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Understanding the MRI

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Abstract
With the use of a powerful magnet, radio waves, and modern computer technology, magnetic resonance imaging (MRI) creates painless, entirely noninvasive scans of the body's many organs and structures. A significant portion of the body may be imaged with MRI in a short amount of time, and it can be used to examine practically any body area.
The use of MRI scans is highly helpful in the diagnosis of a wide range of illnesses and anomalies, including malignant tumors and problems with the hip joint. Studying the spinal cord, brain, heart, and eyes using them is also highly helpful.
According on the size of the area to be scanned and the quantity of pictures acquired, an MRI scan normally takes 30 to 60 minutes.

Keywords: Understanding, MRI

Introduction

MRI is the result of a protracted engagement between physics and medicine. The Nobel Prize was given to Doctor Bloch from Stanford University and Doctor Purcell from Harvard University in 1952 for their research on what was then called "Nuclear Magnetic Resonance (NMR)". However, it was the introduction of computers in medical imaging that marked a paradigm shift 20 years later. By this point, the term "nuclear" has been replaced, and the procedure is now referred to as a "Magnetic Resonance Imaging" (MRI) [1].
When Lauterbur and Damadian [2], were working separately, they declared the potentiality of the science of magnetic resonance in imagining the human body in 1973, the medical field had witnessed a boom. Since then, magnetic resonance equipment has seen enormous technological and design advancements that include computer technology and advanced electronics to produce sectional pictures of the human body with exceptional delineation that are unmatched in the medical field. Utilizing the magnetic characteristics of atom nuclei, primarily hydrogen in human tissues, this novel diagnostic technique provides minute structural features of the human body. The human body is a chemical composition of multiple elements, including hydrogen, carbon, nitrogen, sodium, phosphorus, potassium, etc. in diverse chemical combinations. This composition serves as a testament to their attempts [3].
It has been noted that certain of these elements' atoms, whose nuclei have an odd number of protons, exhibit magnetic characteristics. Magnetic resonance signals and pictures have been created using these elements' protons' magnetic characteristics. The protons of the hydrogen atom, found in water and several other organic substances including lipids, fluids, cholesterol, etc., are the most prevalent of these in the human body [3].

Basic Principle of MRI Electromagnetic Radiation [4,5,6]

The hydrogen nuclei in the body align with the external magnetic field applied when a patient is positioned in the intense magnetic field of the MRI scanner. This alignment occurs when the body is subjected to brief radiofrequency (RF) pulses (Fig 1).

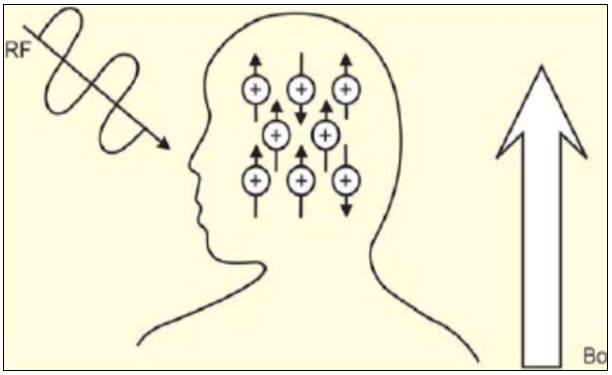

Fig 1: Alignment of hydrogen nucleus in the human body when placed in strong magnetic field

Then the hydrogen nuclei in the patient's body absorb its energy and then generates an MR signal. This process of absorbing energy is known as 'magnetic resonance'. which it forms the basics of MR imaging (Fig 2).

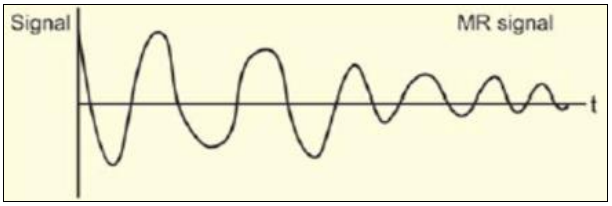

Fig 2: Energy of the generated MR signal

Components of MRI systems [7, 8]

1. The magnet, is a key component of the MRI machine. It is a part of the system, which also has the RF and the gradient system.
2. Power sources
3. a computing device
4. A technique for keeping records
5. The cooling unit
6. Camera for vigilance

Inside the magnet bore, a camera can be positioned to monitor a patient. To stop outside frequency waves from interfering with those used by MR equipment, the magnet chamber must be protected with a Faraday cage.

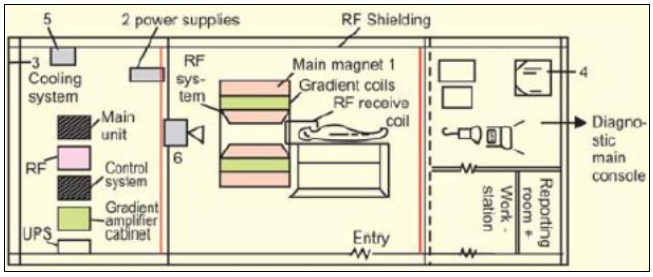

Fig 3: Systems of superconductive MRI system

Contraindications of the MRI and Patient Safety [9]

Due to the high magnetic field strengths used during an MRI examination, certain patients are unsuitable for imaging. These include patients who have:

- Aneurysm clips (Older Ferromagnetic types), Artificial heart valve and Brain aneurysm clips
- Cardiac pacemakers and Implanted neurostimulators or lead wires
- Patients with otologic implants and ocular implants
- Cochlear implants
- Metallic foreign bodies such as Electrodes, Hearing aids, IUD (Intrauterine Device), Joint replacements, Fractured bones treated with metal rods, metal plates, pins, screws, nails or clips, Bone or joint pins, Dentures, Wire sutures, Metal silvers in the eyes, Shrapnel and others.
- Insulin pump, Shunts and Harrington rod

Benefits of Magnetic resonance imaging [10]

- No known biological dangers
- Non-ionizing radiation
- Multiplanar imaging: Any oblique plane, such as the coronal, sagittal, or axial plane, can be used to acquire pictures.
- High resolution for soft tissues
- Better soft tissue characterization than CT due to the tissue's examination using T1, T2, and other sequences
- Imaging of blood flow
- A non-intrusive imaging method.

Disadvantages [11]

- High price
- Claustrophobia (fear of enclosed spaces). The frequency of MRI-induced claustrophobia has decreased as a result of the wider bore design used in current equipment.
- More time requires to image an individual who are extremely ill and show little cooperation
- Calcific lesions and cortical bone are difficult to see
- Requires a high level of technical expertise

The Indications of MRI [12, 13]

MRI stands for Magnetic Resonance Imaging and is based on the magnetic resonance of hydrogen protons.

MRI is an efficient imaging tool for soft tissue abnormalities, particularly modest contrast variations. Consequently, MRI outperforms CT scan in terms of displaying soft tissue disease. The MRI scanner can provide images of almost anything. With new technological advancements, the number of indications grows longer and longer. You can get a general concept of MRI applications by reading the outline that follows.

MRI Sequences [14, 15, 16, 17]

1. T1 weighted sequence
2. T2 weighted sequence
3. PD weighted sequence
4. Gradient & spin echo sequence
5. Fat suppression
6. MRI contrast
7. Diffusion- weighted image
8. In/out-of-phase

To differentiate between pathology and normal anatomy, contrast differences are necessary. When two nearby locations have high and low signal intensities, contrast is enhanced. Over 100 different MRI sequences exist, all of which aim to maximize tissue contrast. A T1 component and a T2 component are present in every MRI scan. The majority of each component may be turned off to produce a T1 weighted image or a T2 weighted image, respectively.

The proton density (PD) weighted picture has a unique shape. The number of protons per volume can be seen thanks to this sequence. The T1 and T2 components must both be turned off in order to accomplish this.

The list of several frequently used MRI sequences is below.

1. T1-weighted sequence
   The contrast in the image is mostly influenced by the distinction between the T1 relaxation periods of fat and water. White represents a high signal intensity (fat) and a low signal intensity (water) (black). The signal intensity of fat on a T1 weighted picture is very high in contrast to water, fat relaxes more quickly than that of water. Fat will recover from longitudinal magnetization more quickly because of its quick T1 relaxation period (Z axis). Water won't have completely recovered in the longitudinal plane when a second 90-degree radio frequent pulse is delivered. Following the second pulse, fat will deflect farther than water and produce more transverse magnetization. Only the transverse plane can accommodate signal processing and reception. More signal is received if the tissue has a higher transverse magnetization. Fat will contribute more to the final MRI image when radio frequent pulses are repeated and will consequently be shown as having a strong signal (white). Only a few structures have a high signal strength (= white) on a T1-weighted image: fat, blood, gadolinium (= contrast), melanin, and protein. T1-weighted images are typically used to examine normal anatomy (e.g., high-protein cysts). Additionally, specific MRI artifacts and accumulation disorders can exhibit a strong signal. On a T1-weighted imaging, collagenous tissue and water have lower signal intensities (ligaments, tendons, scars) (Fig 4).

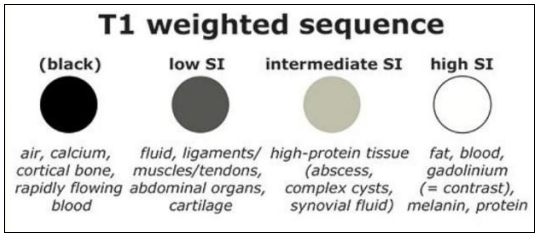

Fig 4: Signal intensities in T1 weighted image. Depending on protein content, the tissue may have an intermediate or high signal intensity (SI)

T1-weighted imaging's main goal is to see normal anatomy, especially in the musculoskeletal system (Fig 5). Beware of bone marrow oedema or bone marrow infiltration if the signal intensity of the fat-containing bone marrow, which is high on T1, is replaced by low signal intensity.

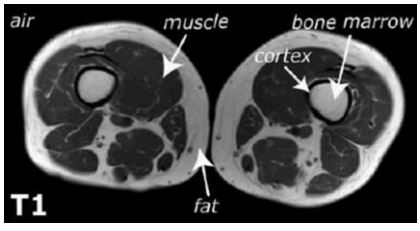

Fig 5: T1 weighted image in transversal direction of the upper legs. Normal Anatomy

2. T2-weighted image
   The high signal intensity of water is typical of a T2-weighted picture. A T2 sequence is excellent for detecting disease because oedema and fluid are frequently linked with pathology (fig 6). Additionally, air and calcifications exhibit extremely low signal intensities in T2, which is comparable to T1-weighted imaging.

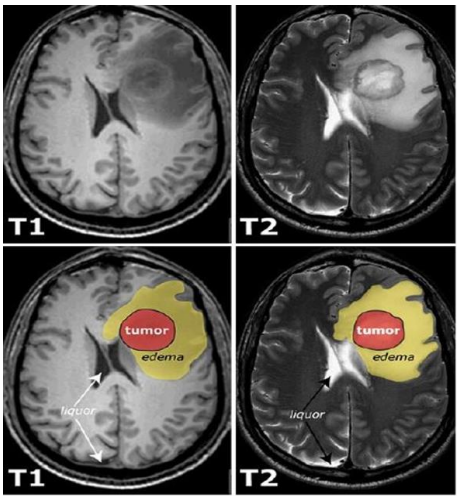

Fig 6: Brain tumour with surrounding (reactive) oedema frontoparietal left. Both the tumour and the oedema have high signal intensity on T2. PA diagnosis: lymphoma.

3. PD-weighted image
   The number of protons per volume is represented visually by the proton density (PD) weighted imaging. The T1 and T2 components are completely turned off to accomplish this. Tissues with a small number of protons have low signal intensity, whereas tissues with a large number of protons have high signal intensity. Although not as high as in a T1 weighted picture, fat exhibits a pretty high signal intensity. Instead of the high signal intensity seen in a T2- weighted picture, fluid displays a medium signal intensity. Meniscal tears in the knee are assessed, among other things, using a PD weighted image (Fig 7).
   A PD sequence can also be helpful in evaluating gray/white matter disease in brain MRI, for example. Reason: A PD distinguishes between gray and white matter with more clarity than a T2-weighted picture (gray matter has a higher signal intensity than white matter). On a T2-weighted picture, pathology and CSF are difficult to distinguish because both have a strong signal. On a PD-weighted picture, the contrast between CSF (medium signal intensity) and pathology (high signal intensity) will be better.

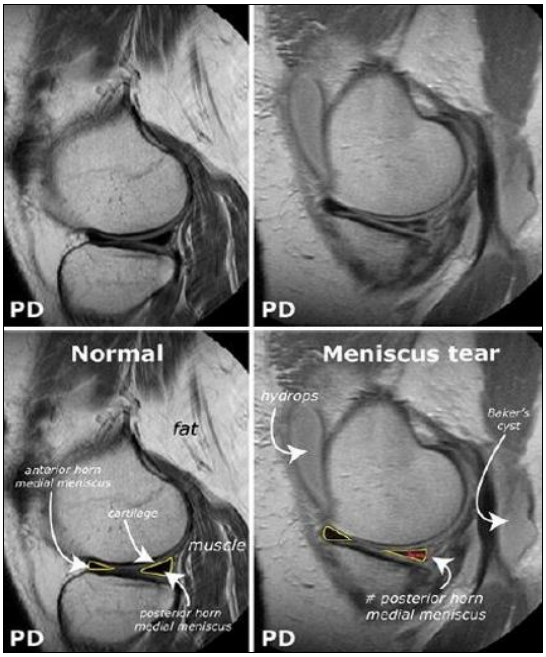

Fig 7: PD weighted image in sagittal direction of the knee in two different patients (at the level of the medial meniscus). Left shows an intact meniscus, at right there is a tear in the posterior horn of the medial meniscus. Note also that fluid (hydrops and baker's cyst) have intermediate signal intensity on the PD.

4. Gradient & spin echo sequence

The phrases "gradient" and "spin echo" are frequently used in relation to MRIs. It's significant that this method may be used to a T1, T2, or PD sequence. The gradient and spin echo techniques may be thought of as two sizable families with several variants. In conclusion, the gradient technique is utilized for angiography, brain, heart, abdomen, and functional MRI, among other procedures, and has a shorter scan duration than the spin echo approach. The gradient approach has a severe flaw in that it is susceptible to artifacts like blood's hemoglobin and prosthetic/osteosynthesis material. Another choice is the spin echo method.

Due to its multiple uses, the conventional spin echo was frequently employed. Fast spin echo (FSE) and single shot fast spin echo are modern variations of the spin echo that are quicker sequences (SSFSE). Now that the scan takes only a few minutes, there are less movement artifacts. Despite not being as quick (as the gradient), the spin echo technique is widely employed due to its superior image quality. The abdomen (using techniques like MRCP), pelvis (using urogenital imaging), and musculoskeletal system are commonly imaged using rapid spin echo sequences (especially in prosthesis material).

5. Fat suppression

One of the numerous possibilities for an MRI sequence is the suppression of fat tissue. It is advisable to muffle the signal from the fat tissue in almost all abdomen MRI scans. The vasculature and pathologies (high signal intensity!) contrast more sharply with the fat's generated low signal intensity. Making a sequence with fat suppression may be helpful while performing skeletal imaging as well. Fat seen in bone marrow can conceal bone marrow edema on a T2 weighted picture. To inhibit fat tissue, a variety of technological approaches are available. The STIR (short-tau inversion recovery) and SPIR (spectral pre-saturation inversion recovery) sequences are often utilized. Both pictures are T2 weighted. Additionally, the acronym FatSat, which stands for Fat Saturation, can be used to identify fat suppression (e.g., T2wFatSat) (Fig 8).

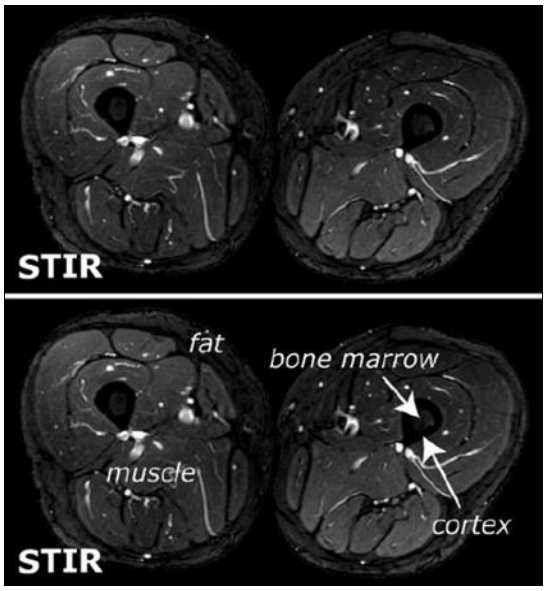

Fig 8: STIR sequence in transversal direction of the upper legs. Note also the good contrast with the vessels (fluid!)

6. MRI contrast

Common reasons for performing MRI examinations with contrast:

- Find lesions (abcess, tumor, metastasis)
- Histopathologic characterization (e.g., hepatic lesions)
- Vascular pathology imaging (also known as MR angiography)

Typically, a T1 weighted picture is coupled with a contrast series. As fluid is frequently linked to disease, the combination of contrast and a T2 weighted picture is of limited use (Note: both fluid and contrast have high signal intensity). Contrast agents come in many different varieties. Gadolinium is a widely used contrast agent (Gd). Due to its paramagnetic characteristics, gadolinium shortens the protons' T1 relaxation time, which helps them absorb contrast. Therefore, these protons will have a stronger signal (whiter). Other types of contrast media are utilized besides gadolinium (e.g., the liver-specific contrast agent Primovist). They are only applied when necessary. A series before and after contrast should be taken in order to properly assess enhancement.

Below is an example of a brain tumor (Fig 9) and an example of a classic enhancement pattern of a hepatic hemangioma (Fig 10).

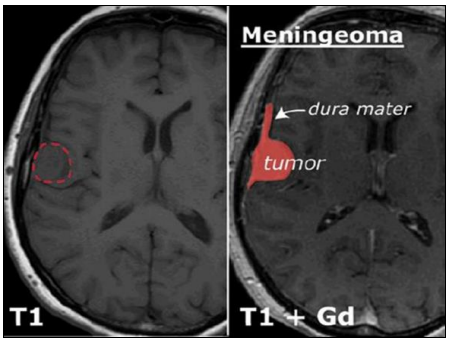

Fig 9: Tumor in the right hemisphere, with good visualization after gadolinium administration. The tumor originates in the duramater. PA diagnosis: meningioma

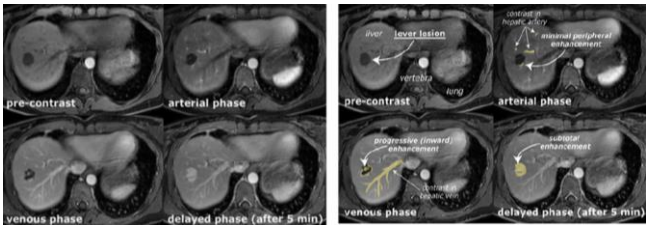

Fig 10: T1 + Gd sequence: Liver series in the transversal direction. The images show the typical enhancement pattern of a hemangioma (slow progressive filling with contrast from the periphery)

7. Diffusion-weighted image

Currently, diffusion-weighted imaging (DWI) is crucial in radiology. Diffusion refers to the Brownian motion, or the random movement of molecules inside a material. In a relatively quick approach called diffusion weighted imaging, the diffusion behavior of hydrogen molecules is assessed under various field intensities. The resulting diffusion pictures are T2-weighted images. Among other factors, the amount of proton motion relies on:

- The tissue's cell density: numerous vs. few cells (in cell-rich tissue there is relatively lower diffusion)
- The cellular membrane's integrity. The cell membrane's ion pump will malfunction in an infarction, causing ions and water to remain inside the cell (resulting in cytotoxic oedema). As a result, there will be an increase in intracellular pressure and a decrease in intracellular diffusion.
- Fluid obstruction; big vs tiny molecules. Large molecule tissues have comparatively lesser diffusion.

Signal loss in DWI happens when protons may travel freely and diffuse away as a consequence. For instance, the CSF exhibits this. Background: the proton needs to receive two pulses in order to receive a signal. Signal loss will take place if the proton doesn't get the second pulse (since the moving proton is now in a different position). Proton mobility is restricted in decreased diffusion (also known as diffusion restriction), which is shown on DWI by a high signal intensity. This can be observed in diseases like inflammation and cytotoxic edema.

DWI is a strong T2 weighted image, which is significant. Recall that high water content tissues exhibit high signal intensity on T2 weighted images. We must eliminate the T2 impact in order to confirm that tissue diffusion has been decreased. In order to do this, a quantitative computation of diffusion—the so-called ADC map—is constructed (apparent diffusion coefficient). The ADC map generates reversed pictures while filtering out the T2 effect. When the tissue exhibits high signal intensity on DWI and low signal intensity on ADC, diffusion is decreased (Fig 11, 12).

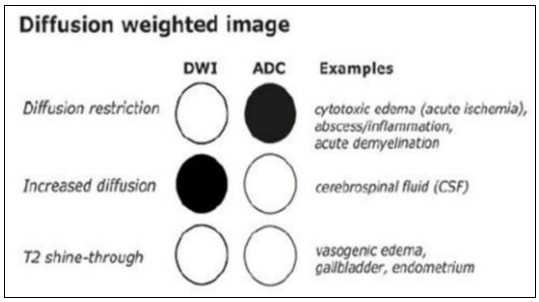

Fig 11: Signal intensity of DWI and ADC in diffusion restriction, increased diffusion and T2 shine - through

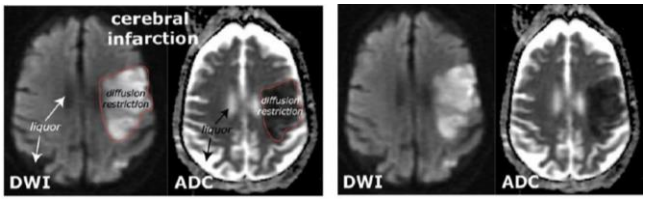

Fig 12: Diffusion restriction secondary to cytotoxic edema in an infraction in the left hemisphere (middle cerebral artery territory). The DWI has high signal intensity and ADC low signal intensity. Note also the (physiologically) increased diffusion of the CSF.

Diffusion limitation may also arise in tumors that are cell-rich in addition to the previously mentioned pathologies (including epidermoid and lymphoma).

It is a useful tool for differentiating between acute and chronic ischemia, as well as between pus from an abscess and tumor necrosis. Diffusion limitation does not imply that disease is always present. For instance, diffusion restriction will be present in the myelum, testicles, stroma of the ovaries, spleen, lymphatic nodes, and red bone marrow.

It is unclear why these tissues move less than other tissues, but high cellularity may play a role. Recent years have seen intensive studies into novel diffusion weighted imaging applications to identify and define disease (e.g., in prostate carcinoma). It may also serve as a further tool for assessing the impact of therapy on malignancies; for example, decreased tumor cellularity following therapy may result in decreased diffusion restriction.

8. In/out-of-phase

A gradient sequence called an in/out-of-phase is utilized to find tiny fat within a lesion or organ. It is utilized in particular to assess liver fatty infiltration and adrenal tumors (fat-containing adenoma vs. adrenal cancer).

Background: A phenomenon known as a chemical shift artifact may result from a tiny discrepancy in the Larmor frequencies of the protons in fat and water.

The in-phase sequence and the out-of-phase sequence are the two halves of the series. The protons of the water and fat have exactly the same phase when reading the signal on the in-phase sequence (despite the slight difference in Larmor frequency). Since the protons are in phase, a signal is produced. When the protons of the water and fat are not exactly in the same phase, the signal in the out-of-phase sequence is read at a specified different time. Signal loss eventually results from this (Note: the protons are out-of-phase).

A fat-containing adrenal lesion, for instance, exhibits high signal intensity during the in-phase sequence and low signal intensity during the out-of-phase period (Fig 13).

Therefore, the in/out-of-phase sequences may be used to identify tiny fat within a lesion. Information on a tumor's fat content might aid in the differential diagnosis.

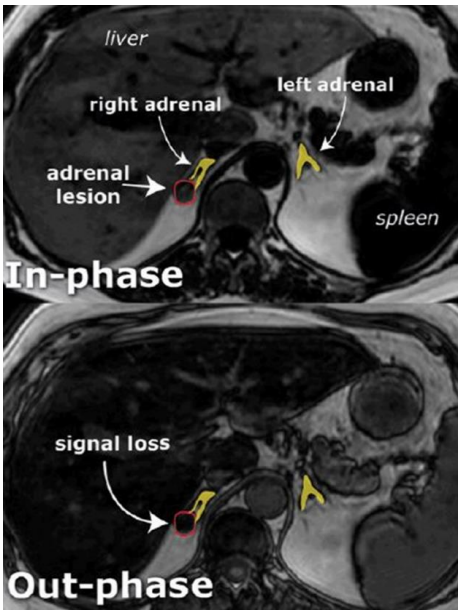

Fig 13: T2 weighted image and in/ out-of-phase of the abdomen in transversal direction. A spherical mass originating in the right adrenal can be seen on the T2 weighted image. As compared to the in- phase, signal loss of the lesion occurs on the out- of -phase series, a sign of microscopic fat. Diagnosis: high- fat adrenal adenoma. Coincidental fnding: note also the buildup of fats in the liver (fatty liver).

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