Volume: 15 Issue: 03 Pages: 5940– 5945 (2023) ISSN: 0975-0290

On the Performance of Histogram Equalization Techniques in Enhancement of Proton Density Weighted Magnetic Resonance Images

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---ABSTRACT---

Magnetic Resonance Images (MRI) are used by Physician to analyse the body structures to find the diseases & to monitor the treatments. For effective analysis, they should consist of all relevant information in a better visualization format. However, MRI images suffer from poor dynamic range which affects the visible quality due to low contrast. Medical Image enhancement is a powerful tool to increase the perception of information to provide better diagnosis. In this study, different histogram equalization techniques like Global Histogram Equalization (GHE), Brightness Preserving Bi-Histogram Equalization (BBHE), Dualistic Sub-Image Histogram Equalization (DSIHE), Recursive Mean Separate Histogram Equalization (RMSHE), Brightness Preserving Dynamic Histogram Equalization (BPDHE), Brightness Preserving Dynamic Fuzzy Histogram Equalization (BPDFHE)and Contrast-limited Adaptive Histogram Equalization (CLAHE) are applied to proton density weighted magnetic resonance image to enhance the contrast and their performance is compared in terms Discrete Entropy (DE), Measure of Enhancement (EME), Average Brightness (AB) and Pixel Distance (PD). Based on the performance metrics, the best histogram equalization technique in enhancing the contrast of PD weighted MRI images is determined.

Keywords - **Average Brightness, Contrast Enhancement, Discrete Entropy, Histogram Equalization, Magnetic Resonance Images, Measure of Enhancement and Pixel Distance.**

Date of Submission: July 26, 2023 Date of Acceptance: September 25,2023

I. INTRODUCTION

Medical imaging techniques like Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and Single-Photon Emission Computed Tomography (SPECT) provide information of the human body characteristics to the doctors. Different imaging methods keep different characteristics and different sensors obtain different imaging information of the part of the body being imaged. Magnetic Resonance Imaging (MRI) system uses a computer, large magnet, shim coils, gradient coils, a radio frequency transmitter & receiver coil to provide information about the size, shape and integrity of gray as well as white matters of the body parts [1]. The magnetic field generated by the magnet is made as homogeneous by the shim coils. The radio frequency transmitter transmits radio signal into the body part being imaged and receiver coil receives the returning radio signals. The spatial localization of the radio signals is provided by gradient coils and finally the computer constructs magnetic resonance image from the received radio signals. MRI system displays the tissue contrast which depends upon the pulse sequence parameters which are defined using specific number, strength & timing of the RF and gradient pulses. Among them, Repetition Time (TR) and the Echo Time (TE) are the most important parameters. The time between two consecutive RF pulses is called as repetition time whereas the time between the initial RF pulse and the echo is called as echo time. The four parameters namely Proton Density (PD), Longitudinal Relaxation Time (T1), Transverse Relaxation Time (T2) and flow determine the intensity of MRI. T1 & T2 are the relaxation times that specify the way by which the protons revert back to their resting states after the initial RF pulse. PD specifies the concentration of protons in the tissue whereas flow is the loss of signal due to arterial blood. These MRI contrast and intensity result MRI triplets, namely T1, T2 and PD images [2, 3] are used by Physician to analyse the body structures to find the diseases & to monitor treatments. For effective analysis, MRI triplets should consist of all relevant information in a better visualization format. However, MRI images suffer from poor dynamic range which affects the visible quality due to low contrast. Medical Image enhancement is a powerful tool to increase the perception of information to provide better diagnosis. In this study, different histogram equalization techniques like Global Histogram Equalization (GHE)[4], Brightness Preserving Bi-Histogram Equalization (BBHE) [5], Dualistic Sub-Image Histogram Equalization (DSIHE) [6], Recursive Mean Separate Histogram Equalization (RMSHE) [7], Brightness Preserving Dynamic Histogram Equalization (BPDHE) [8], Brightness Preserving Dynamic Fuzzy Histogram Equalization (BPDFHE) [9] and Contrast-limited Adaptive Histogram Equalization (CLAHE) [10] are applied to proton density weighted magnetic resonance image to enhance the contrast and their performance is compared in terms Discrete Entropy (DE) [11], Measure of Enhancement (EME) [12], Average Brightness (AB) and Pixel Distance (Pix. Dist) [13]. Based on the performance

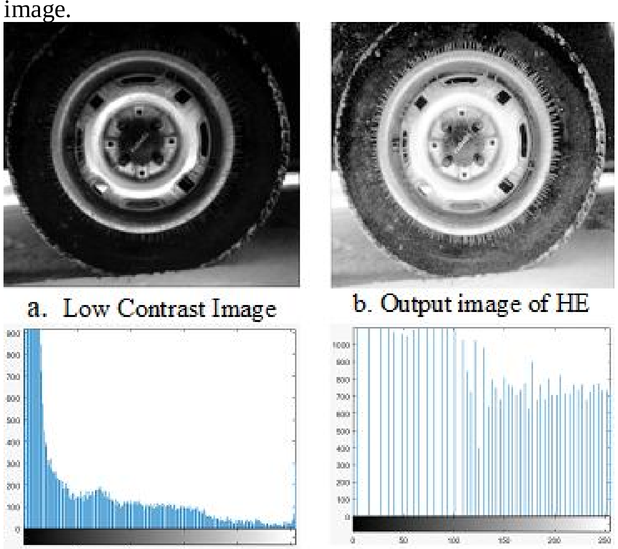
metrics, the best histogram equalization technique in enhancing the contrast of PD weighted MRI images is determined. The following section overviews different histogram equalization techniques. Section 3 presents the performance metrics and Section 4 discusses the results. Finally, summary of the paper with conclusion is presented.
he introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. HISTOGRAM EQUALIZATION TECHNIQUES

Image contrast enhancement plays a vital role in medical image processing since most of the medical images suffers from poor dynamic range which affects the visual quality due to low contrast. The objective of medical image contrast enhancement is to produce the better image quality with improved clarity by changing the characteristics of original image.

- **Global Histogram equalization (GHE)**

It is the most popular and widely used technique for the enhancement of contrast of an image due to its simplicity and easy implementation. GHE flattens the probability distributions and improves contrast of an input image by stretching the contrast of high histogram regions and by compressing the contrast of low histogram region. However, it does not contribute to improve the local contrast of an image since it only uses the global information which in turn not preserves the brightness. Two artefacts are introduced in GHE namely over enhancement and loss of contrast. Over enhancement occurs in image regions with more frequent gray levels whereas loss of contrasts occurs in image region with less frequent gray levels. To overcome the above artefacts, several versions of GHE are proposed and all of them are focussing to preserve image brightness rather than improving image contrast. The following figure shows the histogram of low contrast image and histogram equalised image.



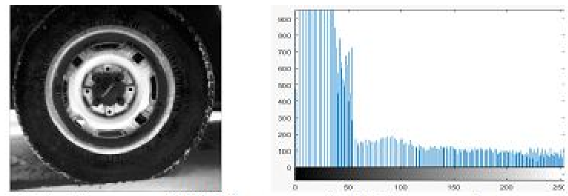
a. Low Contrast Image b. Output image of HE

c. Histogram of a d. Histogram of b

Figure 1 : Example for GHE of Low Contrast Image

- **Brightness Preserving Bi-Histogram Equalization (BBHE)**

To overcome the drawbacks of GHE, BBHE is proposed which preserves the brightness while enhancing the contrast. BBHE divides the histogram into two histograms based on mean brightness. After, each sub-histogram is equalized individually using GHE. BBHE can preserve image brightness to some extent and produces better result when compared to GHE. The following figure shows the results of BBHE of low contrast image.

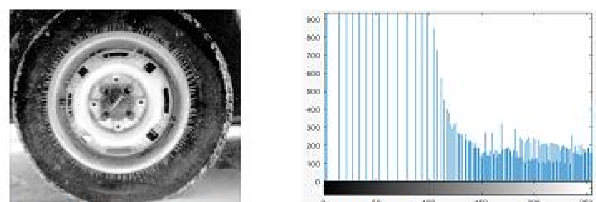


a. Output image of BBHE b. Histogram of a

Figure 2 : Example for BBHE of Low Contrast Image

- **Dualistic Sub-Image Histogram Equalization (DSIHE)**

DSIHE uses the same idea as BBHE. In DSIHE also, the input image histogram is decomposed into two subdivisions. But DSIHE considers median to partition the histogram being one bright and one dark instead of mean. Then, GHE is applied separately on both the sub-histograms. After the equalization process, both the parts are combined to give the resultant output. DSIHE produces better results than BBHE and GHE in terms of preserving the brightness of input image and enhancing the contrast effectively. The following figure shows the histogram of DSIHE of low contrast image.

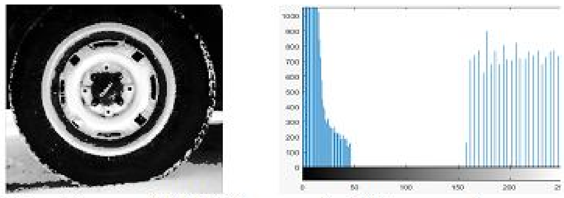


a. Output image of DSIHE b. Histogram of a

Figure 3 : Example for DSIHE of Low Contrast Image

- **Recursive Mean-Separate Histogram Equalization (RMSHE)**

To overcome the problem of over enhancement in DSIHE, RMSHE has been proposed by Chen and Ramli in the year 2003. It also divides the input histogram into two, based on its mean before equalizing them independently. But the difference between BBHE and this method is the histogram is divided into two only once BBHE, but in this method new histograms are divided recursively based on their mean value. Mathematically, it is proved that the mean brightness of output image converges to the mean brightness of input image as the number of recursive division of histogram increases. It generates the 2r sub histograms after the r^{th} recursion, where r is the natural number and it is very difficult to find the best value of r. In order to achieve higher brightness preservation, RMSHE is proposed to perform the mean separation recursively and separate the resulting histograms again based on their respective means. The following figure shows the histogram of RMSHE of low contrast image.

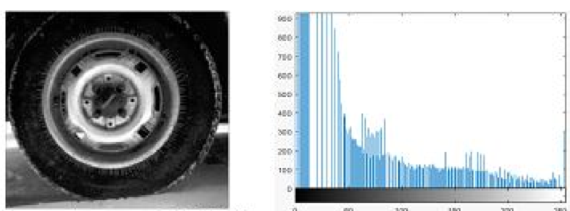


a. Output image of RMSHE b. Histogram of a

Figure 4 : Example for RMSHE of Low Contrast Image

- **Brightness Preserving Dynamic Histogram Equalization (BPDHE)**

BPDHE is proposed by Ibrahim and Kong in the year 2007 as an improvement strategy to preserve mean intensity of the image. BPDHE shows more predominant contrast overhaul stood out and mean quality. To attain this, BPDHE smooth the global image histogram using Gaussian kernel, followed by its segmentation of valley regions for their dynamic equalization. BPDHE processes the crisp histograms of images to enhance contrast. The crisp statistics of digital images does not take into account the inexactness of gray values. Additionally, crisp histograms need smoothing to achieve useful partitioning for equalization. The following figure shows the histogram of BPDHE of low contrast image.

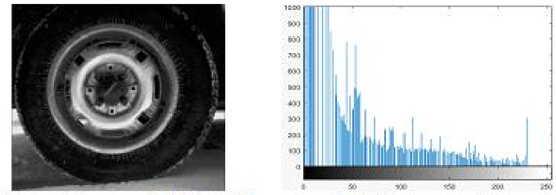


a. Output image of BPDHE b. Histogram of a

Figure 5 : Example for BPDHE of Low Contrast Image

- **Brightness Preserving Dynamic Fuzzy Histogram Equalization (BPDFHE)**

D. Sheet et al introduced a modification to BPDHE with the use of fuzzy statistics of digital images in the year 2010 and developed BPDFHE. Besides, the imprecision in gray levels is handled well by fuzzy statistics, fuzzy histogram, when computed with appropriate fuzzy membership function, does not have random fluctuations or missing intensity levels and is essentially smooth. This helps in obtaining its meaningful partitioning required for brightness preserving equalization. The BPDFHE technique consists of following operational stages: i). Fuzzy Histogram Computation. ii) Partitioning of the Histogram. iii). Dynamic Histogram Equalization of the Partitions. iv). Normalization of the image brightness. It is proved that the use of fuzzy statistics improved the performance histogram equalization technique in preserving the brightness of the input image. The following figure shows the histogram of BPDFHE of low contrast image.

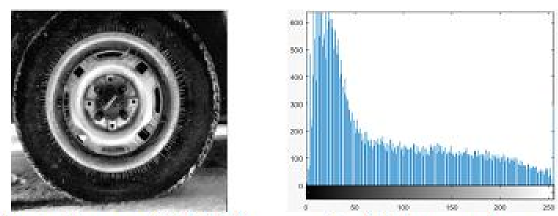


a. Output image of BPDFHE b. Histogram of a

Figure 6 : Example for BPDFHE of Low Contrast Image

- **Contrast-limited Adaptive Histogram Equalization (CLAHE)**

Contrast-Limited Adaptive Histogram Equalization (CLAHE) is one of the most popular and acceptable variant of histogram equalization based contrast enhancement of digital images. This method is implemented by dividing the image into several non-overlapping regions of equal sizes called windows, resulting three regions namely Corner Region, Border Region and Inner Region. At first step, the histogram of each region is calculated. Then based on the clip limited defined by the user for contrast expansion, modified histogram is obtained in which the height of the histogram does not go beynd the clip limit. Finally, CDF of the modified contrast limited histograms are determined for gray scale mapping. In CLAHE method, pixels are mapped linearly by combining the results from the mapping of four nearest regions. Formulation of this approach for Inner Regions is straight forward. However, for regions in Corner Region and Border Region groups, this formulation requires some special consideration. The following figure shows the histogram of BPDFHE of low contrast image.



a. Output image of CLAHE b. Histogram of a

Figure 7 : Example for BPDHE of Low Contrast Image

III. PERFORMANCE METRICS

The various performance metrics used in this study to compare the results of different histogram equalization techniques in enhancing the contrast of PD weighted MRI images are presented in this section.

- **Discrete Entropy(DE)**

DE quantifies the information content of the image. It describes how much uncertainty or randomness there is in an image. The more information the image contains, the better its quality. Shannon's entropy is defined as:

$$E(I) = -\sum_{k=0}^{L-1} p(k) log_2 (p(k)) \quad \text{….(1)}$$

where I is the original image, $p(k)$ is the probability of occurrence of the value k in the image I, and $L=2^q$ indicates the number of different gray levels.

- **Measure of Enhancement (EME)**

The EME is defined as

$$EME_{r,c} = \frac{1}{r\ x\ c}\sum_{l=1}^{r}\sum_{k=1}^{c}[20\ln(\frac{I_{max,k,l}}{I_{min,k,l}})] \quad \text{…..(2)}$$

$$EME_{r,c} = \frac{1}{r\ x\ c}\sum_{l=1}^{r}\sum_{k=1}^{c}[20\ln(CR_{k,l})] \quad \text{…..(3)}$$

where CR is the contrast ratio and is given by

$$CR_{k,l} = (\frac{I_{max,k,l}}{I_{min,k,l}}) \quad \text{….. (4)}$$

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In the above equation, r & c represents the number of rows and columns of the image and I_{max} & I_{min} represents the maximum and minimum intensity of the original image 'I' respectively.

- **Average Brightness (AB)**

AB is the mean value of all pixel values of the image after histogram equalization and is given by

$$AB_{r,c} = \frac{1}{r \times c}\sum_{l=1}^{r}\sum_{k=1}^{c}[I(l,k)] \quad \text{….. (5)}$$

Where I(l,k) represents the intensity of the image at l^{th} row and k^{th} column.

- **Pixel Distance (Pix. Dist)**

PD is the average distance between the pixels on the gray scale image after histogram equalization and is given by

$$PD = \frac{1}{N X N-1}\sum_{l=0}^{r-2}\sum_{k=l+1}^{c-1} H(l)_{n-1} H(k)_{n-1}(k-1)$$
$$for\ l,k \in [0\ to\ L-1], \quad \text{….. (6)}$$

where N is the total number of pixels in the image.

IV. RESULTS AND DISCUSSIONS

Experimental evaluations and results are provided in this section to determine the best histogram equalization technique in enhancing the contrast of PD weighted MRI images in terms of DE, EME, AB and PD. MATLAB was used to implement GHE, BBHE, DSIHE, RMSHE, BPDHE, BPDFHE and CLAHE. These approaches were tested with four Proton Density Weighted Magnetic Resonance images (PD MRI) namely Thorax, Abdomen, Pelvis and Thigh PD MRI which was downloaded from the internet [14]. The results of Medical Image enhancement and the histograms are shown in Figure 8 – 11. The quantitative results are shown in Table 1. From the table, it is inferred that AHE preserves the brightness & DE, RMSHE enhances the MRI PD image in terms of EME, GHE increases the brightness and RMSHE maintains distance between pixels.

V. CONCLUSION

In this study, seven types of histogram equalization techniques are applied to proton density weighted MRI medical images to improve the contrast while preserving the brightness. All proton density weighted MRI medical images in low contrast due to the imaging sensors resulting in lack of clarity of information. Four performance metrics are used to assess quality of enhanced images namely Discrete Entropy, Measure of Enhancement, Average Brightness and Pixel Distance. Based on these metrics, it is determined which histogram equalization technique will be the best one for enhancing the proton density weighted MRI images while preserving the brightness. From this study, it is concluded that Adaptive Histogram Equalization technique is best for improving the contrast, preserving the brightness and improving the information for medical diagnosis. The conclusion is shown in Table 2.

Image	Thorax PD MRI			
Metrics	DE	EME	AB	Pix Dist
Original	6.581	90.834	56.960	24.764
GHE	5.561	29.634	**127.483**	43.124
BBHE	6.347	33.450	102.459	43.691
DSIHE	6.464	39.623	114.710	46.214
RMSHE	5.922	**95.860**	108.818	**51.458**
BPDHE	6.400	34.848	98.164	46.002
BPDFHE	6.183	36.715	57.005	27.350
AHE	**7.349**	39.240	86.117	37.530
Image	Abdomen PD MRI			
Original	6.922	46.909	68.044	18.890
GHE	5.890	30.914	**127.727**	42.953
BBHE	6.743	36.888	105.082	43.709
DSIHE	6.812	37.591	126.227	43.929
RMSHE	6.418	**56.221**	118.470	**46.096**
BPDHE	6.817	30.977	118.997	40.028
BPDFHE	6.541	32.008	68.048	23.530
AHE	**7.736**	38.708	107.470	34.0322
Image	Pelvis PD MRI			
Original	6.744	62.452	71.337	23.927
GHE	5.722	19.608	**127.940**	42.800
BBHE	6.509	22.570	112.593	43.550
DSIHE	6.544	30.969	123.282	44.515
RMSHE	6.128	**68.126**	118.124	**48.106**
BPDHE	6.562	20.003	92.045	31.381
BPDFHE	6.239	27.554	71.3701	24.772
AHE	**7.410**	32.446	94.065	34.266
Image	Thigh PD MRI			
Original	6.207	105.155	63.200	29.750
GHE	5.147	18.535	**129.112**	41.753
BBHE	5.946	22.334	109.077	42.625
DSIHE	6.007	44.257	104.469	47.348
RMSHE	5.387	**107.734**	108.244	**52.067**
BPDHE	5.991	21.830	89.563	33.346
BPDFHE	5.738	37.839	63.224	30.638
AHE	**6.788**	33.554	78.7365	37.182

Table I: Results of PD MRI Enhancement

Table 2: Conclusion

Metrics	Technique
Discrete Entropy	Adaptive Histogram Equalization
Measure of Enhancement	Recursive Mean-Separate Histogram Equalization
Average Brightness	Global Histogram Equalization
Pixel Distance	Recursive Mean-Separate Histogram Equalization

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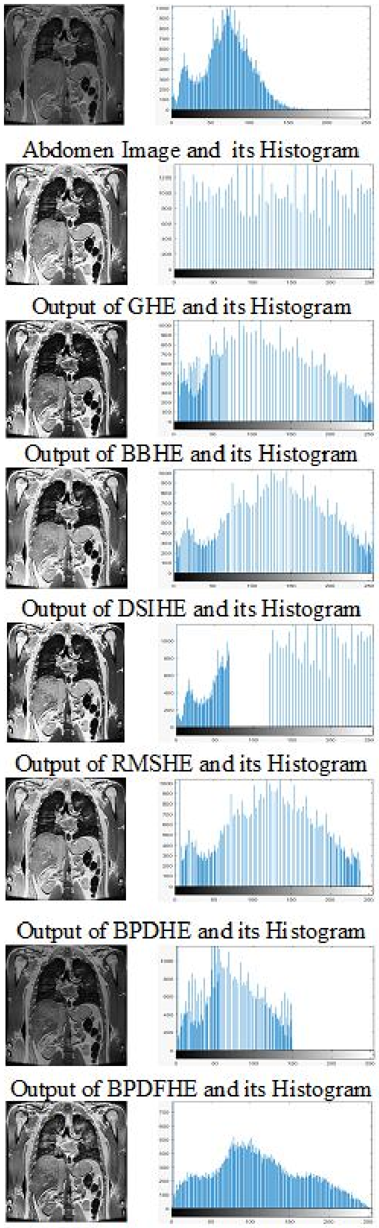

Figure 8 : Results of Various HE Techniques of Abdomen PD MRI

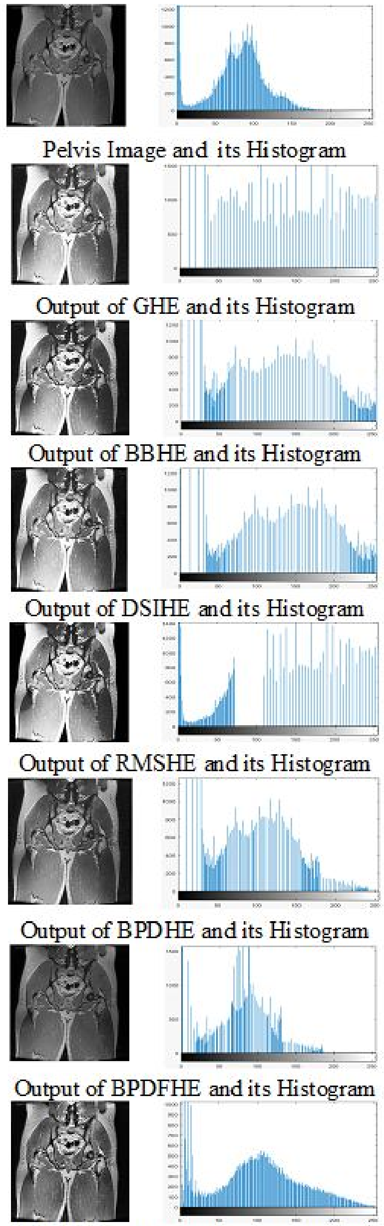

Figure 9 : Results of Various HE Techniques of Pelvis PD MRI

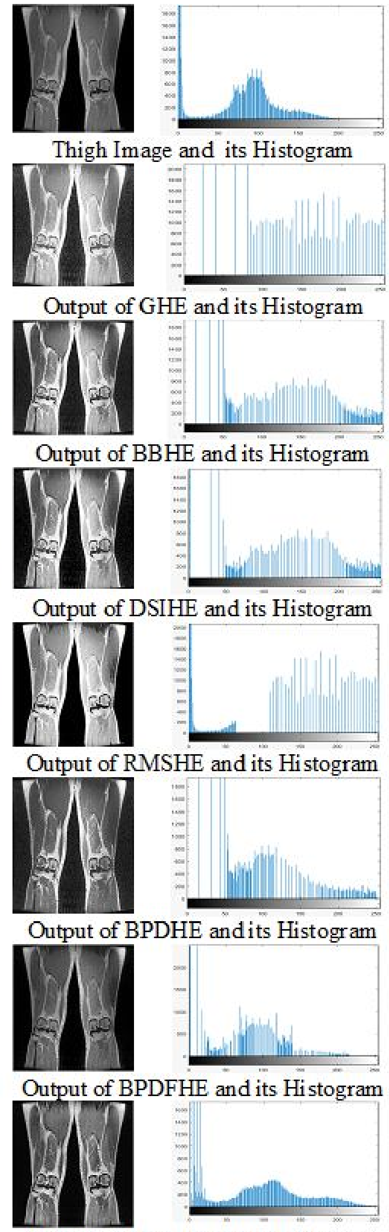

Figure 10 : Results of Various HE Techniques of Thigh PD MRI

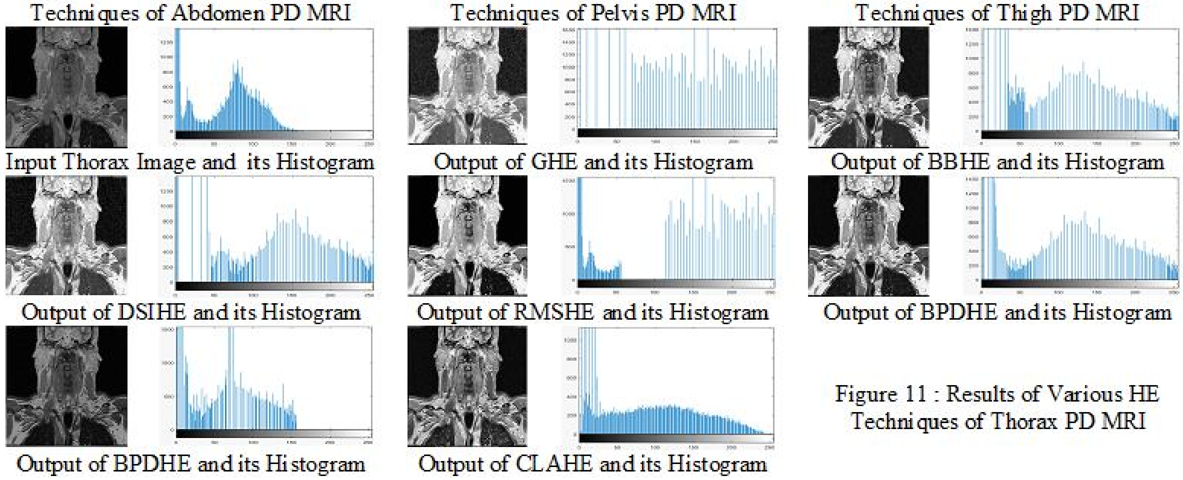

Figure 11 : Results of Various HE Techniques of Thorax PD MRI

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