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Study the effect of metal artifact reduction (MAR) technique in improving CT image quality

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Abstract: It is necessary to decrease metal artifacts to improve the quality of CT image. An option of CT machine called metal artifact reduction (MAR) technique is used to reduce metal artifacts and increase image quality. The aim of this paper is to prove that there is a significant improvement in image quality after using metal artifact reduction technique. Method and results: Using CT images of 24 patients who have metal implants in different parts in body such as (16-lumber sacral spine (LSS) –1-Brain – 1-Hip joint –3- dorsal spine (DS) – 1-cervical spine (Cxs) – 1-Ankle – 1-Elbow) to compare between images quality before and after applying MAR. Image quality was evaluated by comparing p-value (the degree of difference between group with MAR and without MAR). The elements of this comparison are CT number (HU) and stander deviation (SD). This comparison is on the same slice before and after applying MAR technique. The comparison shows that p-value< 0.05 which shows significant difference between with and without MAR. Second step contrast to noise ratio (CNR) and signal to noise ratio (SNR) were calculated for all patients with only metal implants in vertebral fixation in the same slice before and after applying MAR technique, The CNR median of images without MAR was (6.20) and the CNR median of images with MAR was (10.33). The SNR median of images without MAR was (1.50) and the SNR median of images with MAR was (2.35). The relation between CNR without MAR and with MAR was significant difference ($p < 0.05$). In case of SNR the relation between SNR without MAR and with MAR was no significant difference (p-value > 0.05). Conclusion: There is a significant improvement in CT image quality, a reduction in metal artifacts and avoiding creation of new artifacts when using metal artifact reduction technique.

Keywords: computed tomography, noise, metal artifact reduction, beam hardening.

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1 INTRODUCTION

There is a significant increasing in patient numbers with metal implants which can be close to or within region which receive radiation therapy or radiology of CT.

Metal implants result artifacts in CT image. CT images an important imaging method in radiology field for disease diagnosis and therapy planning. (1)

The present of unmovable metallic implants such as (joint replacement, dental implants, orthopedic hardware, surgical clips, or wires) in the bodies of patients, usually produce a lot of streaking artifacts.(2)

In computed tomography (CT), the term artifact come from any disagreement between the real attenuation coefficients and CT number in reconstructed image. (3)

This type of artifacts occurs by two major mechanisms (beam hardening and beam scattering). CT conventional machine use polychromatic x-ray that consist of range of x-ray photons energies. When it pass through metallic object lower energy photons are attenuated easily. However, high energy photons are difficult to attenuate. This causes increase in mean beam energy. This increasing is due to interaction of photons with metal by photoelectric effect and Compton Effect. High energy cannot be attenuated easily.

This leads to a shift of x-ray spectrum toward high energy and x-ray beam become harder. This causes non linear attenuation of x-ray beam that pass through material. CT image consist of several projection of beams from different angles that travel through metal. This shift to higher energy leads to inconsistent information for each projection. (4-5)

Metal artifact reduction is an important research for CT imaging to reduce artifacts and increase image quality. (6)

There some important parameters that affect on CT image quality such as (CT-numbers, image noise, and spatial resolution). Spatial resolution is the ability to differentiate small objects that differ in density compared to the background. (7)

Image quality is calculated by contrast to noise ratio (CNR) and signal to noise ratio.

Now days there are many techniques that try to solve this problem. There are two major algorithms for this purpose.

(1) Correcting of projection (points represent x-ray attenuation values along path through object).

(2) Iterative reconstruction techniques (reconstruct CT image number of times after correcting their projections (8-9). They try lots of Metal Artifact Reduction techniques such as Iterative Reconstruction Technique, Liner Interpolation (LI). LI is using two uncorrupted data on two sides of corrupted metal pixels (10). These techniques failed because of losing image information and produce new artifacts. (3)

Using Metal Deletion technique (one of types for metal artifact reduction) depends on segmentation of image into pixels by using thresholding to identify metal pixels. LI is used for correcting initial image. Forward projection is used iteratively to create projections from known initial image. Using filter back projection (FBP) to reconstruct information lost near metal. (11)

Applying iterative reconstruction four times has great results in reducing these artifacts and avoids introducing new streaks. (4)

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2 SUBJECTS AND METHODS:

128 Multi-slice CT machine (general electric) G.E revolution made in U.S.A has been used. There were 25 patient each of them have metal implants in different part in their bodies.

First step was comparing between (CT number and Stander Deviation) in groups with and without MAR. By draw region of interest (ROI) (200mm²) in low noise region and high noise region. Then the CNR by equation (1-2) and SNR with equation (3) were calculated for all images without and with MAR, at muscle is object and fat is back ground. CNR with equation (1) and SNR were calculated for 16 patients who have metal implants in Lumber spine, at aorta is object, With ROI = 800 mm² . Equations are:

1- $\frac{\text{mean of object} - \text{mean of back ground}}{\text{SD of back ground}}$ …….. (1) (12)

2- $\frac{2(\text{mean of object} - \text{mean of back ground})\ 2}{(\text{SD2 of object} + \text{SD2 of back ground})}$ …….(2) (13)

SNR was calculated for all images without and with MAR by equation:

$$\text{SNR} = \frac{\text{mean of object}}{\text{SD of object}} \quad \text{……… (3)} \quad (14)$$

Statistic calculations were made for resulted data using Statistical Package for the Social Sciences (SPSS) version 21. The normality of data was first tested with Shapiro test.

3 Results:

A total 25 patients were having metal implants in different part in their bodies.(16 patients of them were have metal implants in Lumber spine, Three patients have metal implant in dorsal spine , one patient has metal implant in brain bone, one in hip joint , one in cervical spine , one in Ankle and one in Elbow).

Low noise HU region	Without MAR	With MAR	Mann-Whitney	p-value
Mean ± SD	-256.47±208.1	-12.71±69.22	5.32	<0.001**
Median	-220.69	11.08		
Min-Max	-925.83- -48.63	-186.33 - 103.84		

Table (1): represent the relation between HU at low noise region for images without MAR and images with MAR.

The CT number in low noise region range was (-925.83 to - 48.63 HU) in images without MAR and HU of images with MAR range was (-186.33 - 103.84). The median value of HU was -220.69 HU for images without MAR and the median valve of HU was 11.08 HU for images with MAR, Fig(1). The mean value of HU and SD was (-256.47 ±208.1) and it was (-12.71±69.22) for without and with MAR respectively. From the result there is significant difference between images before MAR and after MAR (P-value <0.001).

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The result is analyzed in figure (1).

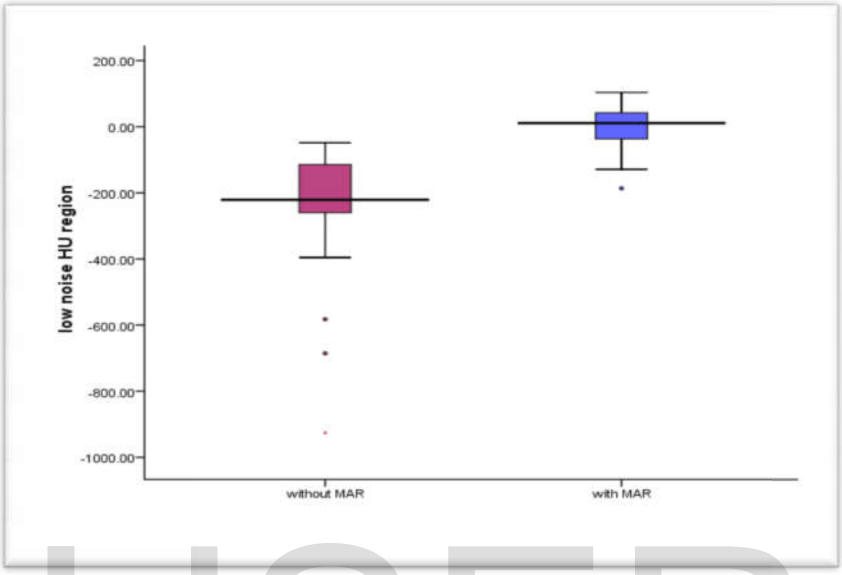
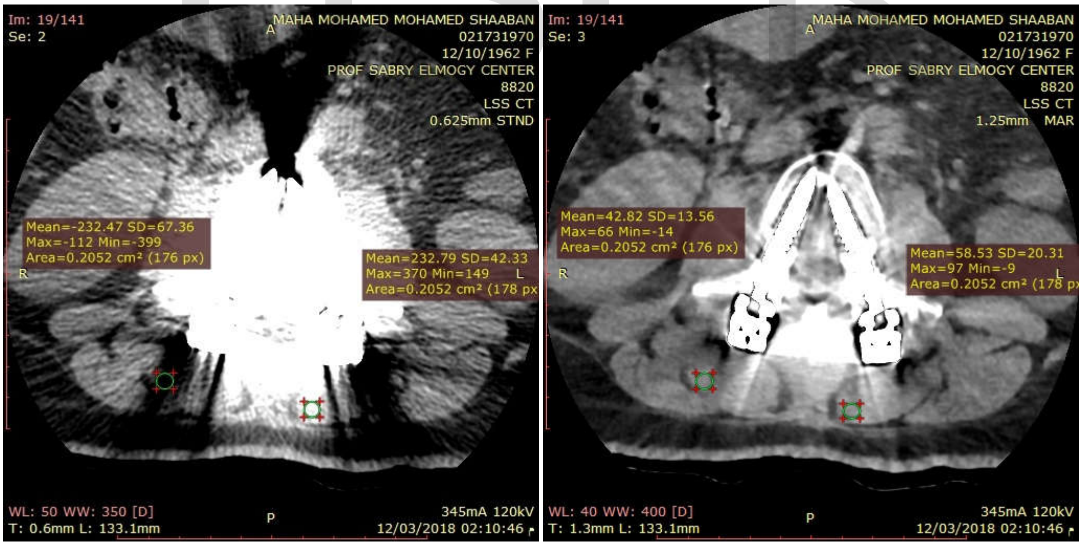


Fig (1): Median HU at low noise HU region for images without MAR and the other with MAR images.



(a) (b)

Fig (2): female patient, 56 years, LSS vertebral fixation, at (a) image of patient before applying MAR,

(b) Image of patient after applying MAR, ROI =200mm², represent HU and SD in low and high CT number regions. CT number in low HU region is -232.47 before MAR and 42.82 after MAR. CT number in high HU region is 232.79 before MAR and 58.53 after MAR.

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Comparison between group without MAR and group with MAR has been made at high noise region (high Hounsfield unit) and the mean, stander deviation, median, minimum and maximum values were calculated and Table (2) shows the results.

High noise HU region	without MAR	with MAR	Mann-Whitney	p-value
Mean ± SD	349.92±194.62	92.71±70.57	5.12	<0.001**
Median	242.39	75.66		
Min-Max	71.12- 826.54	-30.14 - 295.33		

Table (2): represent the relation between HU at high noise region for images without MAR and images with MAR.

The CT number in high noise region range was (71.12- 826.54HU) in images without MAR and HU of images with MAR range was (-30.14 - 295.33). The median value of HU was 242.39HU for images without MAR and the median valve of HU was 75.66 HU for images with MAR, Fig(3). The mean value of HU and SD was (349.92±194.62) and it was (92.71±70.57) for without and with MAR respectively. From the result there is significant difference between images before MAR and after MAR (P-value <0.001).

The result is analyzed in figure (3).

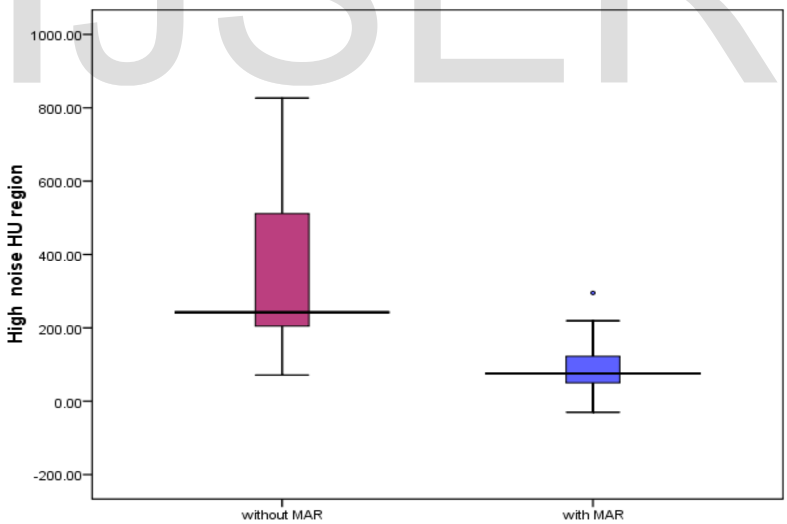

Fig (3): Median HU at high noise HU region for images without MAR and the other with MAR images.

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Images without MAR and with MAR images have been compared by calculating CNR
CNR was calculated by equation (1).

CNR	without MAR	with MAR	Mann-Whitney	p-value
Mean ± SD	6.59±3.53	11.70±6.15	3.32	
Median	6.20	10.33		0.001*
Min-Max	1.06-16.90	2.05- 27.40		

Table (3): represent the relation between CNR according to equation (1) for images without MAR and images with MAR.

The range of CNR reading was (1.06-16.90) in images without MAR and CNR of images with MAR range was (2.05- 27.40). The median value of CNR was 6.20 for images without MAR and the median valve of CNR was 10.33 for images with MAR, Fig(4). The mean value of HU and SD was (6.59±3.53) and it was (11.70±6.15) for without and with MAR respectively. From the result there is significant difference between images before MAR and after MAR (P-value =0.001).

CNR is calculated according to equation (2).

CNR	without MAR	with MAR	Mann-Whitney	p-value
Mean ±SD	48.03±74.54	119.22±112.81		
Median	31.80	88.37	3.83	<0.001**
Min-Max	1.80-360.10	5.84-567.90		

Table (4): This table represents the relation of CNR according to equation (2) between images without MAR and other after applying MAR.

The range of CNR reading was (1.80-360.10) in images without MAR and CNR of images with MAR range was (5.84-567.90). The median value of CNR was 31.80 for images without MAR and the median valve of CNR was 88.37 for images with MAR. The mean value of HU and SD was (48.03±74.54) and it was (119.22±112.81) for without and with MAR respectively. From the result there is significant difference between images before MAR and after MAR (P-value <0.001).

The degree of a agreement between CNR reading according to equation (1) and CNR reading according to equation (2) = (0.758).

The result is analyzed in figure (4).

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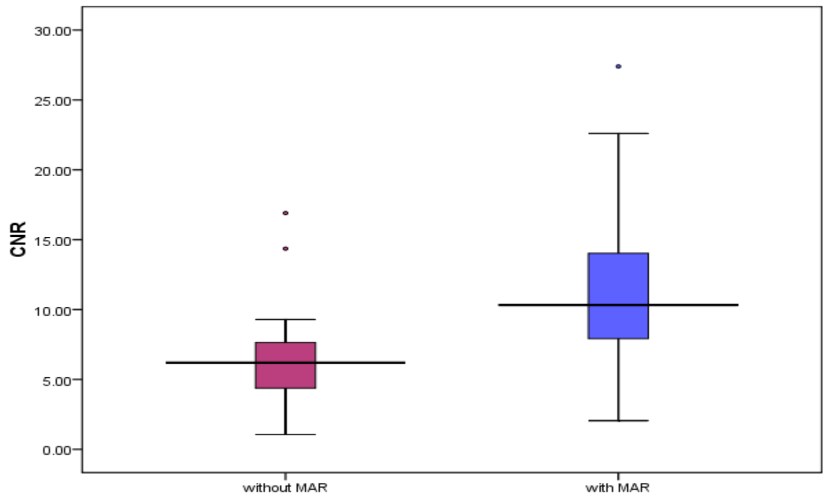

Fig (4): Median of CNR reading among without MAR and with MAR groups.

Calculating SNR by using equation (3)

SNR	without MAR	with MAR	Mann-Whitney	p-value
Mean ± SD	1.71±1.52	2.70±2.05	1.88	0.059
Median	1.50	2.35		
Min-Max	0.28-6.60	0.08-7.91		

Table (5): represents the relation of SNR between images without MAR and other images with MAR. Object is muscle.

The range of SNR reading was (0.28-6.60) in images without MAR and CNR of images with MAR range was (0.08-7.91). The median value of SNR was 1.50 for images without MAR and the median valve of SNR was 2.35for images with MAR, Fig(5). The mean value of HU and SD was (1.71±1.52) and it was (2.70±2.05) for without and with MAR respectively. From the result there is no significant difference between images before MAR and after MAR (P-value =0.059).

The result is analyzed in figure (5).

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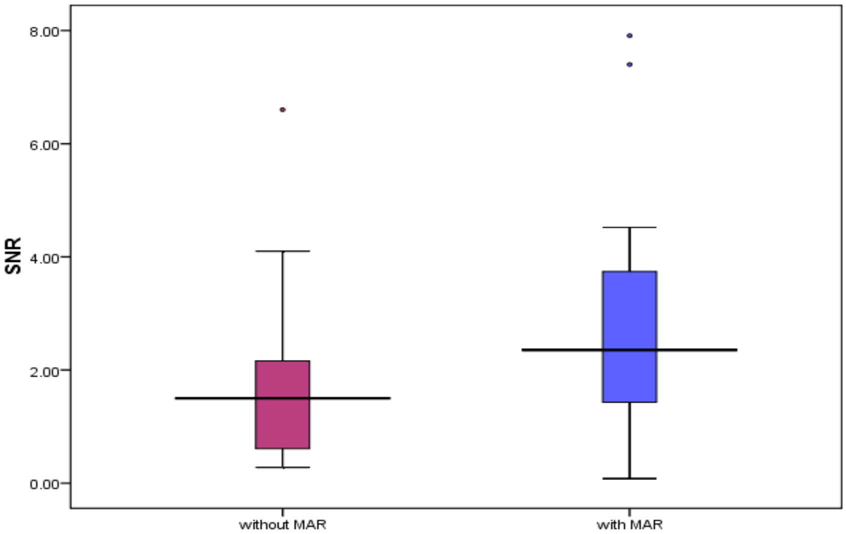
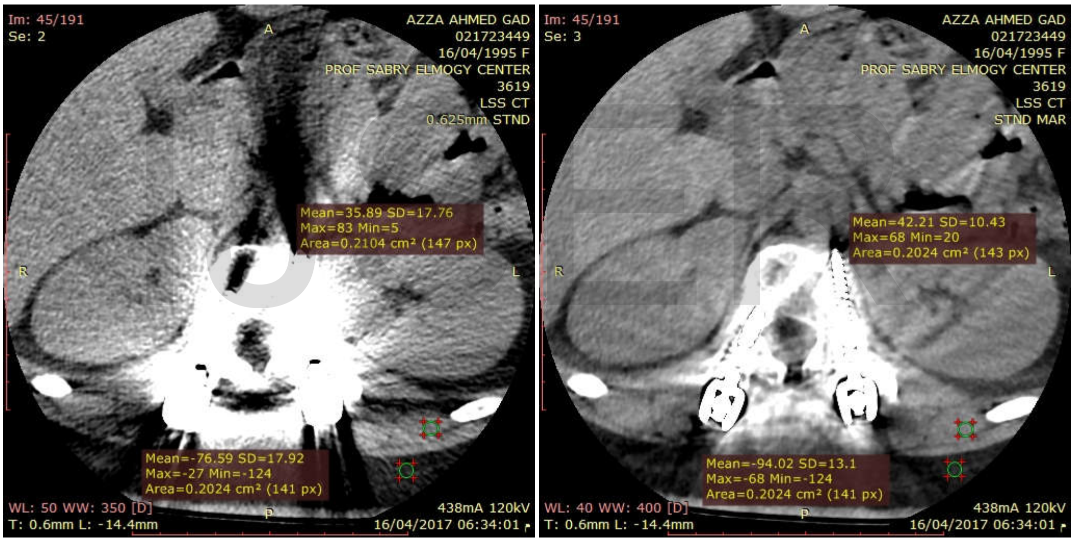


Figure (5): Median of SNR in images without MAR and other images with MAR.



(a) (b)

Fig(6): female patient, 23 years, LSS vertebral fixation, at (a) image of patient before applying MAR, (b) after applying MAR, ROI= 200mm², used for CNR by equation (1-2) and SNR, back ground is fats and object is muscles. CNR with equation (1) is 6.2 before MAR and 10.33 after MAR. CNR with equation (2) is 39.75 before MAR and 123.37 after MAR. SNR with equation (3) is 2.02 before MAR and 4.04 after MAR.

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Images without MAR, with MAR images, and image without artifact have been compared by calculating CNR
CNR was calculated by equation (1) , ROI=800mm^2.

CNR	without MAR	with MAR	slice without artifact	Mann-Whitney	p-value
Mean ± SD	2.79±2.31	1.22±0.89	0.55±0.42	Z1=2.56 Z2=2.16	P1=0.01* P2=0.03*
Median	2.13	1.09	0.43		
Min-Max	0.84-9.68	0.03-2.99	0.07-1.58		

Table (6): represent the relation between CNR according to equation (1) for images without MAR, images with MAR, and image without artifacts before and after MAR.

The range of CNR reading was (0.84-9.68) in images without MAR, CNR of images with MAR range was (0.03-2.99), and rang of CNR in image without artifact was (0.07-1.58). The median value of CNR was 2.13 for images without MAR, the median valve of CNR was 1.09 for images with MAR, and was 0.43 in image without artifacts, Fig(7). The mean value of HU and SD was (2.79±2.31), it was (1.22±0.89), and it was (0.55±0.42) for without, with MAR, and image without artifact respectively. From the result there is significant difference between images before MAR and after MAR (P-value =0.001). There is significant difference between images with MAR and without artifact (P-value =0.03).

The result is analyzed in figure (7).

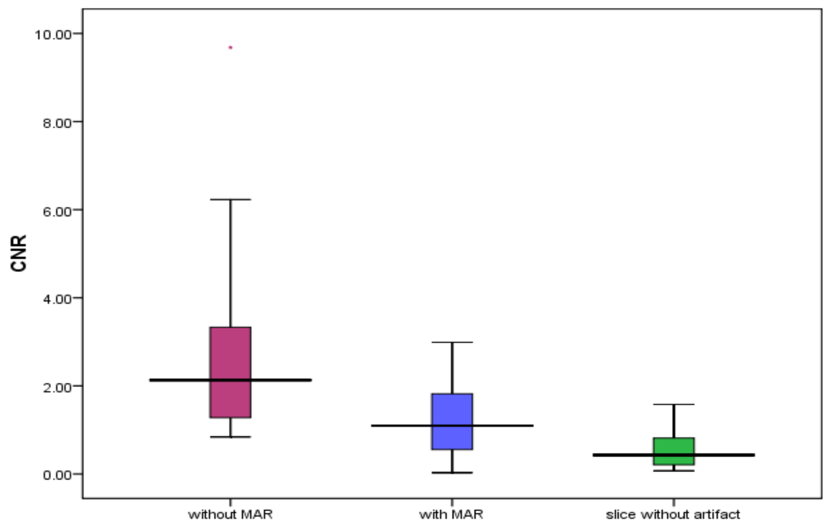

Fig (7): Median of CNR reading among without MAR, with MAR groups, and image without artifacts.

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Calculating SNR by using equation (3)

SNR	without MAR	with MAR	slice without artifact	Mann-Whitney	p-value
Mean ± SD	6.41±20.17	2.04±0.90	1.99±0.84	Z1=1.64 Z2=0.057	P1=0.101 P2=0.955
Median	1.53	1.88	1.99		
Min-Max	0.15- 82	0.76-3.60	0.27-3.40		

Table (5): represents the relation of SNR between images without MAR and other images with MAR. Object is aorta.

The range of SNR reading was (0.15- 82) in images without MAR, CNR of images with MAR range was (0.76-3.60), and rang of SNR in image without artifact was (0.27-3.40). The median value of SNR was 1.53 for images without MAR, the median valve of SNR was 1.88 for images with MAR, and was 1.99 in image without artifacts, Fig(7). The mean value of HU and SD was (6.41±20.17), it was (2.04±0.90), and it was (1.99±0.84) for without, with MAR, and image without artifact respectively. From the result there is no significant difference between images before MAR and after MAR (P-value =0.101). There is significant difference between images with MAR and without artifact (P-value =0.955).

The result is analyzed in figure (8).

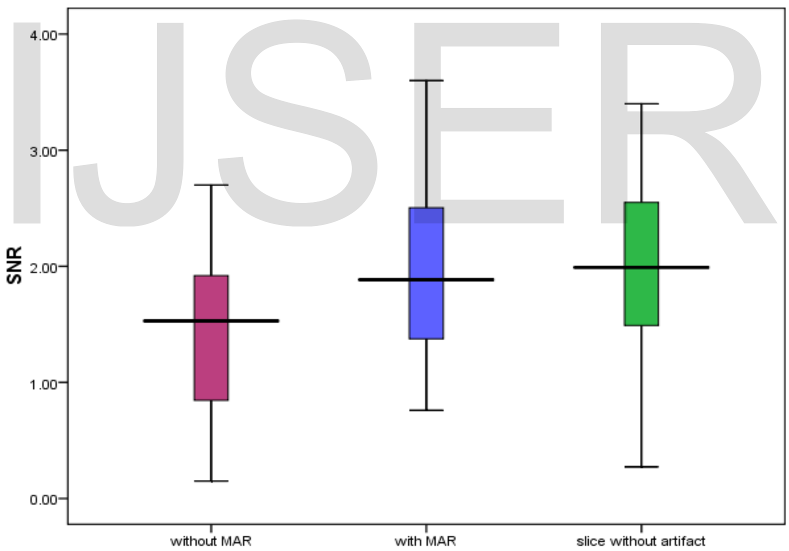

Figure (8): Median of SNR reading among without MAR, with MAR and slice without artifact groups.

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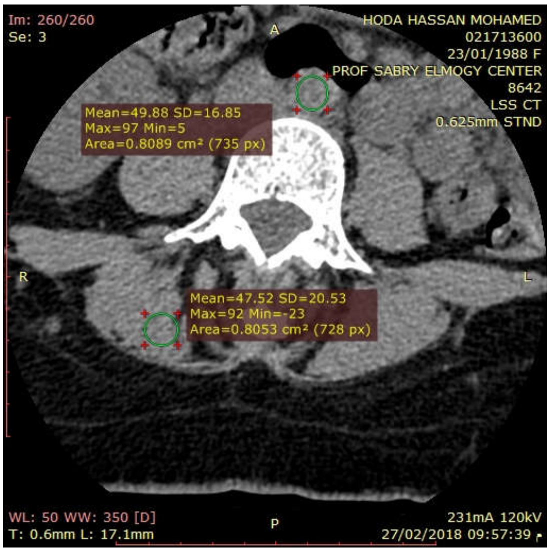
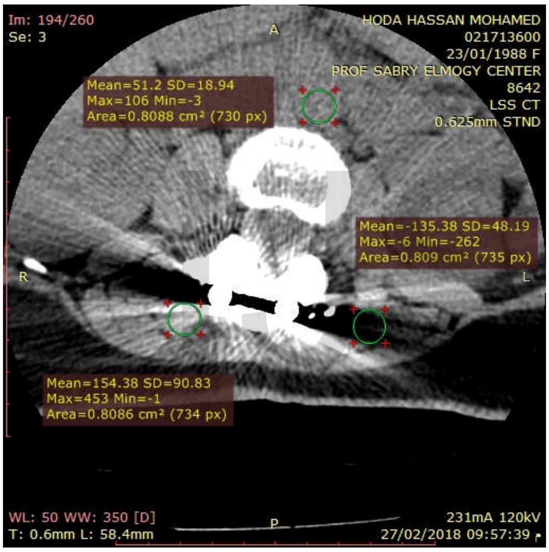
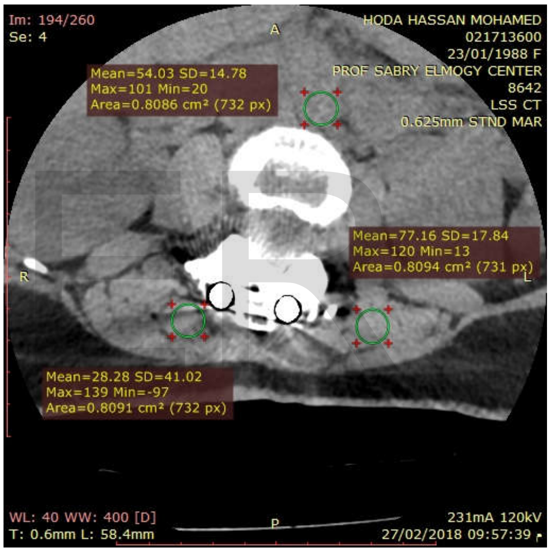


(a)





(b) (C)

Fig(9): female patient, 30 years, LSS vertebral fixation, at (a) image of patient without artifacts,(b) image of patient before applying MAR, (c) after applying MAR, ROI= 800mm^2, used for CNR by equation (1) and SNR, back ground is muscles and object is aorta. CNR with equation (2) is .11, 1.13, .62 in image without artifact, without MAR, and with MAR respectively. SNR with equation (3) is 2.9, 2.7, and 3.6 in image without artifact, without MAR, with MAR respectively.

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Correlation between different groups with MAR and without MAR was calculated by using spearman correlation test.

	CNR (without MAR)		CNR (with MAR)	
	R	p-value	R	p-value
SNR	0.433	0.039*	0.385	0.077

Table (8): shows correlation (r) between CNR and SNR in different groups.

This table shows that there was significant positive correlation between CNR and SNR in without MAR group (r=0.433, p=0.039) by using spearman correlation test.

The result is analyzed in figure (10-11).

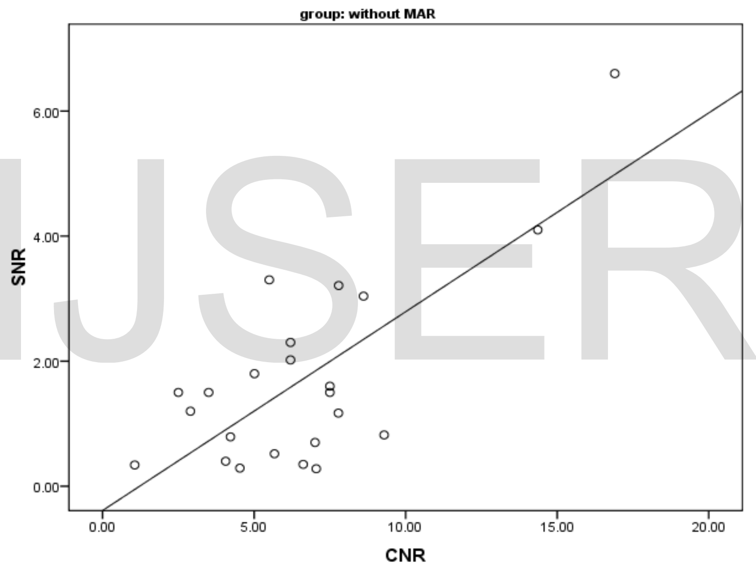

Figure (10): Scatter diagram for correlation between CNR and SNR in without MAR group.

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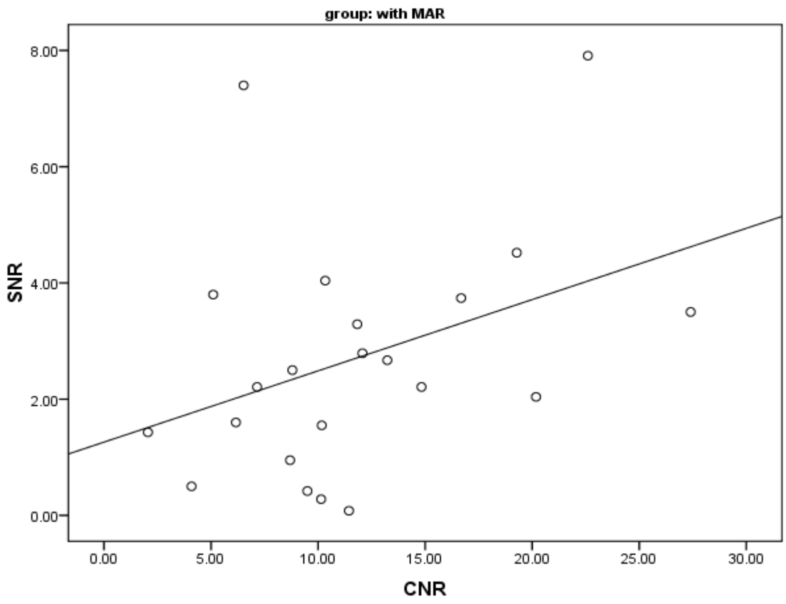

Figure (11): Scatter diagram for correlation between CNR and SNR in with MAR group.

3 Discussion:

CT imaging machine is an important machine in radiology field. The quality of Ct image must be improved to doctors in diagnosis different dieses. Improving image quality and decreasing metal artifacts is very important for CT image. By evaluated metal artifact reduction technique (metal deletion technique). CT numbers are significant difference (p value < 0.005) between images before applying MAR and the same images after applying MAR. CT number increases in case of low noise HU region and decreases in case of high noise HU regions. Stander deviation decreases at two cases in low and high noise HU regions after applying MAR. This leads to increasing in image quality and internal structure becomes clearer.

CNR is very important parameter for evaluating CT image quality and SNR is used to evaluate CT metal artifact reduction algorithm (14) .CNR showed that there is significant difference between image quality before and after applying MAR (15). CNR increasing in images after applying MAR and image quality has been improved after applying MAR technique. SNR shows that p value >0.05 so there is no significant difference before and after applying MAR.

Correlation between CNR and SNR in different groups has been made by Spearman correlation test. It shows that there was significant positive correlation between CNR and SNR in without MAR group (r=0.433, p=0.039).

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4 Conclusion:

Metal deletion technique has effective role in improving CT image quality. It decreases artifacts that come from metal implants and avoid formation of new artifact. So it helps radiologists by increasing the diagnostic value of examination. MDT replacing missing metal pixels and provides CT image with the missed information.

5 Limitations of this study:

1- This study made calculations on images of patient with metal implants in different parts in human body but did not caver all part of body has metal implant.

2- The used machine of CT reduces metal artifacts with metal deleting technique which is one type of metal artifacts reduction techniques. This Study did not caver all types of metal reduction artifact techniques

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