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Effect of magnetic field strength and sequence type on susceptibility artefacts: a comparative study utilizing low and high field strength magnetic resonance imaging scanners

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Thesis Approval

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11/12/2022

Dedication

I dedicate this dissertation to my beloved parents, to my wife, to my children; Omar and Qays, to my sisters and brothers.

Declaration

I certify that this thesis submitted for the degree of master, is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for higher degree to any other university or institution.

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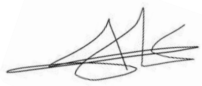
Signed: 

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I thank everyone who supported me and helped me to complete this study.

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I thank my supervisor, Dr. Mohammad Hjouj

I thank my colleagues at PALRAY Center

Abstract

Many patients need to implant metal screws in several areas in their bodies as treatment procedures, and these metal implants cause an artefact around them in the magnetic resonance image, so the area around the metal implants can't be better evaluated, and this artefact increases whenever the magnetic field increased, for example, using the device with the magnetic field 1.5 T causes a greater susceptibility artefact than using a device with 0.4 T magnetic field. This type of artefact leads to repeat the MR image again using low field MR devices, this will increase the costs of diagnosis, increase the patient's exhaustion to obtain sufficient diagnosis, in addition to consuming more time to complete the diagnosis process.

in this study, the measurements of the artefact around the titanium screws in low and high MR field was compared with the measurements of the screws in X-ray images. in addition to other sample was taken from calf spine that purchased from meat store that have been implanted with other 3 titanium screws, then underwent low and high field MR imaging in 3 repeats to get more accurate measurements, this artefact measurement around the screws in the calf spine was compared with the diameter of the same screws measurements on X-ray images.

The result of this study was clarify that the use of low field MR device is better than the high field in case of presence of titanium screws in vertebral body, in addition to use titanium rather than other metallic materials that produce high susceptibility artefact in MR image, and this will be shown in the charts in this study.

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List of Abbreviations

Abbreviation	Definition	Page
MRI	Magnetic Resonance Imaging	1
CT	Computed Tomography	2
T	Tesla: Magnetic field strength unit	3
TSE	Turbo Spin Echo	4
X	Magnetic susceptibility	5
SE	Spin Echo	7
GRE	Gradient Echo	7
RF	Radiofrequency	7
BMD	Bone Mineral Density	8
TE	Time of Echo	9
Bo	External magnetic field strength	10
B1	Local magnetic field	10
DICOM	Digital Imaging and Communications in Medicine	13
Fat Sat	Fat Saturation	21
SAG	Sagittal plane	22
AXI	Axial plane	24
PACS	Picture Archiving and Communication System	35

Chapter 1: Introduction

1.1 Background

There are many disease affects the spine and led to loss of its work and function, or cause pain to the patient, and therefore need surgery for treatment, some of these surgeries require the implantation of metals to fix the vertebrae in an ideal method depending on patient's condition like presence of osteoporosis or fractures, depending on this conditions the specialist surgeon chose the appropriate implantation shape and size to treat patient. (Azwan & Rahim, 2011)

1.1.1 Metallic implants:

The implanted metals used in spine surgery differ from each other in terms of shape and component. Some of these metallic materials are in the form of screws, rods and plates, each of these forms has different uses than others, for example, screws are implanted in the body of the vertebra, and the rods are used to connect and fix these screws with each other's in a specific pattern and shape that suits the pathological condition and the anatomical region, for example, the rods used in the correction of scoliosis are used at different angles from those used to stabilize vertebral fractures, in addition to use small screws in cervical vertebrae comparing with the screws used in lumbar vertebrae, because the vertebral body size is deferent from anatomical region to another. (Tsukimura et al., 2017)

The post-operative spine surgery should be examined by imaging technologies to evaluate the effects and complications of the surgery, the first technology used for this purpose is MRI, due to MRI is very useful in soft tissue and central nervous system more than other modalities, where MRI is giving appropriate tissue contrast in this body regions.

1.1.2 MRI:

MRI is one of the best imaging modality used to diagnose the spine disease, because it gives more informative details about soft tissues, cartilage and articulation of the vertebrae with each other's, either for pre-operative or post-operative conditions, especially if the post-operative complications occurred. In addition to another types of modalities used to diagnose spine conditions like CT, but MRI till now the first choice in neurosurgery field. (Ernstberger et al., 2007)

The main problem in post-operative MR image with implanted metals is susceptibility artefact around these metallic implants. This artefact leads to misdiagnosis in MR image, so that the treating doctor can't chose the appropriate medical procedures or treatment plan depending on this MR image. If the MR image needs to be repeated to clarify diagnosis, this may lead to add some additional financial burden in addition to exhausting the patients. (Krätzig et al., 2021)

The MRI divided into two categories depending on strength of the magnetic field, low field open pore permanent magnet, and high field closed pore superconductive magnet. These two types used in general to produce diagnostic image, but with some differences like image quality, where the high field produce high image quality comparing with the low field device because the later has weak gradient and receiving coil efficiency. In addition to the low magnetic field that less affect hydrogen atoms sufficiently to aligning with external magnetic field, and this is lead to low image quality. (Abildgaard, 2015)

Low field MRI device is comfortable for the patient, due to the shape of this device consisting of two pieces facing each other, one over the patient and the other is below the device table, without the limitation in space around the patient's body, this is very comfortable for the patient. The high field MRI device is exhausted for the patient because the cylindrical shape surrounds the patient's body, in addition to the claustrophobic patients suffering and fear of narrow places in high field devices.

Low field devices are considered more safe in case of metallic implants presence more than high field, on the other hand, high field device produce MR image with high quality comparing with low field, this is a fact, but the low field - in some cases - produce image with high quality more than that acquired from high field MR device, because the effect of susceptibility artefact, this depends on the strength of the magnetic field, this is directly proportional to the magnetic field, where the greater the strength of the magnetic field, the greater the presence of the effect of the susceptibility artefact in the image, and as a result this will affect the quality of the MR image. (Klein, 2020)

1.2 Context and problem statement

In this study the artefact occurs from presence of metallic screws manufactured from Titanium that inserted in the spine and undergo MR imaging was measured, because these metals lead to distort the magnetic field and then to signal artefact appears in MR image, consequently this artefact affects the diagnosis.

1.3 Purposes

This study aims to compare the susceptibility artefact occurs in the post-operative MR image due to presence of metallic screws that inserted in the spine of patients. This MR images performed previously by using two deferent field strength MRI devices, 0.38 T from HITACHI and 1.5 T from PHILIPS.

1.4 Study objectives

This study and others in the same topic aims to raise the level of understand of the impact of susceptibility artefact in MRI that produced from presence of metallic screws, and this understand lead to reduce the repeated MR images, and consequently:

- Reduce the exhaustion for the patients.

- Reduce the costs of medical process.

The measurements from this study can be using in other studies aiming to reduce the level of susceptibility artefacts and to encourage specialists in the field of neurosurgery and orthopaedic to evaluate the post-operative results and complications by using low field MRI instead of high field which they consider the best, while the low is the better in diagnosis in case of metallic implantations.

1.5 Study design

This is a retrospective and prospective study on real human spine and animal spine respectively, and aims to measure the dimensions of the susceptibility artefact in MR image appears on T2 TSE sequence in sagittal and axial cuts, and comparing the results from animal spine by using gradient echo sequence with the T2 TSE to differentiate the susceptibility artefact relations in the sequence type in addition of field strength.

Chapter 2: Literature Review

2.1 Magnetism

"Magnetic susceptibility (X) : The magnetic susceptibility of a substance is the ability of external magnetic fields to affect the nuclei of a particular atom" (Westbrook, 2016)

This susceptibility depends on the paired and unpaired electron in the outer shill of nucleus of the atom, which the atom that contains unpaired electron in the outer shell affected by the external magnetic field more than the atoms have paired electron in the outer shell. (Westbrook, 2016)

There are four types of matter depending on their susceptibility shown in figure 2.1:

- Diamagnetic materials: this type of matter have no magnetic field with absence of external magnetic field that applied, but if this matter is placed inside an external magnetic field, a small magnetic moment is generated for it and opposes the external field, and the most body tissues are diamagnetic, so that this matter has low susceptibility level.

- Paramagnetic materials: this type of matter have unpaired electron, and so that has a small magnetic moment, and when affected by external magnetic field, their magnetic moment aligned with the direction of applied field, so it increases the local magnetic field. Gadolinium and oxygen considered as paramagnetic substances.

- Superparamagnetic materials: this type of matter has magnetic susceptibility more than paramagnetic but less than ferromagnetic. The iron oxide based MR contrast agents considered as superparamagnetic.

- Ferromagnetic materials: This type of material is strongly affected by the external magnetic field by attraction and repulsion, and this can be magnetized permanently, there for it is contraindicated to inter the MRI room if implanted inside the body. Iron is one of these materials. (McRobbie et al., 2017) (Aboelmagd et al., 2014)

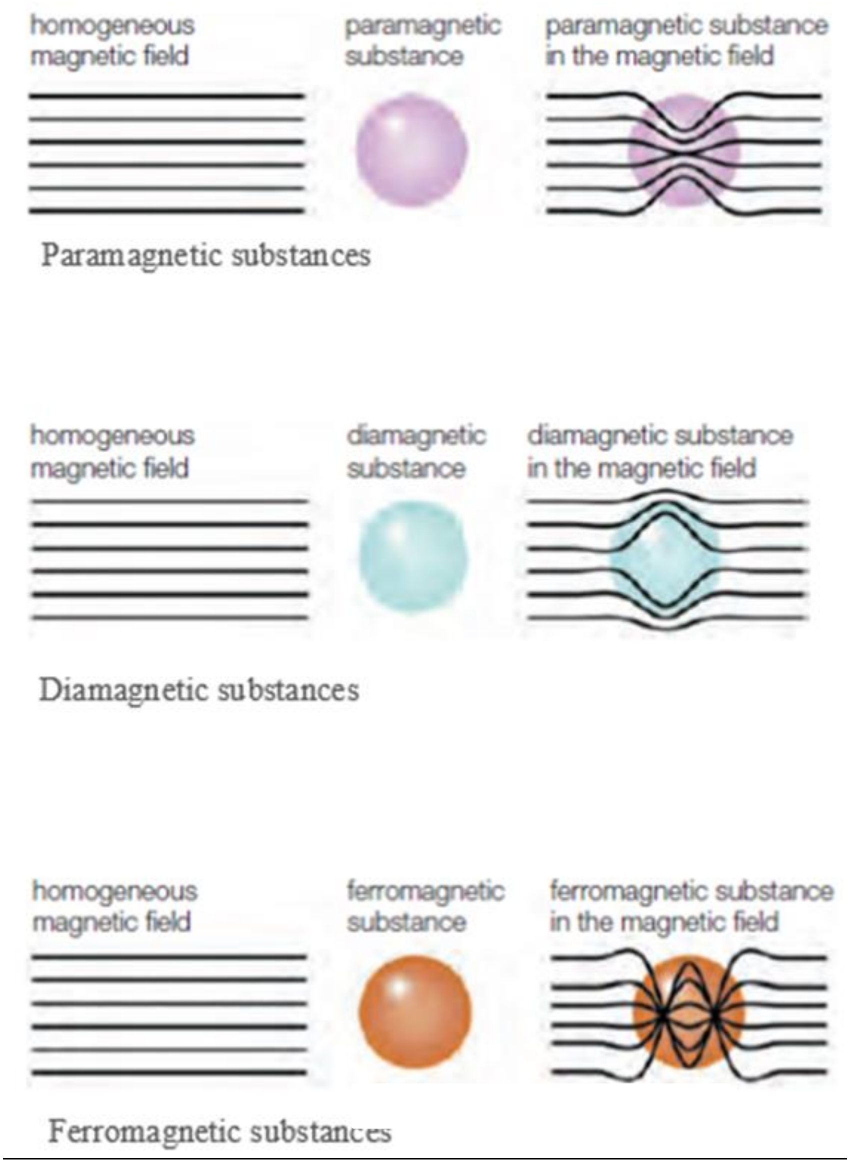

Figure 2.1:_Magnetic substances. (Westbrook, 2016)

2.2 MR sequence

There are many types of sequences used in MR imaging, and all these sequences used in various methods and for many proposes, Spin Echo (SE) and Gradient Echo (GRE) sequences are very important and commonly used.

SE produced by applying 2 RF pulses, 90° and 180° RF pulse, but the GRE produced by only one 90° RF pulse combined with gradient reversal, so that the GRE sequence is very sensitive to the susceptibility more that SE that reduce the susceptibility by using the second refocusing 180° RF pulse. Figure 2.2 (Markl & Leupold, 2012)

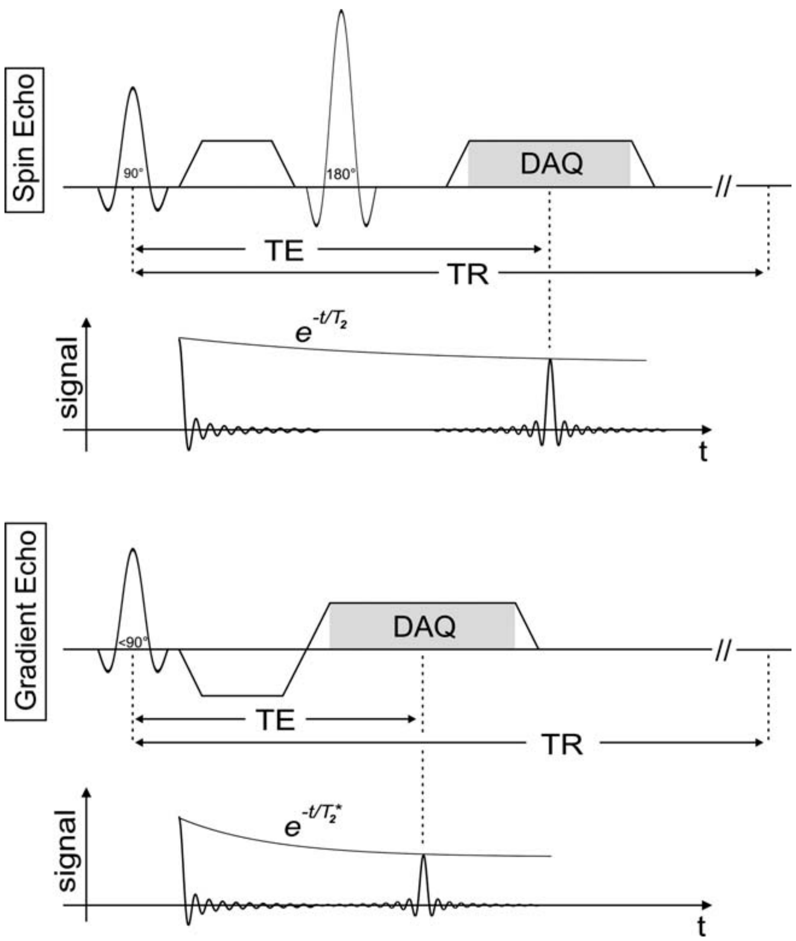

Figure 2.2: the deference's between SE and GRE. (Markl & Leupold, 2012)

The sequence used to create the MR image is very affect the artefact effect, and because the GRE severely affected by metallic implants, The GRE should not be used in this cases, and replaced by SE sequence to minimize the susceptibility artefact as much as possible, even SE can't eliminate the susceptibility artefact completely, but it reduces this type of artefact efficiently more than GRE, especially with TE reduction to the minimum acceptable level. (McRobbie et al., 2017)

2.3 Metallic screws

Metallic screws implantation is the best way to treat some types of disorders and diseases in the spine, especially in the lumbar and dorsal regions, such as fractures and congenital spinal deformities like scoliosis. (Chua et al., 2019)

These metal implants selection depending on many factors, such as the anatomical part of the spine that undergoes the operation. For example, cervical vertebral body is smaller than that in the lumbar, so that the screws inserted in cervical region defer from that inserted in lumber in size either length nor diameter, consequently the amount of inserted metals defer from region to another, and this one of the factors affect the amount of susceptibility artefact occurs. On the other hand, these screws may pull out from the vertebrae to the outside of the trajectory that inserted in, this occur due to many factors, the most important of these factors is the weakness of the bones such as osteoporosis, and osteoporosis affect the pedicle BMD, and it is important to mention that the screws fixation in its trajectory are depending on the pedicle, not on the spongy bone inside the vertebral body, and the osteoporosis affect the pedicle strength greatly, so the length and diameter of the screws are chosen depending on the amount of osteoporosis that the patient suffers from. (Li et al., 2022) (Cho et al., 2010)

The pedicle screw consists of: head, neck and body as shown in Figure 2.3: each screw body has two diameters, the outer diameter and the inner diameter manufacturing from the same material, and the difference between these two diameters depicts screw thread length. All these screw measurements are deferred for many types and shapes for many purposes depending on the patient condition need, like the level of vertebrae, weakness of bone as in osteoporotic patients, the purpose of the screw implantation and the method used to prevent from pulling out of the screw. (Li et al., 2022) (Cho et al., 2010)

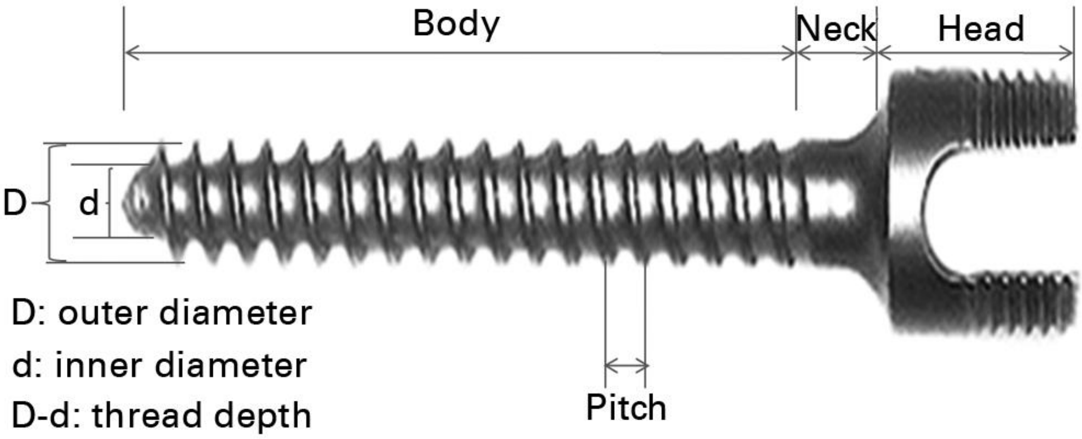

Figure 2.3: The screw structure. (Cho et al., 2010)

2.4 Susceptibility effect

The susceptibility effect as size and shape from the matter depending on the nature of the mater as described previously in 2.2 subtitle of literature review that depend on the number of unpaired electrons in the specific atom, and on the external magnetic field that applied, as the magnetic field strength increased, the susceptibility effect also increases, in addition to TE, as TE increase, the susceptibility effect also increases. (Hori et al., 2021)

$$\text{Susceptibility Artifact Size} \propto \frac{(\Delta\ \text{Susceptibility}) \cdot B_o \cdot TE}{\text{Bandwidth}}$$

The type of MR sequence used in imaging protocol affects the susceptibility effect in the result image, for example the effect of susceptibility increased using a GRE sequence even though this sequence uses a short TE, because the compensation of phase difference impaired by gradient reversal, on the other hand the effect reduced with TSE sequence, this due to using 180° rephasing pulse make more compensation in phase difference, so that reduce the susceptibility artefact in the result image. (Westbrook et al., 2011)

There are four susceptibility artefact shapes may appear in MR image like in figure 2.4:

- Geometric distortion, due to production of local magnetic field B1 transient and interact with the external magnetic field B0 lines.

- Signal loss, this artefact is caused due to deferent susceptibility between the metallic implant and the adjacent tissues, and this lead to magnetic field gradient deference's, and therefore, this cause frequency losing.

- Signal pile-up, while some signals shifted and localized in the wrong pixels with the correct signal of this pixels superimposed together and registered in the same pixels, this lead to hyper intense area.

- Failure of fat suppression, due to erroneous signal placed in the same slice because the frequency selective in the fat suppression is failed, and this is caused by the inhomogeneity in the local field strength that affect the chemical shift. (Lee et al., 2021) (Jungmann et al., 2017) (Germann et al., 2021)

Figure 2.4: Susceptibility artefact caused by Titanium screw in the lumbar spine

2.5 Titanium

There are many types of material that used in manufacturing of the implanted screws, plates, rods and other shapes of this implantations, these types used in specific methods and for many purposes according to the need of the patient's condition, carbon fiber, titanium, ceramic, cobalt chromium and stainless steel are the most common used in this manufacturing.

One of the most these important materials used for implanted pedicle screws is titanium, because it is considered as paramagnetic metal with acceptable susceptibility artefact effect in the MR image. The best materials used for implantation in the body is carbon fiber, as it does not produce artefact in the MR and CT images and therefore does not affect the diagnosis because its density is similar to the density of the bone, ceramics also have very good susceptibility artefact level, but carbon fiber and ceramics have bad resistance for fracture, so that it is not widely used in spine implantations, but it is used in other body regions that do not need to bear pressure and body weight. On the other hand, the worst material used is stainless steel, because it creates a significant artefact in the image and affects the diagnosis. As a better solution, titanium is used, which is considered strong to stabilize the bones and at the same time does not produce huge susceptibility artefact like stainless steel. (Fleege et al., 2020) (Ortega et al., 2020)

2.6 Previous studies

Some of recent previous studies comparing the types of the implanted materials under the same magnetic field in MRI or under the same CT device, on the other hands, few of recent studies make the comparison between material types and components using more than one of magnetic fields specially 1.5 T and 3 T devices in susceptibility artefact deference's. Most of these studies compare the artefact from screws made of carbon fiber and stainless steel, or compare carbon fiber with titanium using the same magnetic field strength, and there are some studies that have compared the results of the artefact resulting from the implantation of the artificial hip or knee joint, or the cochlear implants that contain a small magnet.

To the best of the researcher knowledge there are no published studies comparing susceptibility artefacts in the spine using 0.4 T with 1.5 T

Chapter 3: Methodology

This chapter provides the framework of quantitative and qualitative retrospective review for specific number of patient who undergo MRI by using low and high field MR machines, and prospective experiment on phantom spine in the same MR fields. Data collection, data analysis method, materials and the equipment will be explained in this chapter.

3.1 Materials and methods

Two MRI machines were used in this study:

A. Hitachi Aperto Lucent 0.38 T as a low field device.

B. Philips Ingenia 1.5 T as a high field.

3.1.1 Measurement method:

First, all low-field images were taken, and the number of screws in the spine images was counted. It was discovered that there were 24 of these screws in total, and they were all reviewed and tested using RadiAnt DICOM viewer measurement tools, as shown in figure 3.1, and STRADUS tools, as shown in figure 3.2, to determine the diameter of the artefact extension area for each screw and the surrounding affected area in millimeters.

The diameter of the screws was measured using the same technique for both the inserted screws in the phantom and the actual patient's X-ray image.

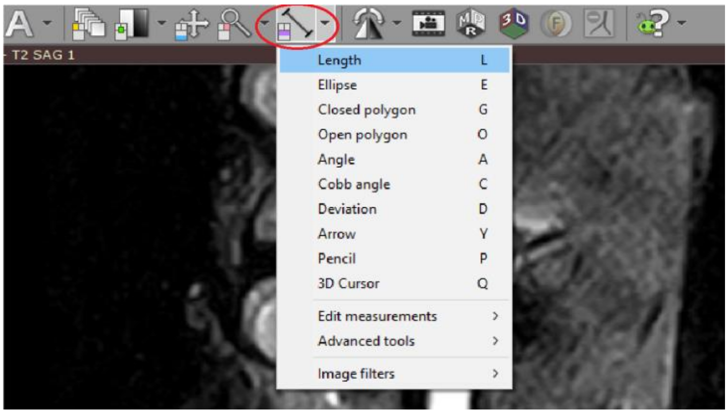

Figure 3.1: Measurement tool in RadiAnt DICOM viewer

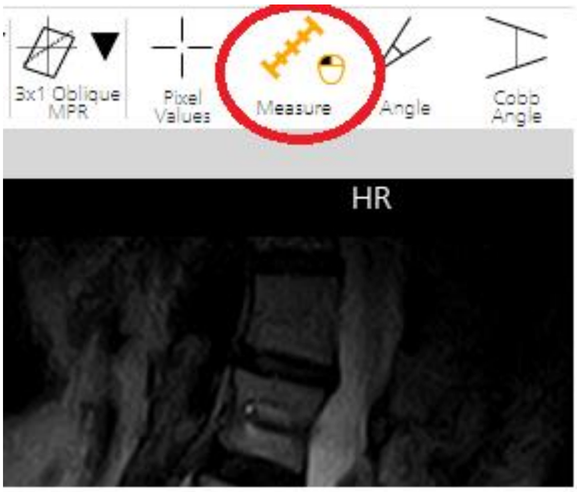

Figure 3.2: measurement tool in STRADUS

Using the aforementioned tool, measure the susceptibility artefact from end to end, from top to bottom in the sagittal plane as shown in figure 3.3, and from right to left in the axial plane as shown in figure 3.4. Each titanium screw produces susceptibility artefacts that surround it and extend to the surrounding tissues. This point is crucial because it is a very delicate region in diagnosis due to the foramen's existence and the nerve root that passes through it. These measures were applied as closely as possible to the point of the intervertebral foramen and the rear border of the vertebral body. Additionally, because it is far from both the small and big heads of the screw, this point reflects the true diameter of the screw was tested in this study.

Figure 3.3: Lumbar spine T2 sagittal with measurement

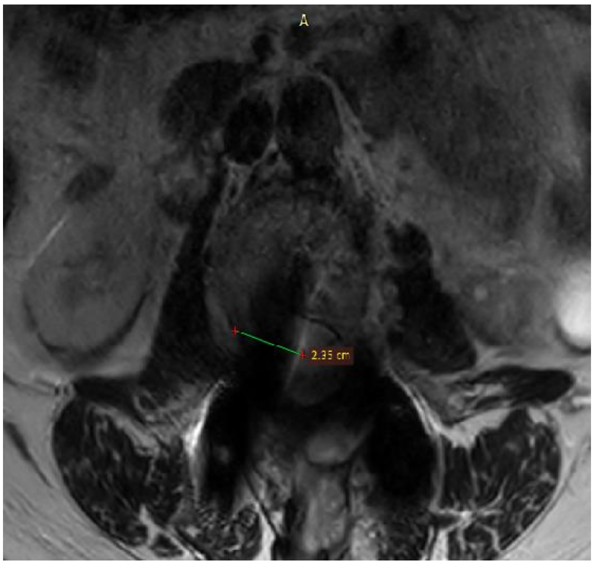

Figure 3.4: Lumbar spine T2 axial with measurement

3.1.2 MR sequences:

The MR sequences used to measure the artefact extension is T2 TSE sequence, in sagittal and axial planes, because it is the most widely used sequence in spine diagnosis. Susceptibility artefact measurement's also compared between T2 TSE axial with T2* axial for low field cervical spine only because:

A. T2* is not a part of lumbar spine protocol, so that it is not done for high field lumbar spine patients.

B. It is not possible to measure the suscep[tibility artefact in the high field cervical spine image, because this artificial extension is closed to each other and overlapping and has no clear boundaries, so that cannot be measured accurately.

knowing that no any artefact reduction technique was used in any of the MR images that were used in this study either in low or high field images, as these metallic artefact reduction techniques would have changed the artefact measurements, and this would lead to a defect in the results of this study.

3.1.3 Phantom spine sample:

In this study, there are 24 screws in patient images that were made using the low and high field devices, in addition to using a real phantom consisting of a calf spine surrounded by true muscles and fat, at first, an imaging experiment was carried out for a lamb spine, but the result was unexpected, as it turned out that the whole image did not contain any signals of fatty tissue, then a fresh spine of a calf as a large vertebral body size and similar to the human vertebrae was purchased from a meat store and the experiment was conducted on it for the second time, as show in figure 3.5, but the same result was obtained. The result was not a justified so far for the researcher, so this images were adopted, including the defects of fat signals, and this of course does not affect the progress of the study here because this study does not measure the signals resulting from fat, but from metal screws only.

This phantom was implanted by 3 titanium screws in the spine through the pedicle to the vertebral body, and then undergo to an MRI with a low field as well as high field in three repeats for each magnetic field strength to get more accurate results, and the comparison was done in the same way as on the images of real patients.

The titanium screws used in phantom measured 6 cm in length, 4.5 mm for inner diameter and 6.5 mm for outer diameter.

Figure 3.5: Calf spine phantom

The MR image done as conventional lumbar spine position and protocol, by using supine position, with T2 sagittal, T2 axial and T2* axial, and these three sequences repeated three times to get more accurate measurements, thus, obtaining more accurate results in this study, this sequences repeated three times on low field MR machine, and undergo to high field MR machine to make other three repeats for T2 sagittal and T2 axial only without T2* axial, because T2* axial will be comparing with T2 axial in low field machine only, this due to T2* don't performed for any real patients with metallic screws because the huge susceptibility artefact produced, so that the comparison done in the low field only between these two axial sequences.

3.2 Study population

Study population includes all patients underwent low field MRI in the PALRAY diagnostic center in Nablus, those patients have been asked to use here images that done by high field machine.

3.3 Study sample

After reviewing the whole patients in PALRAY Diagnostic Center 6 patients found underwent low and high field MR image, the number of the screws appeared in the low-field magnetic resonance images is 32, and after reviewing the images that were made on the high-field MRI machine, it was found that the number of screws in these images is 30, and these differences in the number of screws are due to some patients underwent other surgeries, some of them add new screws and some remove screws that were present, but the total number of screws that were imaged on the two devices is 24, in addition to 9 screws in repeated phantom spine MR image, so that the sample number in this study is 33 because each screw was tested separately.

3.4 Statistical analysis

In this study, Pearson Correlation were used to analyse the susceptibility artefact measurements for all samples that obtained from low and high magnetic fields, in correlation with the measurements in x-ray for each pedicle screw considering that the measurements on the X-ray images are the reference to determine the extension of the susceptibility artefact size.

3.5 Ethics

The proposal presentation for this study was presented on 2/4/2022 and was discussed in the presence of the discussion committee.

Letter of approval was received on 11/10/2022

All participants agreed to use their MRI images in this study, knowing that no patient information was used in this study, whether it was the name, ID number, etc.

3.6 Inclusion criteria

All patients in PALRAY diagnostic radiology center as low field MR images with pedicle screws are used in this study without restrictions of age or gender, and underwent previously an MR image using high field MR image with the same screw also.

3.7 Exclusion criteria

This study excludes any patients who underwent low field MR imaging with screw implantation but who had not previously undergone high field MR imaging. And any patients who have metallic fragments, such as those from gunshots, are also disqualified because they have a high level of undesirable susceptibility artifact that is not consistent with the findings of this research, which only clarifies the susceptibility artifact produced by titanium.

Chapter 4: Results and Discussion

This study was prepared to find out the difference between the susceptibility artefact in magnetic resonance images using the low and high magnetic field strengths. In this study, the artefact was measured in both fields for the screws, and these measurements were compared with each other to find out the difference between the artefact caused by each field in the presence of titanium screws in the spine of patients

This unit of the study shows the results obtained from using the low and high magnetic field, and the measurements for this artefact are presented in a table, which will be analysed and discussed later.

4.1 Unexpected results for phantom

A calf tissue consisting of lumbar vertebrae, muscles and fat surrounding it completely was used. This real phantom was undergoing low and high field magnetic resonance imaging, in both fields using the same parameters used for real patients in lumbar spine, unexpected results were obtained, were the T2 in sagittal and axial appear as T2 fat sat, and this is unexpected results as shown in figure 4.1, where the image a is for the first phantom that was used, which is the spine of a lamb, it was made using a low-field magnetic resonance device, while the image b is for the second phantom that was used, which is the spine of a calf made using the MRI device with a low-field, and image c, it is for the same calf, but by using the device with high magnetic field, and as it is clear in the three images, the fatty tissues did not appear as it should in all images, where it should be hyper intense and not hypo intense. This results need further investigations to evaluate the reasons of hypo intensity of fat tissue in T2 TSE.

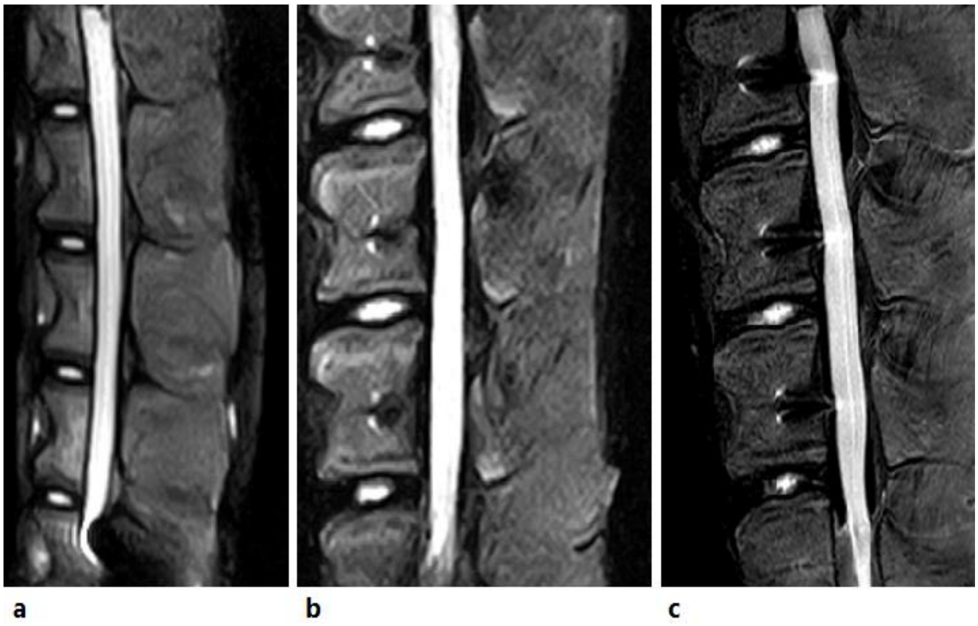

Figure 4.1: T2 TSE SAG using both fields appear as T2 FatSat

Knowing that the phantom underwent an MRI before and after implanting the titanium screws by the researcher in the same way as possible that an orthopaedic surgeon would, and in the before and after titanium implant images, the fat tissues do not appear as bright signal as they should have appeared in the T2 TSE in MR regardless of field strength or the presence of metal or not.

4.2 Screws measurements

The diameter of the screws was measured on X-ray images at the posterior aspect of the vertebral body at the pedicle for all 33 screws in real patients as it was found that the minimum diameter was 4.5 mm for cervical spine cases, and the largest diameter was 7.5 mm.

The diameter of inserted screws in calf spine phantom is 6.8 mm as measured on X-ray images of these screws.

4.2.1 Screws measurements on T2 TSE SAG for both fields:

The diameter for the screws on T2 SAG was measured for low and high fields, where the minimum diameter in low field is 5.1 mm, and the maximum diameter is 15.1 mm, in addition to measure the diameter on T2 SAG for high field, where the minimum diameter is 6.4 mm, and the maximum diameter is 24 mm, other measurements detailed as shown in table 4.1

Table 4.1-a: Measurements of the screws on T2 in SAG plane for both low and high magnetic fields

Screws number	Diameter on X-ray	Diameter on SAG low field	Diameter on SAG for high field
1	7.5	9.8	15
2	7.5	11	18
3	7.5	9	16
4	7.5	10	19
5	4.5	6.8	7.2
6	4.5	6.3	7.2
7	4.5	5.1	6.4
8	4.5	4.5	7.5
9	6	12	17
10	6	10.9	16
11	6	8.2	20
12	6	8.4	19
13	6.5	9.4	24
14	6.5	13	16
15	7	8.1	22
16	7	9.5	22
17	7	9.8	22
18	7	13	20
19	7	9	20
20	7	11	21
21	4.5	6.2	6.6
22	4.5	6.1	6.4

Table 4.1-b: Measurements of the screws on T2 in SAG plane for both low and high magnetic fields

Screws number	Diameter on X-ray	Diameter on SAG low field	Diameter on SAG for high field
23	4.5	6.6	7
24	4.5	5.5	6.8
25	6.8	11	19.4
26	6.8	11	19.5
27	6.8	14	19.6
28	6.8	13	18.2
29	6.8	11.4	18.9
30	6.8	15	20.5
31	6.8	14	18.4
32	6.8	12.7	19
33	6.8	15.1	18.6

4.2.2 Screws measurements on T2 AXI for both fields:

The diameter for the screws on T2 AXI was measured for low and high fields too, where the minimum diameter in low field is 4.6 mm, and the maximum diameter is 15.4 mm, in addition to measure the diameter on T2 AXI for high field, where the minimum diameter is 6.1 mm, and the maximum diameter is 22 mm, other measurements detailed as shown in table 4.2

Table 4.2-a: Measurements of the screws on T2 in AXI plane for both low and high magnetic fields

Screws number	Diameter on X-ray	Diameter on T2 AXI for low field	Diameter on T2 AXI for high field
1	7.5	11	22
2	7.5	8.5	13
3	7.5	9.5	18
4	7.5	12	15
5	4.5	5.1	6.1

Table 4.2-b: Measurements of the screws on T2 in AXI plane for both low and high magnetic fields

Continue to table 4.2			
Screws number	Diameter on X-ray	Diameter on T2 AXI for low field	Diameter on T2 AXI for high field
6	4.5	5.3	6.5
7	4.5	5.4	6.3
8	4.5	5.2	6.7
9	6	11.1	18
10	6	12	17
11	6	9	17
12	6	8.2	17
13	6.5	13	16
14	6.5	13.3	16.1
15	7	11.8	17
16	7	11.2	16
17	7	11.4	16.2
18	7	12.2	17.1
19	7	10	16.1
20	7	12	17
21	4.5	5.3	7.2
22	4.5	4.8	7.7
23	4.5	4.6	7.3
24	4.5	5.1	6.3
25	6.8	12.2	16
26	6.8	12.3	15.4
27	6.8	14.5	15.2
28	6.8	10	16.6
29	6.8	13.1	15
30	6.8	15	15.1
31	6.8	12.3	17
32	6.8	12.9	16.4
33	6.8	15.4	16.3

4.2.3 Screws measurements on T 2 AXI and T 2* AXI for low field:

The diameter of the screws was measured on the T2 AXI and T2* AXI for 9 screws in low magnetic field, these screws numbered from 25 to 33 were implanted in phantom, and this is to provide a brief overview of the difference between the artefact on T2 TSE and T2* for the same magnetic field.

The minimum diameter in low field for T2 AXI is 10 mm, and the maximum diameter is 15 mm, in addition to measure the diameter on T2* AXI for low field also, where the minimum diameter is 21.4 mm, and the maximum diameter is 24.7 mm, other measurements detailed as shown in table 4.3.

Table 4.3: Measurements of the screws on T2 and T2* in AXI plane for low magnetic fields

Screws number	Diameter on X-ray	Diameter on T2 AXI for low field	Diameter on T2* AXI for low field
25	6.8	12.2	21.5
26	6.8	12.3	22.3
27	6.8	14.5	22.2
28	6.8	10	24.7
29	6.8	13.1	23.9
30	6.8	15	24.3
31	6.8	12.3	22.3
32	6.8	12.9	21.4
33	6.8	15.4	23.8

4.3 Analysis

Pearson Correlation is the statistical analysis that will be used to understand the relationship between the measurements of the diameter of the screws that were measured on the MRI images and those measurements on the x-rays of real patients, and to compare the measurements on the MRI with the real size of the screws that were implanted in the phantom as follows:

4.3.1 Comparison of measurements on X -ray with T2 SAG in low field:

According to the correlation of screws diameter measured on x-ray and T2 SAG in low field, there is a moderate positive correlation at Pearson's correlation statistical analysis at r value 0.71.

Measurements of the screws diameter on X-ray and T2 SAG in low field MRI were represented in the figure 4.2.

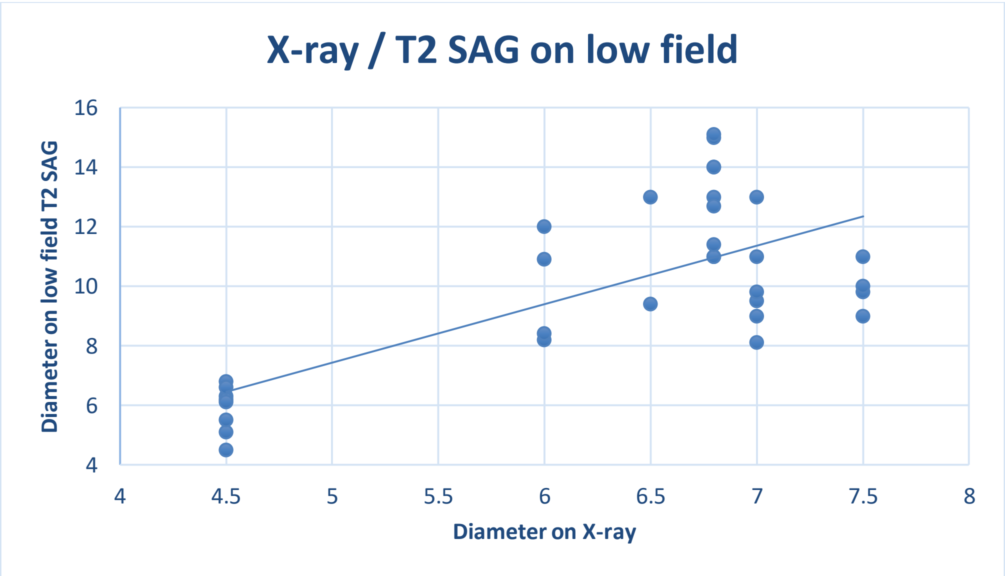

Figure 4.2: correlation between screw diameter on X-ray and T2 SAG in low field

4.3.2 Comparison of measurements on X-ray with T2 AXI in low field:

According to the correlation of screws diameter measured on x-ray and T2 AXI in low field, there is strongly positive correlation at Pearson's correlation statistical analysis at r value 0.81.

Measurements of the screws diameter on X-ray and T2 AXI in low field MRI were represented in the figure 4.3.

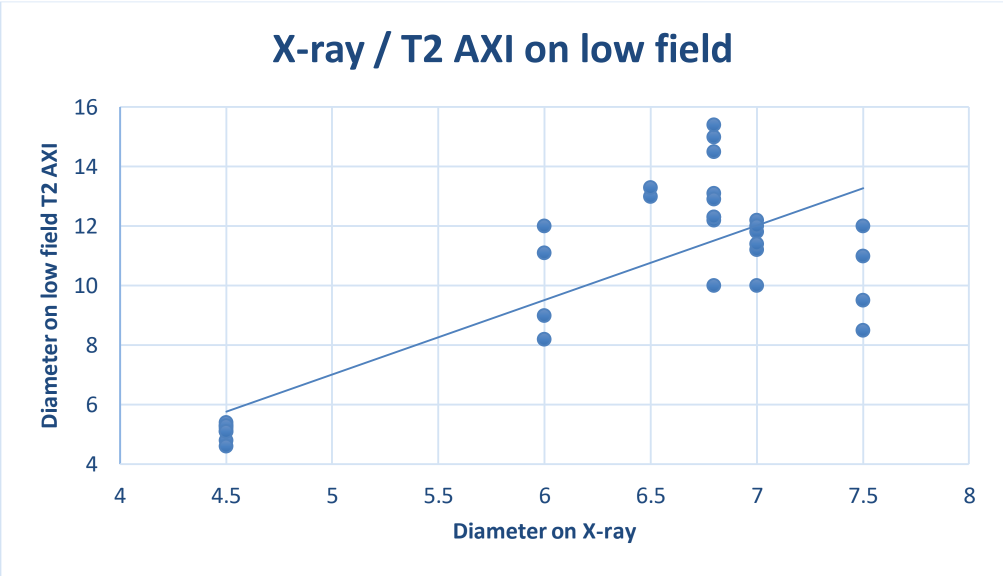

Figure 4.3: correlation between screw diameter on X-ray and T2 AXI in low field

4.3.3 Comparison of measurements on X-ray with T2 SAG in high field:

According to the correlation of screws diameter measured on x-ray and T2 AXI in low field, there is a strongly positive correlation at Pearson's correlation statistical analysis at r value 0.87.

Measurements of the screws diameter on X-ray and T2 SAG in high field MRI were represented in the figure 4.4.

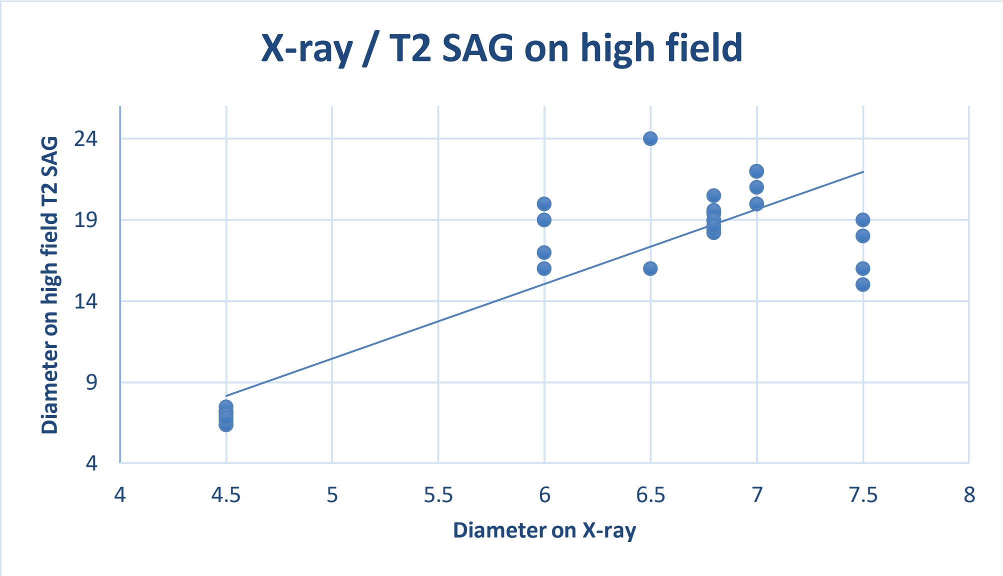

Figure 4.4: correlation between screw diameter on X-ray and T2 SAG in high field

4.3.4 Comparison of measurements on X-ray with T2 AXI in high field:

According to the correlation of screws diameter measured on x-ray and T2 AXI in low field, there is a strongly positive correlation at Pearson's correlation statistical analysis at r value 0.88.

Measurements of the screws diameter on X-ray and T2 AXI in high field MRI were represented in the figure 4.5.

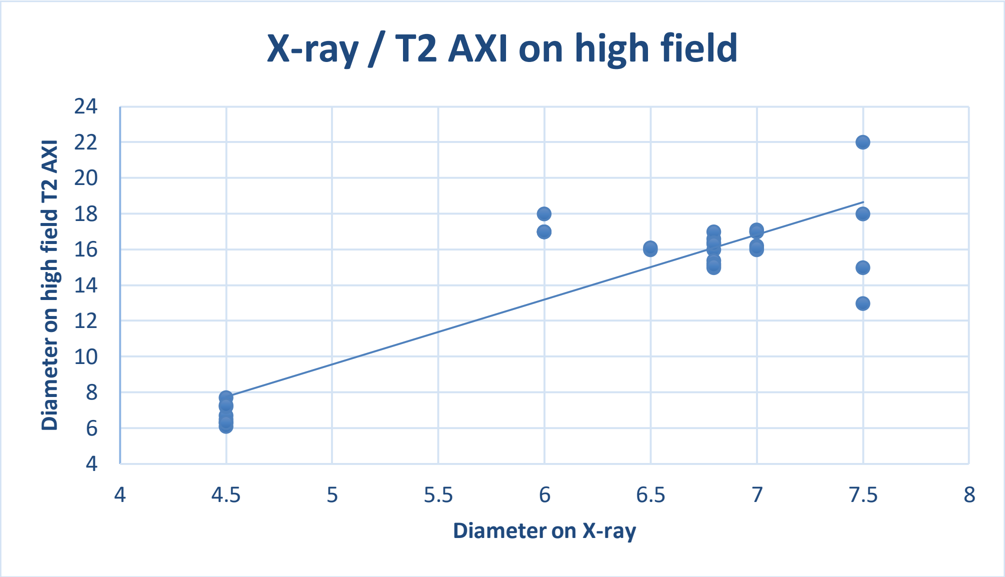

Figure 4.5: correlation between screw diameter on X-ray and T2 AXI in high field

4.3.5 Comparison of T2 SAG measurements for both fields:

According to the correlation of screws diameter measured on T2 SAG in both fields, there is a moderate positive correlation at Pearson's correlation statistical analysis at r value 0.69.

Measurements of the screws diameter on T2 SAG in both MR fields were represented in the figure 4.6.

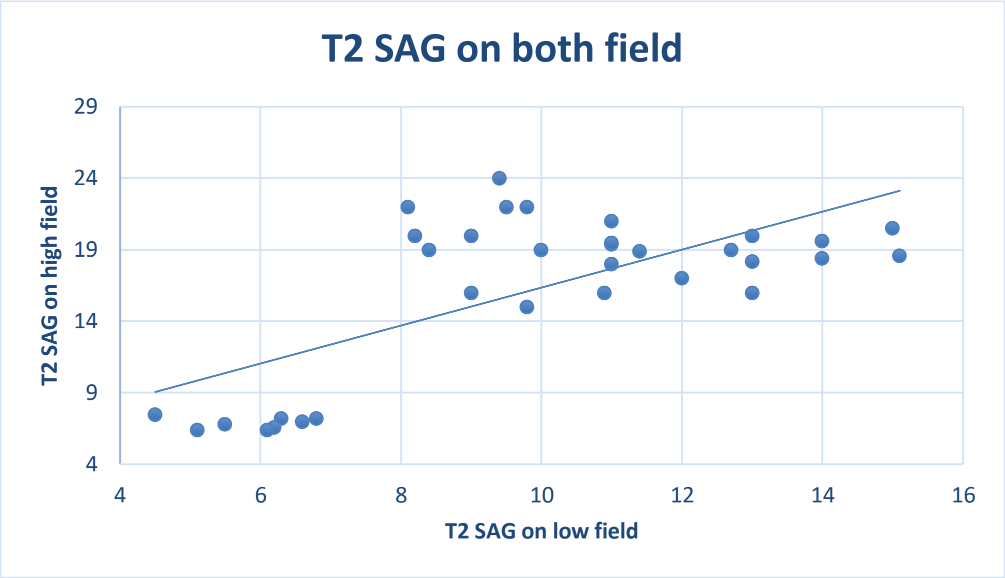

Figure 4.6: correlation between screw diameter on T2 SAG in both fields

4.3.6 Comparing T2 AXI measurements for both fields:

According to the correlation of screws diameter measured on T2 AXI in both fields, there is a strongly positive correlation at Pearson's correlation statistical analysis at r value 0.8.

Measurements of the screws diameter on T2 AXI in both MR fields were represented in the figure 4.7.

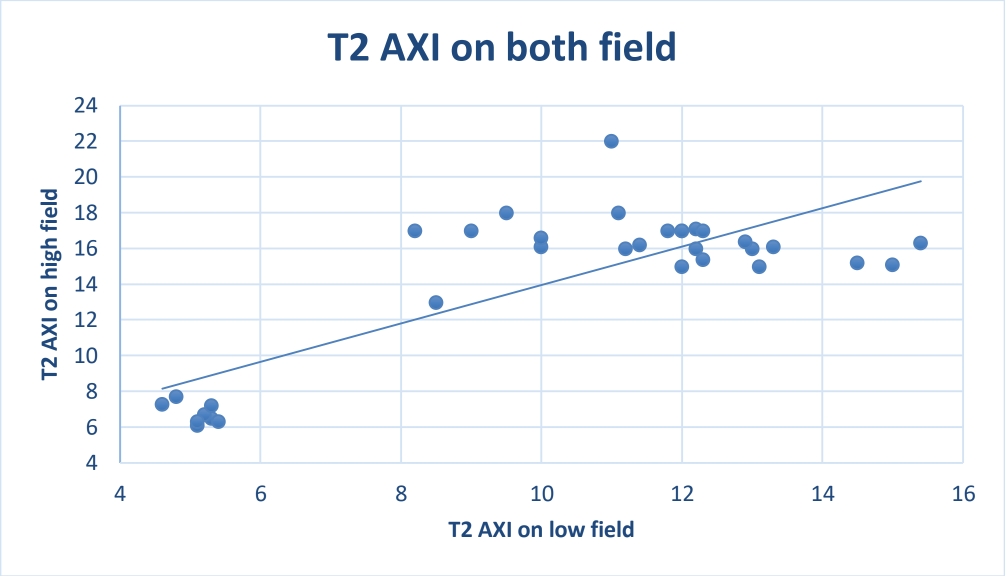

Figure 4.7: correlation between screw diameter on T2 AXI in both fields

4.3.7 Comparing T2 AXI with T2* AXI measurements for low field:

According to the correlation of screws diameter measured on T2 AXI and T2* AXI in low field, there is a weak positive correlation at Pearson's correlation statistical analysis at r value 0.04.

Measurements of the screws diameter on T2 AXI and T2* AXI in low MR field were represented in the figure 4.8.

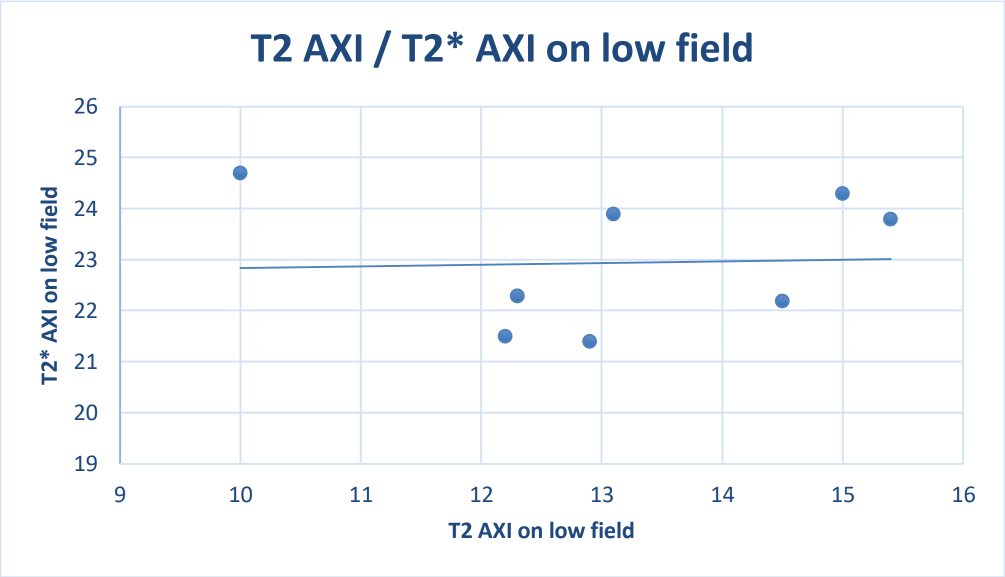

Figure 4.8: correlation between screw diameter on T2 AXI and T2* AXI in low field

4.4 Discussion

The presence of titanium screws in the spinal vertebrae leads to produce susceptibility artefact around these screws, and this artefact is not limited to the screw area only, but extends to around the screw, which means that a part of the tissues surrounding the screw are not sufficiently evaluated because they are not seen in the MR image.

In the measurements that were analyzed in this study, a large difference was observed between the diameter of the screws if it was imaged using a low magnetic field device or using a high field, and these differences are caused by the difference in the strength of the magnetic field. With the strength of the magnetic field used, as this artefact was significantly less in low-field MRI images, whether in T2 SAG, T2 AXI or in T2* AXI,

In addition, the size of the susceptibility artefact is directly proportional to the diameter of the screw that was studied. The screws found in the MR image of the cervical spine are usually small and have a small diameter, and due to this, the susceptibility artefact around them was very small compared to other larger screws that were used in the lower back area. The amount of metal the screw is made of affects directly the amount of this artefact produced around it in the MR images.

For example, the small screws in the cervical vertebrae with a diameter of 4.5 mm on X-ray image led to produce susceptibility artefact on T2 TSE SAG in low magnetic field in about 5.88 mm in average, and 6.88 mm on the same sequence in high magnetic field, that's mean the susceptibility artefact in the high field is more than in low field in about 25% on T2 TSE SAG sequence. As for the screws with the largest diameter in this study, it was in the lumbar vertebrae, this screws diameter was measured on x-rays image of 7.5 mm, while its diameter was measured on T2 TSE SAG in low magnetic field of 9.9 mm in average, and 17 mm in high field on the same sequence, that's mean the susceptibility artefact in the high field is more than in low field in about 42% on T2 TSE SAG sequence.

The same screws that have the smallest diameter on X-ray image that measured of 4.5 mm produced susceptibility artefact on T2 TSE AXI in low magnetic field about 5.1 mm in average, and 6.7 mm on the same sequence in high field, that's mean the susceptibility artefact produced on T2 TSE AXI in high field is more than that in low field in about 24%. And the largest screws diameter measured of 7.5 mm on X-ray image produced susceptibility artefact on T2 TSE AXI in low magnetic about 10.2 mm in average, and 17 mm in high field, that's mean the susceptibility artefact on T2 TSE AXI in high field is more than in low field in about 40%.

As for the susceptibility artefact measurements in the T2*AXI image in low field, it was very large compared to the measurements made on the T2 AXI images in the low field, the reason for this is the sequence type used in the imaging, where GRE sequence was used, and this type of sequence uses a reversal gradient instead of using a 180 RF refocusing pulse, this makes it more likely to be affected by the presence of metal screws in the area being imaged in MR image.

For example, the screws that were inserted into the phantom had a diameter of 6.8 mm on the x-ray image, and when measuring the susceptibility artefact resulted in T2 TSE AXI, it measured 13 mm while 22.9 in T2* GRE, that's mean the susceptibility artefact on T2* GRE is more than that on T2 TSE AXI in about 43.2%. This is the biggest difference in the amount of susceptibility artefact that occurred in this study.

4.5 Study limitation

This study is very important in understanding the amount of differences between the susceptibility artefact produced by titanium screws in the magnetic resonance imaging, and it provide an understanding of the extent of this artefact in low and high field magnetic resonance imaging, but it would have been better if the planning of the slices of the sequences that taken for the screws was uniform and better controlled similarly as much as possible.

This study is performed in the West Bank, which is an area that contains only three centers work on low field MRI machines, these centers were contacted and no patients were available from them because they did not have PACS previously, and therefore they do not save patients images, only patients who were found at the PALRAY Diagnostic Center were satisfied, therefore this is considered the most important limitation in this study, which is the small number of patients who performed magnetic resonance imaging by the low field and high field strength devices together, and therefore the number of screws that were implanted in the patient's spine will be adopted as the number of the sample in this study, because actually each screw studied separately even if one patient has several screws.

4.6 Conclusion

All screws that were used were made of titanium, which is a material that allows imaging using an MRI machine, whether it is low or high magnetic field, but even with the use of a low field device, there is susceptibility artefact in the image around the screw, knowing that this artefact reduces due to the use of a low magnetic field and titanium rather than other ferromagnetic materials, which helps to obtain better diagnostic results in patients who have metallic implants in general, and in the spine as this study clarify.

The decrease in the amount of susceptibility artefact in the images with screws implantation in the cervical spine was observed using both magnetic fields, and the high artefact in the lumbar spine, this is due to the diameter of the screw used, as the cervical vertebrae are small, so screws of small diameter are used, and this affects the amount of the artefact in the MR image around the screws.

In addition to unexpected results that occurred in the images of the spine of the calf that was underwent MRI, these results are related to the absence of the Signal from the fat in the tissue, the sequence that used is T2 TSE but the results are typically T2 fat sat, and this is not affect the susceptibility effect, but also it is undesired result, knowing that the imaging was repeated after the phantom was modified by adding another large amount of fat, but the same results of fat sat are still, where the images remained without a sign of fat, and after searching in previous studies and through several references, the reason remained unknown until now for the researcher, and this will be my next research after completing this study.

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الملخص:

تأثير شدة المجال المغنطيسي ونوع الصورة على تأثير المعدن في الصورة: دراسة مقارنة باستخدام اجهزة التصوير بالرنين المغناطيسي ذات قوة المجال المنخفضة والعالية

اعداد: علاء محمود علي قلالوة

إشراف: د. محمد حجوج

الكثير من المرضى يضطرون الى زرع براغي معدنية في عدة مناطق في اجسامهم كإجراءات علاجية، وهذه الزرعات المعدنية تسبب حولها تشويشا في صورة الرنين المغناطيسي، فتصبح المنطقة التي تحيط بالزرعات المعدنية غير قابلة للتشخيص، ويزيد هذا الخلل كلما ارتفع المجال المغناطيسي المستخدم، فمثلا استخدام الجهاز ذو قوة المجال المغناطيسي 1.5 تسلا يتسبب في خلل أكبر من استخدام جهاز بقوة 0.4 تسلا، هذا الخلل الناتج في الصورة يتسبب أحيانا بإعادة تصوير المريض على الجهاز منخفض المجال، ويزيد من تكاليف التشخيص، بالإضافة الى انه يزيد من معاناة المريض للحصول على تشخيص كاف، بالإضافة الى استهلاك المزيد من الوقت لإكمال عملية التشخيص.

في هذه الدراسة يتم قياس الخلل الذي تسببه براغي التيتانيوم حولها عند التصوير باستخدام جهاز الرنين المغناطيسي منخفض المجال والجهاز عالي المجال، هذه القياسات تؤخذ لنفس البراغي بعد تصويرها في كلا المجالين، ثم يتم قياسها بالمليميتر، ومقارنتها مع القياسات لنفس البراغي على صور الاشعة السينية. بالإضافة الى غرس 3 براغي في عمود فقري لعجل تم شرائه من متاجر اللحوم، هذه البراغي جميعا تم تصويرها باستخدام المجالين أيضا، وتم إعادة تصوير هذه البراغي 3 مرات لزيادة دقة النتائج، وتم عمل القياسات لجميع هذه البراغي ومقارنة نتائجها بعضها مع بعض، ومقارنتها مع القياسات التي كتبت على البراغي بواسطة الشركة المصنعة.

تبين في هذه الدراسة ان الخلل الناتج في صور الرنين المغناطيسي باستخدام الجهاز ذو المجال المرتفع أكبر بكثير من الخلل الناتج من استخدام الجهاز ذو المجال المنخفض، بالإضافة الى ان استخدام مواد مثل التيتانيوم التي تعتبر اقل تأثيرا في قابلية التمغنط يقلل من التشوه الموجود في صورة الرنين، وتبين المنحنيات في فصل نتائج الدراسة هذه الفروقات بشكل مفصل.

Appendices

بسم الله الرحمن الرحيم

Al Quds University
Faculty of Health Professions
Jerusalem –Abu Dis

جامعة القدس
كلية المهن الصحية
القدس – أبو ديس

Research Ethics Subcommittee of Faculty of Health Professions
Letter of approval

Oct. 11, 2022
Ref. No.: RESC/2022-18

Dear Applicants, (**Dr. Mohammad Hjouj, Mr. Alaa Qalalweh**)

Program: **MSc Medical Imaging Department**

The Research Ethics subcommittee of Faculty of Health Professions has recently reviewed your proposal entitled (**Effect of magnetic field strength and sequence type on susceptibility artifacts: a comparative study utilizing low and high field strength magnetic resonance imaging scanners**) submitted by (**Dr. Mohammad Hjouj**). Your proposal is deemed to meet the requirements of research ethics at Al-Quds University, but further assessment is required by the Central Research Ethics Committee of Al-Quds University. We wish you all best for the conduct of the project.

Hussein ALMasri
Research Ethics Subcommittee Chair
Faculty of Health Professions

Hussein ALMasri

CC: File
CC: Committee members

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