig. (21) where the PSNR and SSIM gave higher and lower values respectively which indicated an improvement with the developed technique, a subjective assessment was also carried out to determine the quality of each technique implemented, through a radiologist.

Liver slice

a

b

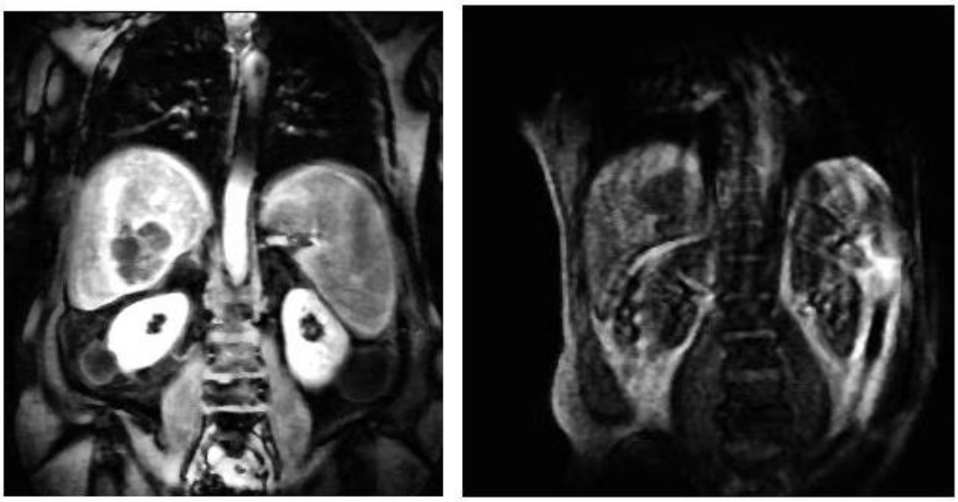
Fig. (1): Result of Histogram Equalization Technique on Liver slice:
(a) Image obtained from TCIA. (b) Image obtained from JUTH.



a b

Fig. (2): Result of Contrast Limit Adaptive Histogram Equalization Technique on Liver slice:

(a) Image obtained from TCIA. (b) Image obtained from JUTH



a b

Fig. (3): Result of Contrast Limited Adaptive Histogram Equalization Technique on Liver slice:
(a) Image obtained from TCIA. (b) Image obtained from JUTH

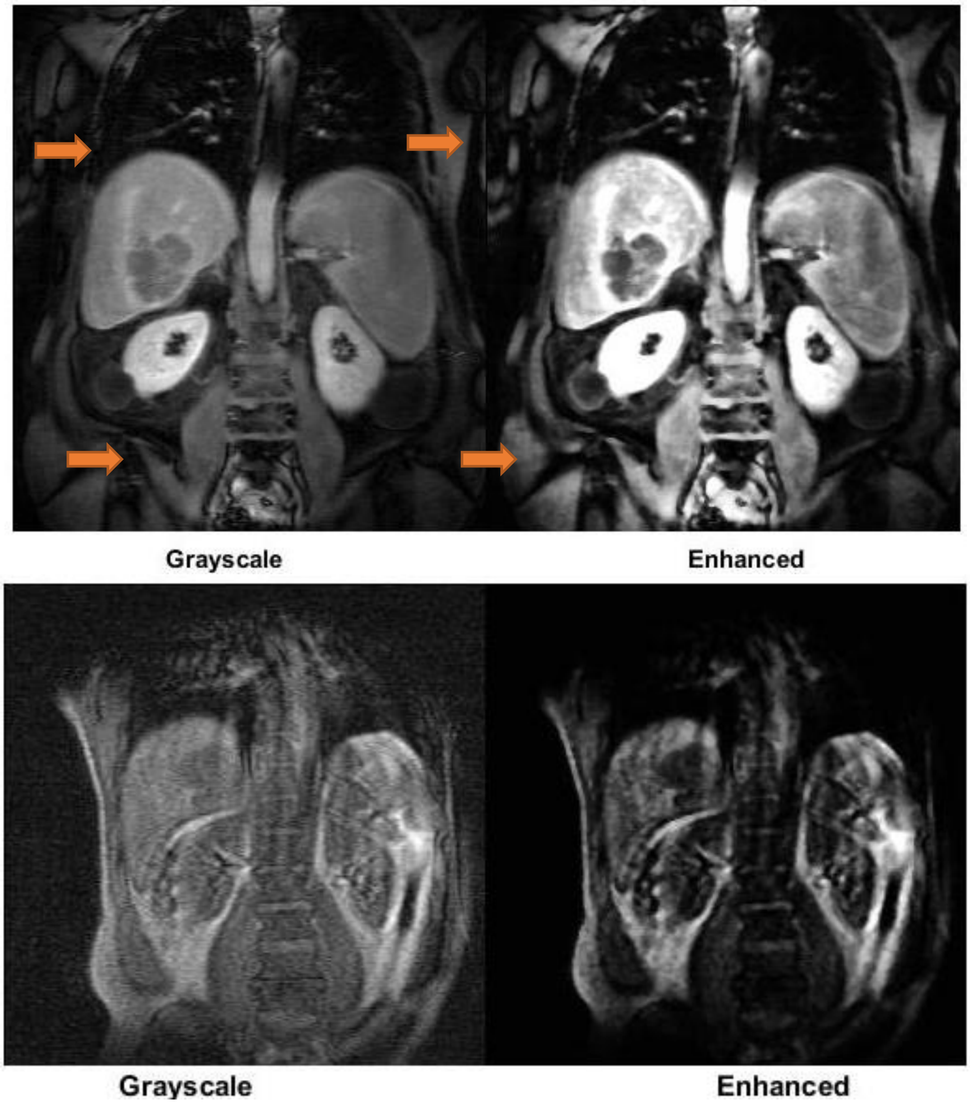


Fig. (4): Comparison of Enhancement Technique on Liver slice; 1st & 2nd frame: Original grayscale and enhanced image obtained from TCIA. 3rd & 4th frame: Original grayscale and enhanced Image obtained from JUTH.

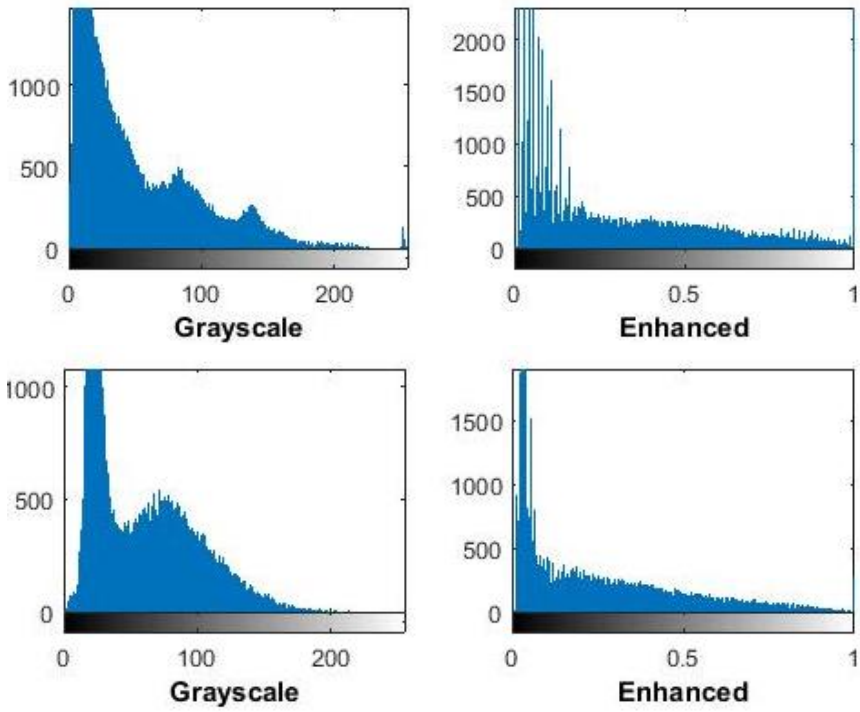


Fig. (5): Histogram of Enhancement Technique on Liver slice; First frame: Original grayscale and enhanced Image obtained from TCIA. Second frame: Original grayscale and enhanced Image obtained from JUTH.

Kidney slice

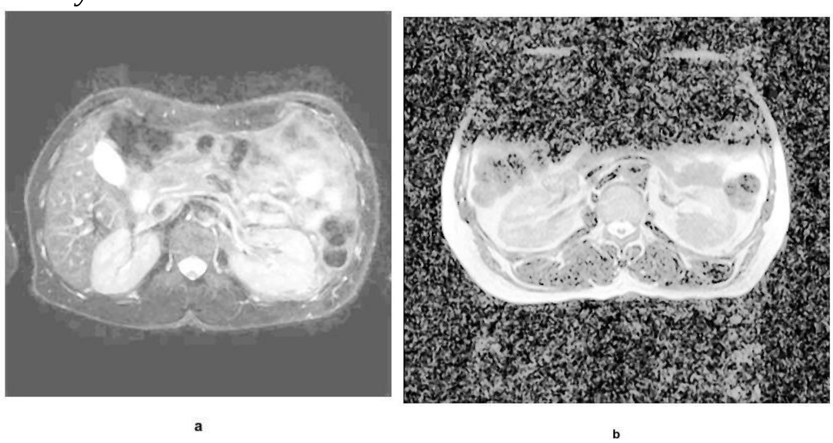


Fig. (6): Result of Histogram Equalization Technique on Kidney slice:
(a) Image obtained from TCIA. (b) Image obtained from JUTH.

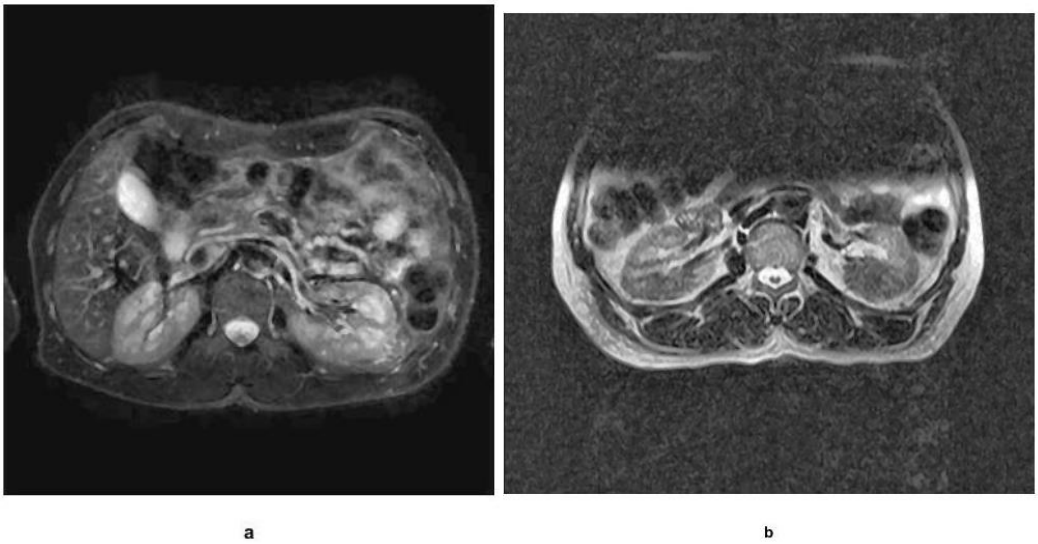


Fig. (7): Result of Contrast Limited Adaptive Histogram Equalization Technique on Kidney slice:
(a) Image obtained from TCIA. (b) Image obtained from JUTH

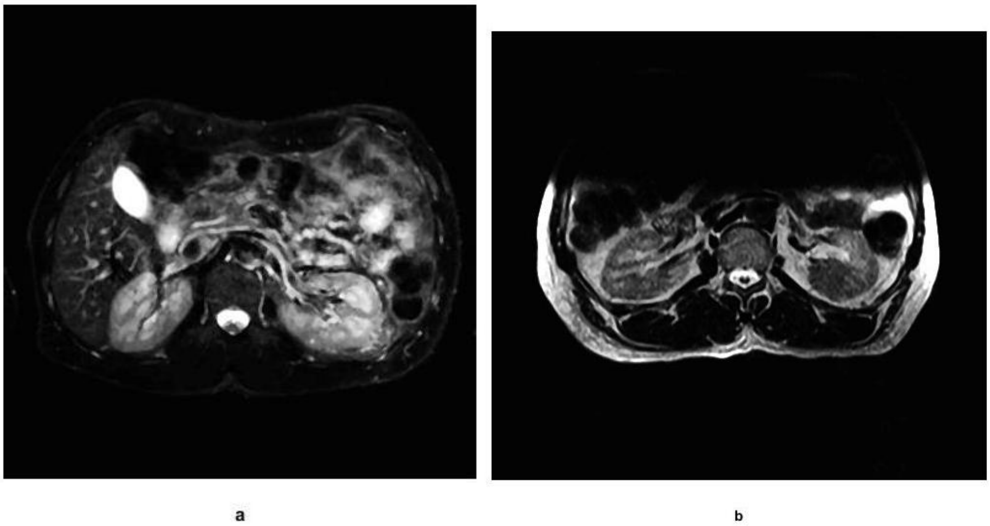


Fig. (8): Result of Contrast Limit Adaptive Histogram Equalization Technique on Kidney slice:

(a) Image obtained from TCIA. (b) Image obtained from JUTH

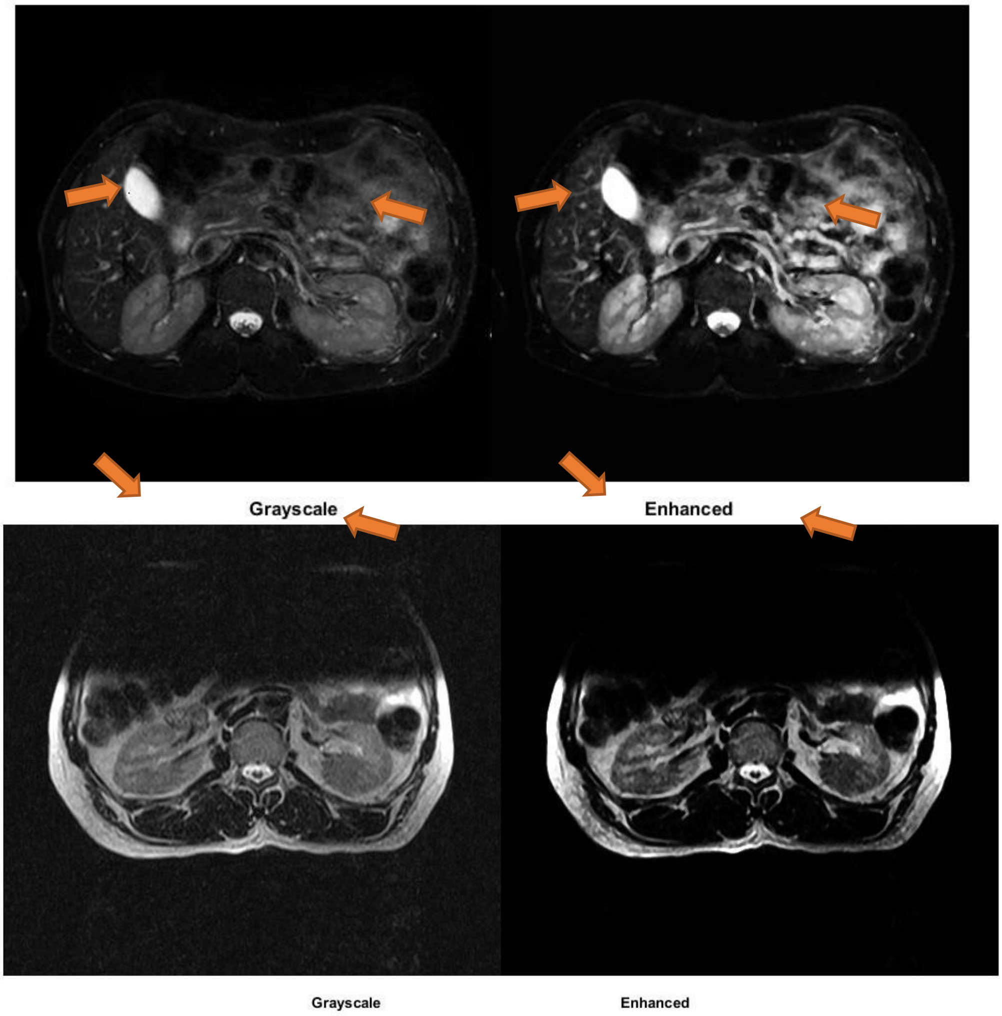


Fig. (9): Comparison of Enhancement Technique on Liver slice; 1st & 2nd frame: Original grayscale and enhanced image obtained from TCIA. 3rd & 4th frame: Original grayscale and enhanced Image obtained from JUTH.

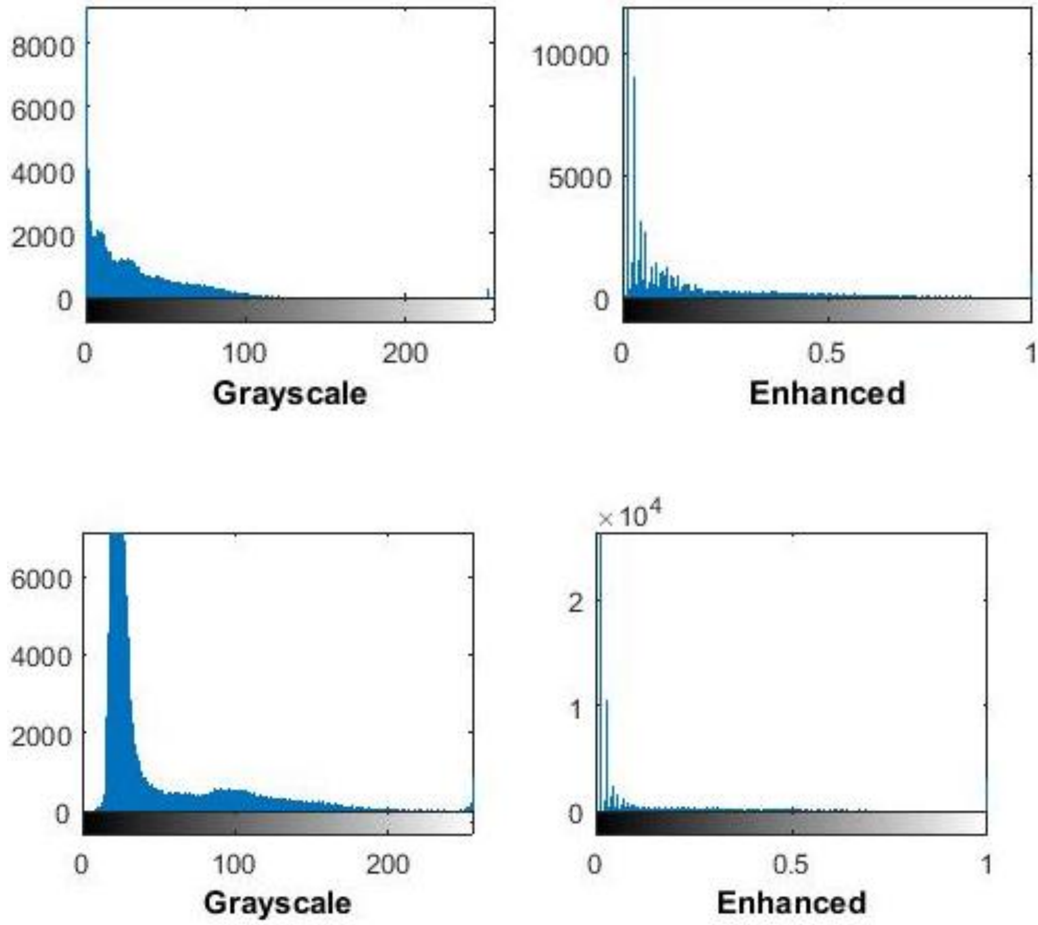


Fig. (10): Histogram of Enhancement Technique on Liver slice; First frame: Original grayscale and enhanced Image obtained from TCIA. Second frame: Original grayscale and enhanced Image obtained from JUTH.

Spleen slice

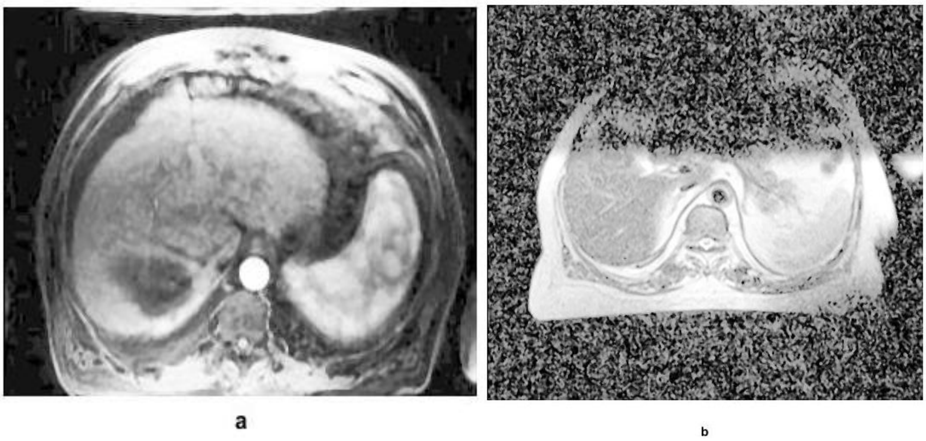


Fig. (11): Result of Histogram Equalization Technique on Spleen slice:
(a) Image obtained from TCIA. (b) Image obtained from JUTH.

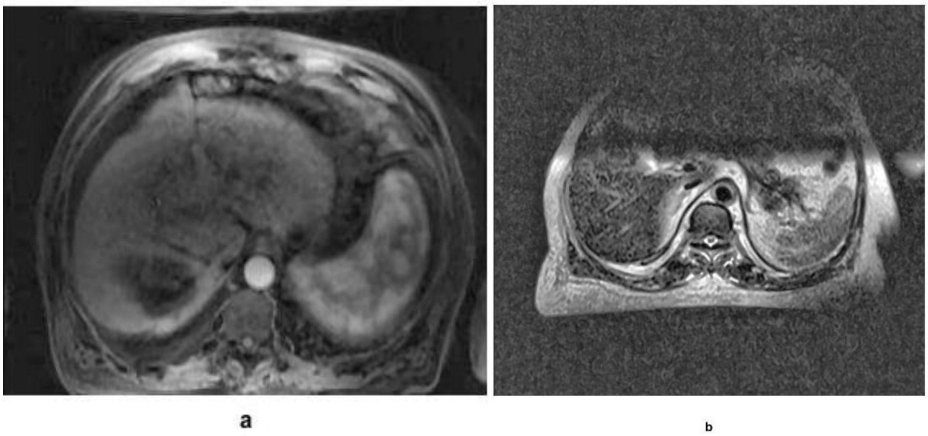
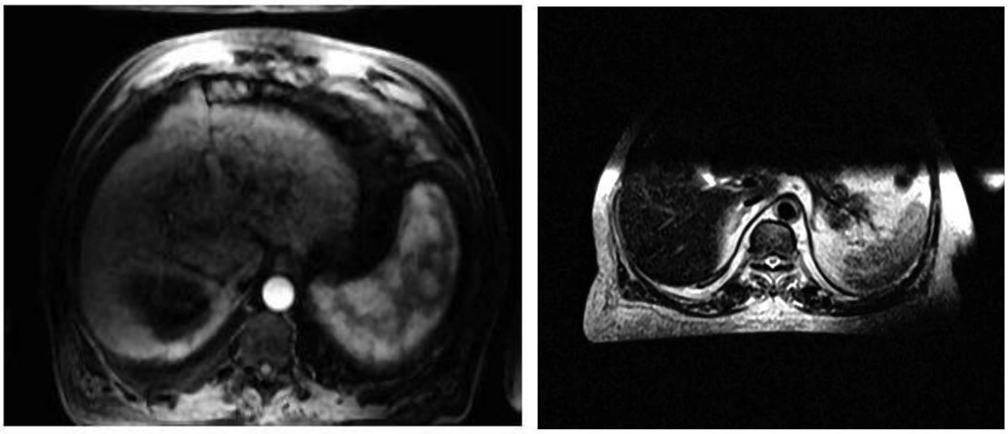
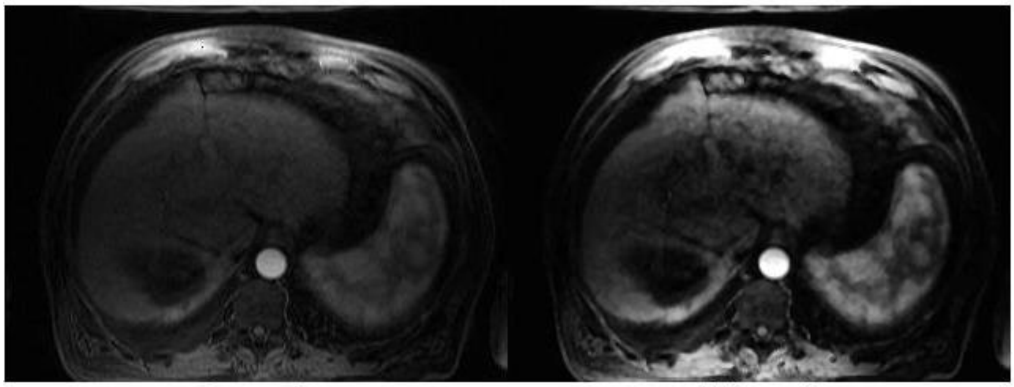


Fig. (12): Result of Contrast Limited Adaptive Histogram Equalization Technique on Spleen slice:
(a) Image obtained from TCIA. (b) Image obtained from JUTH



a b

Fig. (13): Result of Contrast Limit Adaptive Histogram Equalization Technique on Spleen slice:
(a) Image obtained from TCIA. (b) Image obtained from JUTH



Grayscale Enhanced

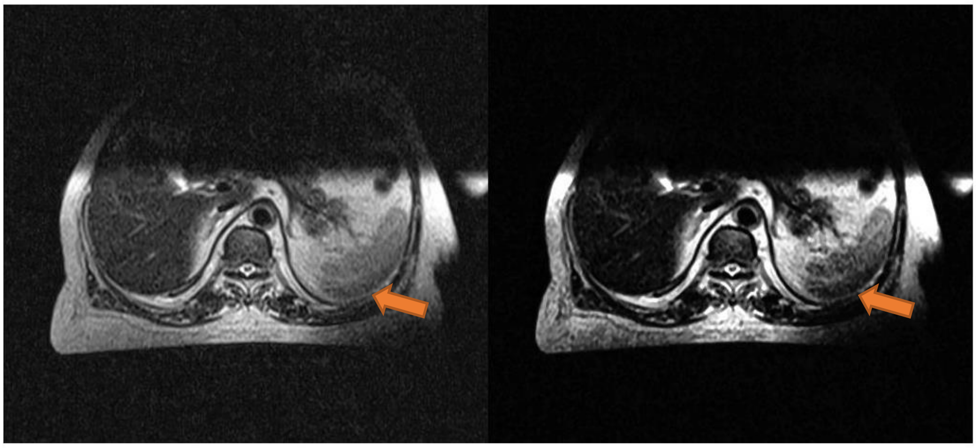


Fig. (14): Comparison of Enhancement Technique on Liver slice; 1st & 2nd frame: Original grayscale and enhanced image obtained from TCIA. 3rd & 4th frame: Original grayscale and enhanced Image obtained from JUTH.

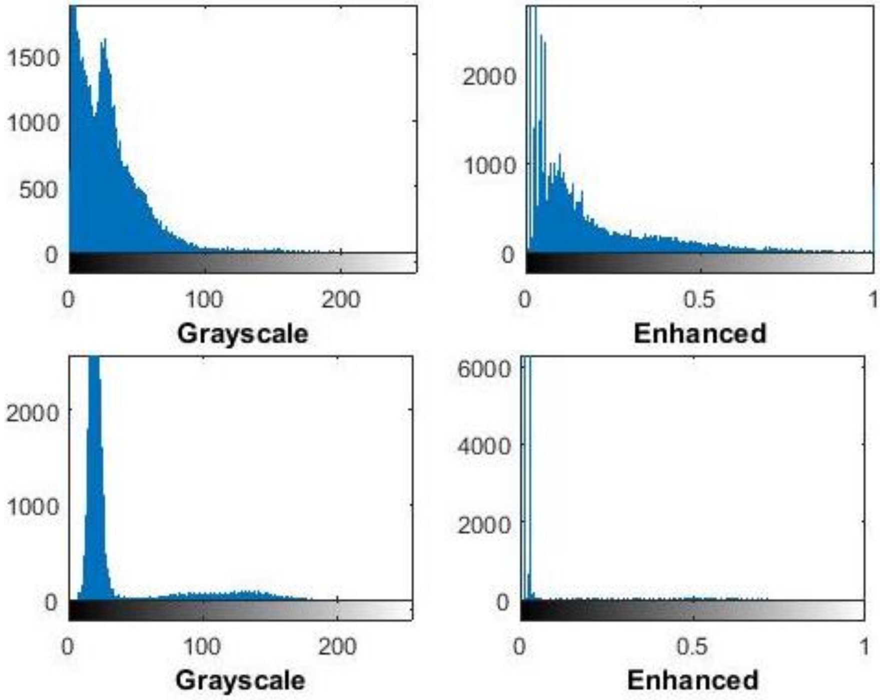


Fig. (15): Histogram of Enhancement Technique on Liver slice; First frame: Original grayscale and enhanced Image obtained from TCIA. Second frame: Original grayscale and enhanced Image obtained from JUTH.

Table 1: Image Quality Metrics showing the computed Peak Signal to Noise Ratio (PSNR) and Similarity Structural Index Measure (SSIM) values for liver, kidney, and spleen slices by the application of enhancement techniques on samples obtained from TCIA.

Images	Image Quality Metrics (IQM)	HE	CLAHE	PLTAHE (Proposed)
Liver	PSNR	9.3478	11.2962	14.2838
	SSIM	0.4525	0.5795	0.0211
Kidney	PSNR	5.8160	15.7534	16.3783
	SSIM	0.4528	0.2964	0.1418
Spleen	PSNR	7.0653	14.7734	16.2217
	SSIM	0.2390	0.4822	0.0857

Table 2: Image Quality Metrics showing the computed Peak Signal to Noise Ratio (PSNR) and Similarity Structural Index Measure (SSIM) values for liver, kidney, and spleen slices by the application on enhancement techniques for samples obtained from JUTH

Images	Image Quality Metrics (IQM)	HE	CLAHE	PLTAHE (Proposed)
Liver	PSNR	10.1924	11.0751	16.7064
	SSIM	0.5005	0.5795	0.0039
Kidney	PSNR	8.3332	12.1979	17.6501
	SSIM	0.2219	0.6897	0.0074
Spleen	PSNR	9.7211	10.6836	19.0840
	SSIM	0.3175	0.7767	0.0033

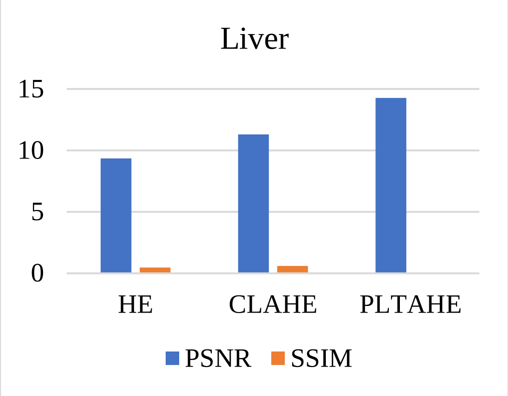


Fig. (16): PSNR and SSIM values for enhanced liver slice obtained from TCIA

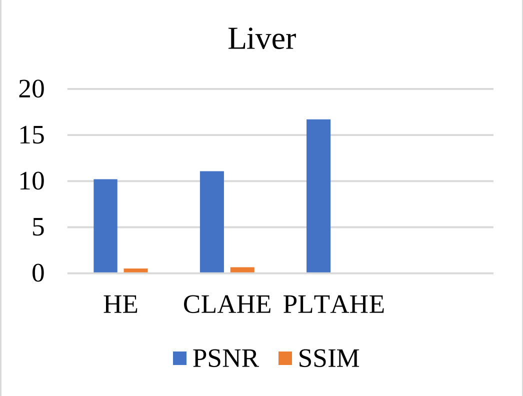


Fig. (17): PSNR and SSIM values for enhanced liver slice obtained from JUTH

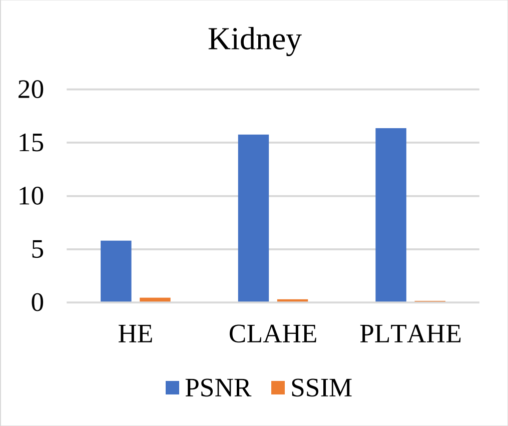


Fig. (18): PSNR and SSIM values for enhanced kidney slice obtained from TCIA

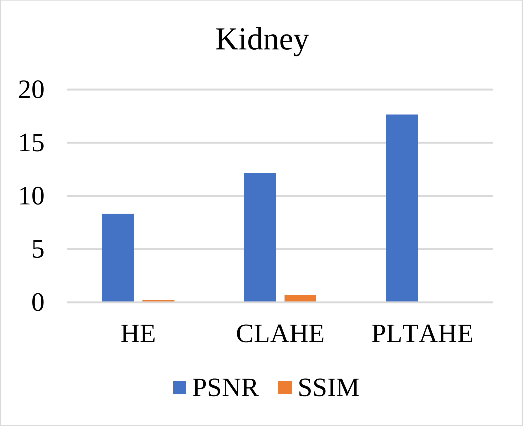


Fig. (19): PSNR and SSIM values for enhanced kidney slice obtained from JUTH

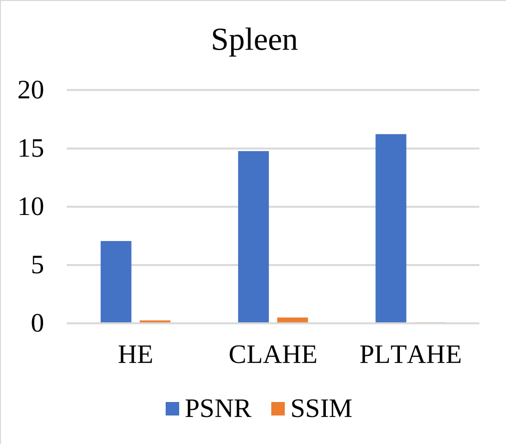


Fig. (20): PSNR and SSIM values for enhanced spleen slice obtained from TCIA

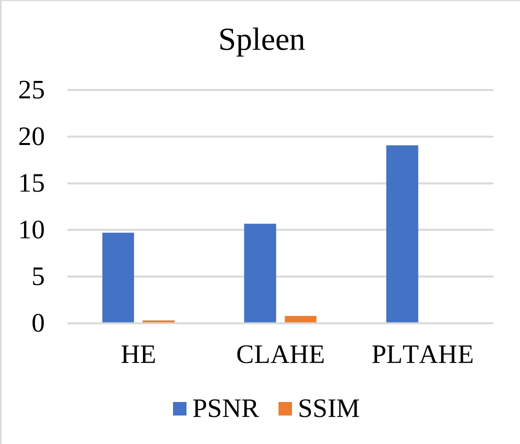


Fig. (21): PSNR and SSIM values for enhanced spleen slice obtained from JUTH

4. DISCUSSION

The images analysed were presented as in Fig. (1)- Fig. (5) for the liver samples, Fig. (6)-Fig. (10), for the kidney samples and Fig. (11)- Fig. (15) for the spleen samples. The MRI machines used for the TCIA samples were Siemens Magnetom Symphony 1.5T eco scanner utilized for the liver and spleen slices, Philips Achieva 1.5T-Ds for the kidney slices and that of JUTH was a 0.2T Siemens Magnetom scanner for the liver, kidney and spleen slices.

For Fig.(1)- Fig.(5) presenting the liver slice, the effect of the Histogram Equalization (HE) technique in Fig. (1) gave a deeper contrast of the gray level of the coronal plane of the liver for both samples from TCIA and JUTH when compared side by side. Fig. (2) further showed the effect of the Contrast Limited Adaptive Histogram Equalization (CLAHE) technique with a contrast limit but introduced an amplification of noise present in both samples. The Power Law Transformed Adaptive Histogram Equalization (PLTAHE) in Fig. (3) gave a better view for the identified tumor in both samples when compared. Fig. (3b) showed an improvement on the scanned sample from JUTH having a lower tesla rating when compared with that of TCIA in Fig. (3a) having a higher tesla rating. Fig. (4) showed a comparison of the native samples first from TCIA, then JUTH with that of the enhanced samples, respectively. The histograms presented in Fig. (5) showed the effect of the native and enhanced images in terms of their gray levels.

For the kidney slices presented in Fig. (6)-Fig. (10), the effect of the HE technique also gave a deeper contrast on the kidney for both TCIA and JUTH samples in Fig. (6a) and Fig. (6b). The CLAHE technique as in Fig. (7) eliminated the noisy images to a certain degree while the effect of the PLTAHE technique gave a better perception to the axial plane of the kidneys for both TCIA and JUTH samples were the kidneys, and other structures around the kidneys can be easily identified as well as the spinal canal was preserved. A comparison of the effect of the PLTAHE technique was shown in Fig. (9) for proper analysis as well as their corresponding histograms in Fig. (9).

There was a deeper contrast with ghost imagery on the spleen slices as presented in Fig. (11)- Fig. (15), for both TCIA and JUTH samples in Fig.(11a) and Fig.(11b) .Also in Fig.(11a) there was an over amplification of noise present in the image which is poor for diagnosis. The effect of the CLAHE technique as in Fig. (12) on both samples showed an improvement in the image quality but there was still some level of noise present in both samples. Fig. (13) following the application of the PLTAHE technique gave a better perception to the enhanced native images where the spleen can be identified clearly as well as the spinal canals unaffected. The native images were compared with the enhanced images as in Fig. (14) as well as their corresponding histograms showing the gray level transformations in Fig. (15). To further verify the effects of the developed enhancement technique the application was extended further to spine samples where TI and T2 samples were tested and the results showed an improvement to a mild degree for both native and post contrast samples of the spine. Thus, the technique can also be applied to images from such organs as the pancreas and lungs

5. CONCLUSION

Enhancement techniques are fundamental in improving the quality of medical images as they serve as a pre-processing step for further analysis. In this study, the developed technique Power Law Transformed Adaptive Histogram Equalization (PLTAHE) when compared to hitherto known techniques gave major improvement on the study areas considered. In addition, comments from the radiologists in JUTH confirmed that there was some level of improvement in the quality of the images even if it was to a mild degree. Therefore, the PLTAHE technique has shown it provides significant enhancement of MRI derived abdominal scanned images.

6. RECOMMENDATION

It is recommended that when applying such enhancement techniques on other areas of interest of the human anatomy, the contrast difference should provide a diagnostic value which would determine the quality of such technique and not just a general enhancement.

7. ACKNOWLEDGEMENT

The authors wish to acknowledge The Cancer Genome Atlas (TCGA) Research Network and Jos University Teaching Hospital (JUTH) which provided samples for the research. Medical physicians and senior radiologists at JUTH. Special thanks to the Head, Radiology Department Dr. Ani Charles Chibunna and visiting Consultant Radiologist Prof. Ibinaiye Philip.

REFERENCES

Akintunde, (2019). Digital Image Enhancement Techniques: A Study on Abdominal Magnetic Resonance Imaging. M.Sc thesis, University of Lagos, Nigeria, 2019.

Aparna, P., Jatti, A., & Bharadwaj, S. (2015). Contrast Limited Adaptive Histogram Equalization with Edge Enhancement for Medical X-RayImages. *Internation Journal of Humanities, Arts, Medicine and Sciences*, *3*(6), 9–16.

Clark, K., Vendt, B., Smith, K., Freymann, J., Kirby, J., Koppel, P., Prior, F. (2013). The Cancer Imaging Archive (TCIA): Maintaining and Operating a Public Information Repository. *Journal of Digital Imaging*, *26*(6), 1045–1057. https://doi.org/10.1007/s10278-013-9622-7

Dougherty, G. (2011). Introduction. In G. Dougherty (Ed.), *Medical Image Processing: Techniques and Applications* (pp. 1–4). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4419-9779-1_1

Erickson, B. J., Kirk, S., Lee, Y., Bathe, O., Kearns, M., Gerdes, C., Lemmerman, J. (2016). Radiology Data from The Cancer Genome Atlas Liver Hepatocellular Carcinoma [TCGA-LIHC] collection. The Cancer Imaging Archive. http://doi.org/10.7937/K9/TCIA.2016.IMMQW8UQ. [Accessed: 24-March-2018]

Lauterbur, P. C. (1973). Image Formation by Induced Local Interactions: Examples Employing Nuclear Magnetic Resonance. *Nature*, *242*, 190. Retrieved from http://dx.doi.org/10.1038/242190a0

National Cancer Institute Clinical Proteomic Tumor Analysis Consortium (CPTAC). (2018). Radiology Data from the Clinical Proteomic Tumor Analysis Consortium Clear Cell Renal Cell Carcinoma [CPTAC-CCRCC] collection [Data set]. The Cancer Imaging Archive. https://doi.org/10.7937/k9/tcia.2018.oblamn27. [Accessed: 24-March-2018]

Saleh, H., Ahmed, S., & Nordin, M. J. (2011). Improving Diagnostic Viewing of Medical Images using Enhancement Algorithms. *Journal of Computer Science*, *7*(12), 1831–1838.

Solomon, C., & Breckon, T. (2011). *Fundamentals of Digital Image Processing*. Wilet-Blackwell.

Vimal, S. P., & Thiruvikraman, P. K. (2012). Automated image enhancement using power law. *Indian Academy of Sciences*, *37*(December), 739–745.

Xu, Z., Liu, X., & Chen, X. (2009). Fog Removal from Video Sequence Using Contrast Limited Adaptive Histogram Equalization. In *2009 International Conference on Computational Intellligence and Software Engineering, Wuhan, China* (pp. 1–4). https://doi.org/10.1109/CISE.2009.5366207

