Biointerface Research in Applied Chemistry
Open-Access Journal (ISSN: 2069-5837)

Review
Volume 13, Issue 3, 2022, 288
https://doi.org/10.33263/BRIAC133.288

Recent Advances of Magnetic Resonance Imaging in the Diagnosis of Spinal Cord Injury

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Scopus Author ID 35417390100
Received: 22.10.2021; Accepted: 21.11.2021; Published: 10.07.2022

Abstract: Magnetic Resonance Imaging is one of the diagnostic processes being employed in the medical field for monitoring the physiological processes and anatomy of the body. The circumstantial images of organs and tissues of the body are attained by availing the colossal magnets and radio waves. A huge surge of medical investigation in radiology detects the potential diseases and health disorders in the living body. In contrast to CT scans and X-rays, they are the safest diagnostic machine as they avoid the noxious potential to permeate the body tissues. It is becoming more prominent in clinical practices owing to the ease of availability and extremely cost-effective way of examining the erroneous conditions of the body. The review enlightened the history, classification, principles, applications, limitations of its use, and investigations of genetic damage by the prolonged exposure of disrupting frequency radio waves on exposure to in-vitro and in-vivo cells. MRI is the most efficacious and developed imaging system, and further advances in 3D imaging will increase their application even further.

Keywords: diagnostic machine; cost-effective; genotoxicity; magnetic field; Rf waves.

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1. Introduction

MRI is an inoffensive system of monitoring the interior structure and studying all the characteristic functions of the living body. The electromagnetic radiations are non-ionized and do not cause any health-related issues due to exposure to radio waves. The three-dimensional and finest quality images of the body part in the plane are produced by the use of radio frequency in the presence of applied magnetic fields. Patients are placed in the machine containing large tube-shaped magnets and generate extremely strong magnetic fields, resulting in the alignment of nuclei of atoms and hydrogen along the external magnetic fields [1]. The body's energy liberated is detected by using RF signals for imaging purposes. Formerly introduced with a simple technique, MRI has been developed into the potential analytical approach for various clinical problems within a period of approximately 30 years. In 1952, Bloch and Purcell were the first to get the Noble Prize in 1956 for operating this machine for the first time in 1946 [2,3]. It is one of the persuasive diagnostic techniques, and the first images of the organs were taken in Nottingham and Aberdeen in the year 1980 [4-5]. Carret *et al*. was the first to use gadolinium compound as a contrast agent for visualizing the internal organs [6]. The history of MRI is discussed given in (Table 1).

Table 1. The History of MRI.

Year	Achievements	References
1857-1952	Joseph Larmor gave the Larmor relationship.	[7]
1930	Isaac Rabi determined the magnetic moments of the nuclei, atoms, and molecules' rotation strength.	[8]
1946	Bloch and Purcell gave the working phenomenon of MR experimentally.	[9]
1952	Bloch and Purcell were awarded by the noble prize for physics.	[10]
1950,1960 1970	NMR progressed as an analytical approach.	[7]
1972	Computerized Tomography came into existence.	[7]
1973	Lauterbur gave the phenomenon of Back projected MRI.	[7]
1975	Ernst determined the Fourier Imaging.	[7]
1977	Mansfield gave the phenomenon of the imaging by Echo-planar approach.	[11]
1980	Edelstein demonstrated FT MRI.	[11]
1986	The concept of Gradient Echo Imaging and NMR Microscope came into existence	[8]
1987	Dumoulin demonstrated MR Angiography	[7]
1991	Ernst received the Nobel Prize	[12]
1992	The Functional MRI get determined	[7]
1994	Hyperpolarized 129Xe imaging progressed	[7]
2003	Lauterbur and Mansfield awarded by Nobel Prize	[7]

2. The Basic Magnetic Resonance Physics

Atoms contain neutrons, protons, and electrons revolving around the nucleus. The atomic number of an atom is the sum of protons and neutrons. Nuclear spin is one of the properties of the nucleus. The physics of magnetic resonance imaging is illustrated in Fig. 1.

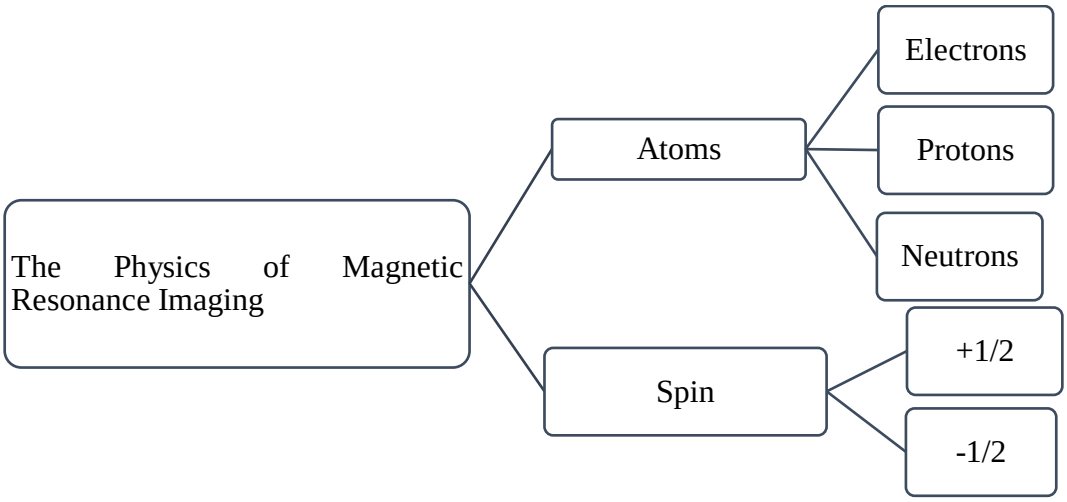


Figure 1. The basic physics of MRI comprises atoms, including electrons, protons, and neutrons, as well as spins state constituting clockwise and anti-clockwise spins.

When the atom is being placed in the applied magnetic field (B_0), the particle absorbs the particular frequency (ν) of photons. The gyromagnetic ratio on which the frequency depends is denoted by $\nu = \gamma B$, $\gamma = 42.58$ MHz / T (for hydrogen).

The nucleus with spin number is preferred for the magnetic resonance imaging as in the applied magnetic fields, and the spin will act as small magnets with two poles, north and south poles, respectively.

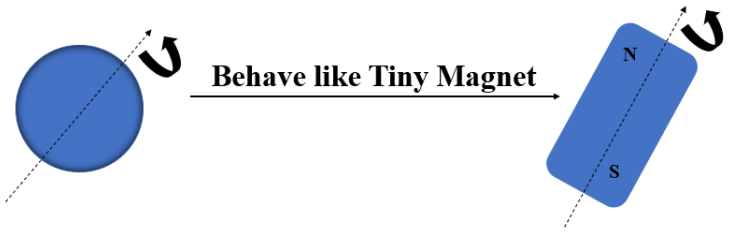


Figure 2. The spinning of the nucleus about their symmetry axis, a spinning charge producing a magnetic field

The arrows' direction of the nucleus spinning on their axis gives information about the direction of the magnetic field, whether clockwise or anti-clockwise. Nuclei with a spin are subjected to the short pulses radio frequency wave where the static magnetic field (B_0) lies at an angle of 90° to the transient magnetic field (B_1). The energy absorbed by the nucleus causes its excitation and relaxation from a higher energy state to a lower energy state and vice versa. This absorption and emission of radiation produce voltage that can further be measured and analyzed as free-induction decay (FID). The system will attain a state of thermal equilibrium in the absence of RF waves. In the characteristic magnetic field, each nucleus tends to resonate at a particular frequency. The difference in energy between two levels of energy state (higher energy level and lower energy level) is directly proportional to the subjected magnetic field (B_0) of the nuclei [13- 15].

$$\Delta E = \gamma h B_0 / 2\pi$$

h= Planck's constant; ΔE= Energy differences; B_1= transient magnetic field; B_0= static magnetic field

There is no direct alignment of the north and south poles of the nuclei with that of the external magnetic field direction. The spinning proton axes showed a slight tilt in their oscillation and are parallel to the flux of an applied magnetic field [16]. The tilting phenomenon of the nuclei is known as precession. The resonate frequency/Larmor frequency directly depends upon the precession rate. The hydrogen nuclei have the Larmor frequency of 42.58 MHZ when applied, and the magnetic field is 1 Tesla, which is 1000 times the earth's magnetic field. The MR imaging has a magnetic field strength of 1-4.0T [16].

The following equation gives the Larmor equation

$$F = r B$$

F = Larmour frequency; r = gyromagnetic ratio; B is the externally applied magnetic field

There is the formation of two spin states, one with the direction of the applied magnetic field (spin in the upward direction) and another opposite in the direction of the external magnetic field (spin in the downward direction), causing the formation of weak magnetization vector as shown in Fig. 2. When the hydrogen nuclei of the tissues of the living body experienced the RF waves, aligned themselves in the Z-axis due to the static magnetic field as a result of all protons in the tissues with same larmour frequency to that of the absorbed electromagnetic radiations shifted away from the direction of imaging magnets. As long as the RF pulses applied more is, the rotation angle of protons of the nuclei. If the RF pulse is of normal duration, then the magnetization vector will be rotated in the XY plane perpendicular to the Z-axis, and the hydrogen atoms show the flipped angle of 90^0 [17]. The signals detected depend upon the bonding of protons in molecules as the protons of the bones give weak signals due to strong interactions of hydrogen atoms [18]. The behavior of protons of hydrogen is shown in Fig. 3.

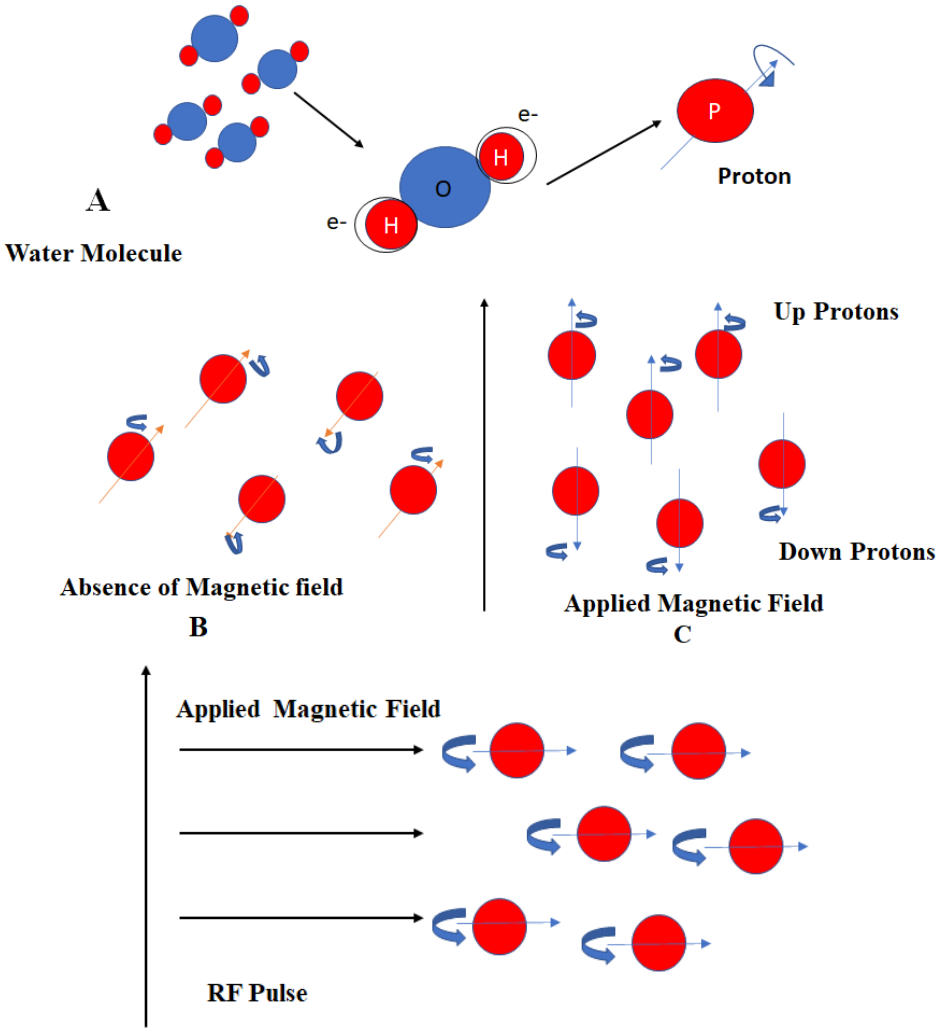
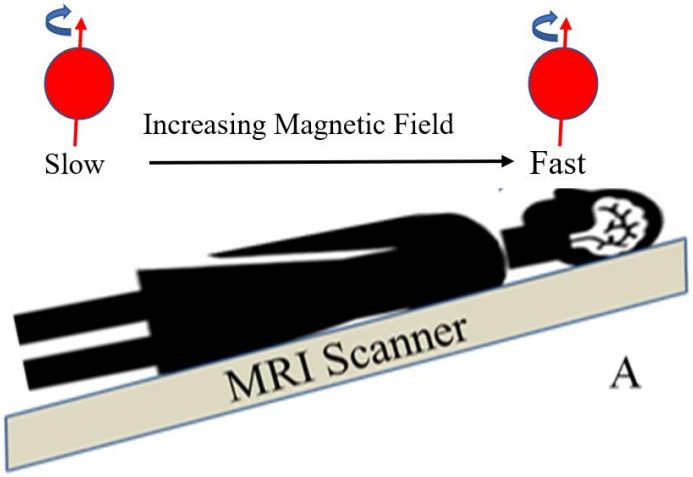


Figure 3. Protons behavior in External magnetic field. **(A)-** Water has one oxygen atom and two molecules of hydrogen atoms. The hydrogen nucleus has one proton (P+) that spins on its axis and behaves like tiny magnets. **(B)-** In MRI Scanner, the protons of the water aligned themselves in the direction of the applied magnetic field; some rotated in the clockwise direction (up) protons and anti-clockwise direction (downward direction). The total magnetic fields generated by protons cancel one another while the extra "up" protons result in a small proportion of the magnetic field measured by MRI scanner. **(C)-** When the frequency of RF pulse matches with the precessional frequency of protons, the up protons absorb the RF energy and flip away from the applied magnetic field.



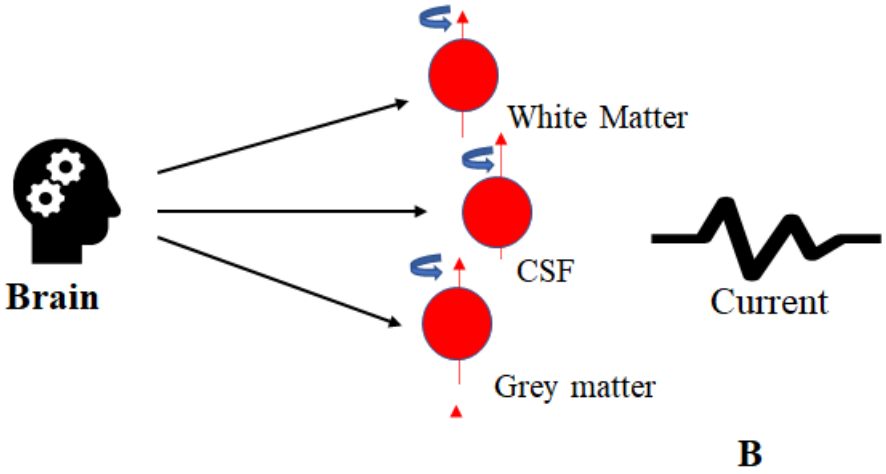


Figure 4. Focusing on the MRI scan of the brain, revealing the different amounts of energy liberated by white matter, CSF, Grey matter. **(A)** In the presence of an applied magnetic field, the protons in the foot spin slower than the protons present in the brain. **(B)** The brain's tissues, that is, cerebral spinal fluid, white matter, and gray matter, produce different amounts of energy. The brain tissues connect with each other and communicate with each other. The coil is placed around the head to measure the amount of energy given to the brain's protons when RF pulses are cut off.

3. Contrast Agents of Magnetic Resonance Imaging

The pharmaceuticals used in examining magnetic resonance imaging are known as contrast agents for MRI. The contrast agents are water-soluble and classified based on various features shown in Fig. 5. Afterward, they are classified based on magnetic properties such as paramagnetic or superparamagnetic agents.

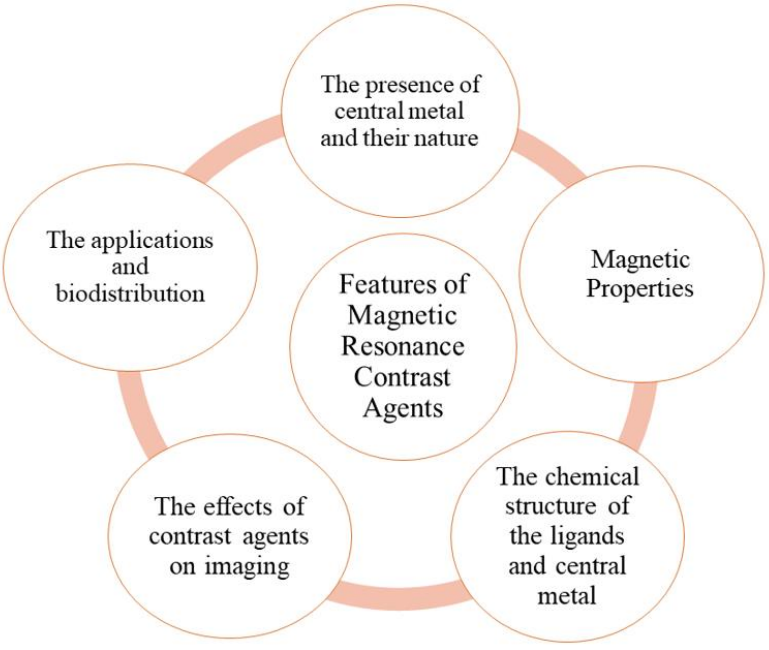


Figure 5. Features of resonance contrast agents tend to be in mind while choosing the contrast agents for MRI scanning.

3.1. Paramagnetic agents.

The paramagnetic agents are compounds with unpaired electrons and own the magnetic dipole moment. The free radicals in organic compounds also possess the dipole moment due to the presence of unpaired electrons. The magnetic interaction occurs between the magnetic

moments of the nearby hydrogen of the water molecules and the magnetic moment of the paramagnetic atom in the aqueous solution. The random fluctuations created by the molecular motions in the magnetic dipolar interaction decrease the transverse (T_2) and longitudinal relaxation times (T_1) of the water molecules' hydrogen. The magnetic resonance contrast agents Gd^{3+} (Gadolinium) and Mn^{2+} (manganese) are some of the examples of paramagnetic ions that decreased the relaxation times of both T_1 and T_2. They have a low relaxation rate because of the presence of many unpaired electrons. Gadolinium ions cannot be used as a contrasting agent as it causes toxicity due to their accumulation in the spleen, liver, and bones. Gd^{3+} is not stable in the physiological pH as it undergoes hydrolysis and produces $Gd(OH)_3$, which is insoluble. So, to use these ions, metal ions (chelates) are needed to render high stability, safety, and better distribution of these drugs. The contrast agents lower the relaxation time of nuclei of the desired tissue, and their effectiveness is checked by the relaxivity values (r_1 and r_2) that tell their efficiency in reducing the relaxation time (T_1 and T_2) of water hydrogen per unit metal ions concentration (mM) respectively. In the case of tumor cells, excess intake of contrast agents resulted in detailed pictures of the tissues as these cells are different from normal cells [19-21].

3.2. Superparamagnetic agents.

They contain the materials such as the colloidal forms of iron oxides with a diameter between 5–200 nm in suspension and small crystallites in size 1 to 10 nm possessing a number of magnetic ions. The temperature lower than Curie temperature can change the magnetization direction of the crystallite but cannot affect the coupling forces experienced by the neighboring atoms. The fluctuations of the magnetization direction resulted in the changes of the internal magnetic field to zero. The behavior of superparamagnetic material is the same as that of paramagnetism, with the expectation that the applied magnetic field influences every single atom. The crystallite magnetic moment shows the alignment of the external magnetic field. The crystallites are non-stoichiometric iron oxides which further are of three types: (i) Ultra-small superparamagnetic iron oxide possessing a diameter less than 50 nm; (ii) Small superparamagnetic iron oxide possessing a diameter less than 50 nm; (iii) Larger micron-sized particles of iron oxide possessing a diameter of many microns.

The larger particles are taken orally to capture the images of the gastrointestinal tract and do not administered through the intravenous route as they are gathered in the lungs' alveoli. In contrast, the former two are taken intravenously. The small superparamagnetic iron oxide found its application in negative contrast for taking pictures of the liver. The particle with less than 300nm remains in the blood for longer. The Curie relaxation theory explained the superparamagnetic particles' relaxation caused by the superparamagnetic particles [22]. This theory depends upon the relaxation rate of protons of water molecules diffusing nearby the surrounding unpaired electrons and contributes to the magnetization of the particles. These agents showed powerful relaxation effects (T_1) and gave rise to a local magnetic field that is strong enough and increases the T2 relaxation effects. This theory showed that the ratio of r_2 and r_1 (r_2:r_1) depends directly on the particle size as the best T_1 shortening agents are smaller particles compared with larger particles. Due to the drawbacks of the large-sized particles, such as high magnetic moment, the small size particles act as negative contrast agents due to the formation of dark pictures in MRI images. Furthermore, the ultra-small superparamagnetic particles with diameters less than 10 nm showed good T_1 increasing properties [23].

3.3. Susceptible agents.

At the macroscopic scale, T_2 and T_2* relaxation properties are dominated by the long-range interaction for all kinds of contrast agents. This relaxation mechanism is linked with the contrast agent's magnetization due to the partial alignment of the magnetic moments towards the magnetic field interactions. When contrast agents get assembled in the blood vessels, Kupffer cells and other parts of the body become compartmentalized, and the compartments loaded with contrast agents behave as the secondary contrast agents. The compartment containing protons of water molecules at their outer sides gets affected by the internal magnetization of the bulk materials inside the compartment; hence, the outer-sphere mechanism gets relaxed. The ratio of T_2 and T_2* (T_2/T_2*) relaxation properties affects the oxygen level of blood because of the paramagnetic nature of the colored pigment present in the blood erythrocytes and one of the basic principles of MRI. These effects vary with the concentration, magnetic moments of the contrast agents, compartment's dimensions and geometry, and the water diffusion constant, etc.

4. Pathophysiology of Traumatic Spinal Cord Injury

The external forces could result in serious spinal cord injury leading to the death of the cells at the injury site and also causing secondary injury in which tissues get damaged by the intricate mechanisms. The primary injury caused vascular damage and hemorrhage, edema, and ischemic changes. The inflammation at the injury site occurs with the rise of neutrophils and macrophages [24]. Furthermore, the deaths of oligodendrocytes and demyelination occur with the neuron's necrosis. Cavities are formed at the lesion level when the damaged cells are removed by macrophages [25]. There is a formation of the glial scar by astrocytes, and at the site of injury, there is a formation of collagenous fibrosis.

Furthermore, schwannomas replace varying amounts of tissues of the spinal cord as there is an arrival of peripheral types of remyelination through Schwann activity of the cell [26]. Moreover, the lipid peroxidation, excitotoxicity, and unstable free radicals resulted in the cells' further death, leading to the initial trauma. The spinal cord injury also leads to local neuronal damage and progressive neural tracts at the distant area from the lesions for several years [27]. The degeneration spreads in retrograde and anterograde directions after the spinal cord injury. The axonal changes cause the acute phase's degeneration triggered by increased calcium levels intracellularly [28]. The degeneration occurs by slow myelin degradation and continues for several years after the initial trauma. The spinal cord becomes atrophic after the spinal cord injury. The secondary degeneration reaches the cerebral regions, and there exists evidence of corticospinal neuron atrophy after the spinal cord injury [29]. The thickness and grey matter volume of the sensorimotor cortex and corticospinal tract volume of the white matter reduces after the injury [30]. The changes in the structures were observed in the first year of the injury, and after 6 months, the atrophy rate decelerated in the region of the cranial CST [31]. Despite any external force, pathological processes cause damage to the spinal cords like spondylotic myelopathies, neoplastic diseases, metabolic conditions, and congenital disorders [32]. Moreover, the treatment of spinal cord injury requires the classification of spinal cord injury in non-traumatic, traumatic, and acerbity of the injury form for the rehabilitation and recovery of the patients [33]. Spinal cord injury causes partial or total sensory or motor deficit [34].

Furthermore, a neurological examination was done to check the magnitude of the injury and the damages to the sensory or motor function. MRI diagnosed the injury site and evaluated the repercussion of trauma on the spinal cord diameters [35]. MRI can detect spinal cord injury and soft tissue abnormalities easily [36]. The MRI possesses good contrast resolution, negligence of bony artifacts, multiplanar capabilities, and pulse sequence choices and gives clear images of spinal trauma [37]. In the condition of spinal cord edema, ischemia, and hemorrhage MRI also acts as a prognostic indicator [38].

5. Prediction of Spinal Cord Injury Outcomes by MRI Findings

In roughly two-thirds of instances, spinal cord injury (SCI) is situated in the cervical spine. As a result, cervical trauma is a significant source of stress and long-term impairment [39- 40]. Historically, predictive studies in SCI have concentrated on using early clinical characteristics to predict neurological prognosis. A variety of problems, such as limited scanning rates, limited spatial resolution, and the difficulty of maintaining patients throughout extensive scans, hampered initial MRI usage for such injuries. With subsequent advancements, MRI has become the standard method for diagnosing severe spinal injury [41]. It has high contrast resolution, computed tomographic capabilities, and can correctly detect spinal damage with different pulse sequences. The MRI has become a crucial tool in displaying bleeding, contusion, cord edema, stenosis, and harm to vertebral bodies, including paraspinal tissues, as the amount and amount of trauma have become more easily identified. The predictive usefulness of MR scanning in spinal injury, on the other hand, is much less apparent [42]. Several writers investigated the relationship between the degree of SCI represented by the MRI and the person's neurological prognosis[43-45]. This study aimed to determine the predictive significance of characteristics found on MRI done immediately after a severe cervical spinal cord injury in respect of neurological prognosis. Two prospective investigations [13,16] and two observational studies [46] with a total of 319 patients looked at the effect of cord edema and duration of edema on neurological prognosis.

According to Miyanji *et al*. [43], the occurrence of cord edema was more commonly linked with full SCI and was directly proportionate to the extent of the damage (P0.001), though it wasn't indicative of neurological prognosis or recovery. Boldin *et al*. [45] investigated the neurological restoration prognostic validity of MRI findings in 29 individuals having acute cervical spinal injury over a 35-month period. They found spinal cord edema in all (n=29/29) of the patients. (P=0.001). The length of edema was the only predictor of SCI retention. Each millimeter increase in edema length resulted in a higher chance of preserving a full SCI (P=0.017). Martinez-Perez *et al*. [46] investigated Imaging prognostic variables in the context of chronic cervical illness in 86 patients with a diagnosis and a one-year follow-up. They discovered that edema lengths more than 36 mm were significantly (P=0.006) related to poorer neurological performance on the ASIA scale, defined as a general decline of at least one “point on this scale.

5.1. MRI extradural findings

Rao and Fehlings [47,48] noted a dearth of research that tried to estimate the level of spinal canal impairment or spinal compression in severe cervical spinal injuries in an evidence-based literature review. Hayashi *et al*. [49] studied the extent of nerve compression at the site of maximal damage in 31 individuals having cervical SCI using MRI. Moderate spine

compression was characterized as an anteroposterior cord dimension greater than two-thirds of the chord diameter there at C_1 level. Acute cord constriction was defined as a posterolateral cord diameter of only about two-thirds of the total chord diameter. Compared with individuals with modest cord compression, the total motor deficiency was greater in individuals with severe tissue destruction (20 percent). Yamazaki *et al*. [50] investigated the parameters determining the outcome of damaged central spine syndrome using only a CT evaluation of the anterior thickness of the spinal canal. They concluded that a greater canal diameter was related to improved neuronal loss. According to Aarabi *et al*. [44], the greatest predictors of protracted neurological rating improvement were arrival ASIA movement score (P=0.003), MCC % (P=0.02), and sagittal cervical width at the moment of maximal stenosis (P=0.02).

5.2. MRI intradural findings.

The clearance of spinal cord edema following SCI with repeated MRI scans has traditionally been described in the studies [50]. Martinez-Perez *et al*. [46] discovered that edema more than 36 mm in diameter was significantly (P=0.006) linked with a poorer cerebral outcome. Tewari *et al*. [51] discovered that patients with minor cord alterations on MRI had the greatest results, followed by individuals with cord edema. Patients who suffered from bleeding and injury had the poorest results. The intradural variables of cord edema length, the existence of intramedullary hemorrhage, and its duration were shown to be significantly linked with neuropsychological outcomes. We urge that participants with chronic cervical illness get an MRI as promptly as feasible (and as their circumstances allow) for not only the clinical techniques but also the extra diagnostic evidence that it provides, described herein.

Finally, the necessity for the standardization of trauma quantification and assessment in the perspective of pre-operative mortality in patients referred has long been urged. Still, no clear prognostic knowledge has been supplied. The significance of the pathophysiological explanation of cord edema in SCI has been acknowledged. Furthermore, the registration of spinal cord edema in debilitating conditions is still debatable, both from the perspective of surgical justification and the impact of postoperative cord alterations. Neuroradiological and clinical examination and an appropriate morphological and pathophysiological evaluation can inspire anterior and posterior decompressive operations either with monitoring or fusion [52–55].

6. Challenges for the Applications of MRI Scanning in Human Spinal Cord

The challenges to the uses of MR spectroscopy in the detection of human spinal cord injury hindered its utilization in clinical practices as the signal-to-noise ratio gets reduced due to the powerful susceptibility changes associated with anatomical tissue heterogeneity, including muscle tissue vertebral bodies, and CSF all over the spinal cord. While the reduced diameter of the spinal cord, even less than 1 cm in the cervical and thoracic cord, results in decreased signal-to-noise ratio and inexplicit amount of metabolites. The signal-to-noise ratio is also affected by the distance from the required region to the receive coils. Greater will be the distance of interest and receive coils; lesser will be the signal-to-noise ratio. Furthermore, the CSF flow occurs by the arterial pressure waves transferred by the contraction of the brains due to the fixed quantity of volume in the skull to the CSF, further decreasing the spectral quality. The spinal cord-induced motion is not critical as the transversal displacement occurred in the site of interest near about 0.6 mm in the anteroposterior direction. Another problem MRI faces

is subject motion as the dimensions of the voxels are in millimetres and gets maximized and include maximum spinal cord tissue for a better sound-to-noise ratio. The motion of patients in the millimeter ranges that is not, considering the long scanning times required for spectroscopy, moves the position of the voxels out of the spinal cord. The reduction of sound to noise ratio occurs due to the spectral contamination by the resonance of lipids, muscles, or bone marrow. Pathophysiologic changes, the subject motion of anatomic variability of the properties of electromagnetic tissues affects the transmit field and alters the localization profiles and sound-to-noise ratio. The smaller size of the spinal cord, the more metabolites excitation volumes occur out of the spinal cord, which further minimizes the measurement errors in relation to metabolite concentrations [56].

7. Magnetic Resonance Imaging of Injured Spinal Cord in Spinal Trauma

The extent of subsequent neurological problems and deficiency is influenced by the extent, severity, and degree of injury, which can significantly negatively impact these patients' life rate and efficiency [57]. In the event of an emergency, patients must receive immediate imaging following basic resuscitation. MRI is reserved for patients with spinal cord dysfunction, symptoms that can only be characterized by the radiography findings, or an absence of a convincing neurologic assessment [58,59]. MRI plays an important role in assessing spinal injuries because it detects soft tissue, bone marrow even spinal cord irregularities that all other detection methods may be detected. Timely screening allows for appropriate immediate diagnosis and quick treatment [60]. MRI provides an advantage in identifying neural and extraneural ailments such as spinal cord edema, epidural hematomas, spinal cord edema, contusion, bleeding, ischemia, and disc herniations. This seems to be due to the increased multiplanar capabilities, contrast sensitivity, and diverse pulse durations, which make it an excellent technique for detecting spinal injuries [61]. Nonetheless, because of the non-specificity of signal intensity changes that do not match precisely with unpredictable metabolic responses, traditional MRI is limited in providing optimal information on the integrity of the spinal cord tissue. That explains why standard MRI results have a poor association with neurological and functional problems in many spinal cord diseases. As a result, it is critical to employ newly designed MRI patterns for the most accurate assessment of the damaged spine, including the spinal cord [62,63]. Another use of DTI is diffusion tensor tractography, which offers a 3-D representation of diffusing the white matter mostly in the orientation of fibers [64].

MRI was recommended to check for any abnormalities in the spinal cord after injury. The study was done in 30 patients where the MRI revealed abnormalities in about 76.67%, while in others, no abnormalities were detected by MRI scanning. The purpose of the study is to evaluate the integrity of spinal cord fibers in a patient with spinal trauma by the mean of diffusion tensor MRI. They revealed nearly 90% of abnormalities in patients with spinal trauma and detected the spinal cord white matter fibers structural changes in an injury of the spinal cord [65].

8. Pathogenic Features and their Role in MRI

Magnetic resonance scanning (MRI) is used in diagnosing patients suffering from spinal trauma and is highly sensitive in detecting acute spinal cord and soft tissue injuries. MRI techniques for spinal trauma diagnose many patients in an emergency, so physicians should be

familiar with the findings of MRI in spinal trauma [66]. In the discussed Table 2 about the injury and role of MRI in particular conditions

Table 2. Injury and Role of MRI scanning.

Injury	Role of MRI Scanning
Ligamentous injuries	1. Differentiates the unstable injuries from the stable ones. 2. It differentiates the complete (ligaments discontinuity) and partial shear (abnormal signals). 3. Differentiates the unstable injuries from the stable ones.
Herniations and damages Disc	1. The abnormalities in the disc signal detections due to traumatic herniations 2. Early detections needed as the undetected disc herniations can even worsen the cord injury.
Medullary hemorrhage	1. The range of hematoma are detected by MRI, which helps in surgical planning. 2. It also detects the extradural hematoma that causes compression of the cord.
Vascular Injury	1. Diagnosis of arteries injury possible
Cord injuries	1. Diagnosis of non-hemorrhagic and hemorrhagic cord injuries by MRI scanning
Malignant vs. Benign fractures	1. Evaluation of spinal trauma. 2. Abnormal cord signals with hemorrhages get visualized. 3. Differentiate between malignant and benign fractures by MRI possible

9. Technological Advances in MRI Imaging

With the advances in computers, physics, engineering, and material sciences, MRI have become more advanced; hence, their technical capabilities have been increased Fig. 6.

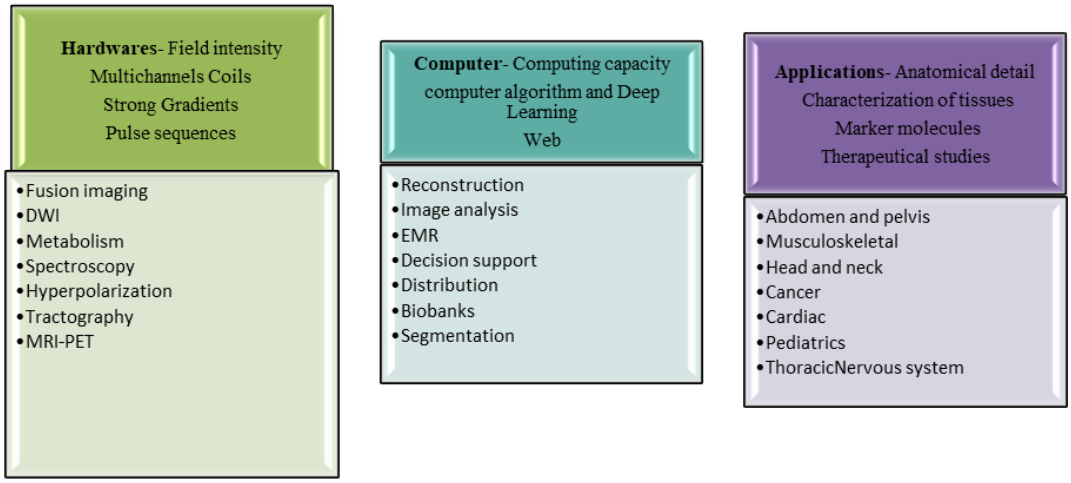


Figure 6. Advancement in MRI technology with a wide range of applications in various fields.

Though highly advanced technologies, including single-atom imaging and very high field anatomical imaging, draw the attention of many, there is a multitude of development in MRI pictures. Improved quality of images and tremendous resolution power of MRI transpires due to the development of MRI pulse sequences and hardware employed for MRI with ultra-high field strengths, advanced coils, and powerful gradients. As used earlier, the coils employed for imaging are flexible printed, phased array or blanket coils rather than bulky cage-like coils [67]. Along with high image quality, functional MRI has been enabled in today's era, such as vascular mapping, both the morphological and biological information of the brain and cardiac imaging. Engineers have to lead to the development of an open and wide bore magnet that helps in surgeries and obliging claustrophobic patients. MRI takes very less time to take images of bodies' organs and tissues; as a result, they render comfortability to the patients and can take pictures of the more delicate organ such as the heart, joints, and muscles. Advanced technologies such as parallel imaging, Fourier reconstruction, non-Cartesian sampling, and compressed sensing have been employed to capture images even faster. Artificial intelligence and computer abilities play an important role in MRI acquisition. AI-based image has improved

the quality of images, decreased the time required for the reconstruction of images, and increased the data processing speed [68]. Furthermore, the increasing availability of AI resulted in an automatic system of image post-processing that includes volumetric analysis of Alzheimer's dementia and quantification of the medial temporal lobe and is predominantly employed in segmentation. Afterward, new technologies arise, such as MRI–positron emission tomography (PET), which displays the information on receptor density and uptake of glucose on the anatomic structures and has an important application in neurological imaging systems [69]. MRI pulse sequences have allowed fibrosis, fat quantification, hemochromatosis, and water distribution. The other techniques like MR tractography and Deuterium metabolic imaging have abilities to access the brain tissues and generate the 3-D metabolic maps of ^{2}H-labeled substrates, respectively. The gadolinium chelates, the contrast agents, help detect the tumor cells in cancer-suffering patients. They help predict nanotherapeutics efficacy and quantify innate immune cells in the body [70-72].

10. Recent Advances in the Diagnosis of MRI in the Spinal Cord Injury

Magnetic resonance imaging (MRI) displayed various damaging effects and abnormalities in the spinal cord, although patients have tolerances for spinal compression. Diffusion tensor imaging demonstrated that modest lesions could predict the degree of spinal cord affection. The elevated difference was observed in fractional anisotropy among lesions or regulation of significant variation in (ADC) apparent diffusion coefficient among both lesions but also controlled cut-off value giving higher sensitivity and specificity with 87.5 percent efficacy. The newly devised protocol's results provided functional plus numerical markers that would aid in diagnosis and prognosis [73].

Diffusion Tensor Imaging characteristics must be better characterized in diverse tissue diseases, including scar tissue owing to hemorrhage, astrocyte aggregation, demyelination, cerebrospinal fluid infiltration, and edema. The integration of Diffusion Tensor Imaging and also the Fourier Transform likewise held potential as a technique for guiding the repair or eradication of particular fiber tracts following spinal cord damage. Furthermore, if Diffusion Tensor Imaging is always to be employed in a therapeutic environment, future research must develop standard, specific time changes in the Diffusion Tensor Imaging measures. There are currently no randomized clinical studies for Diffusion Tensor Imaging in spine injury that is either ongoing or planned. To summarise, the use of Diffusion Tensor Imaging to detect and assess spinal disorders caused by trauma clearly shows significant potential as a standard diagnostic approach and, therefore will continue to advance as a biomarker of the neuropathological disorder [74].

It has been demonstrated that epidural lumbosacral spinal cord stimulation can restore limb of lower volitional motor function in subjects with severe, motor-perfect spinal cord damage. This finding implies that a significant supraspinal connection to the spinal lumbosacral spinal circuitry is maintained after the spinal cord injury. This study aimed to investigate the neuroimaging indicators at the spinal cord lesion site using magnetic resonance imaging. Before installing the epidural stimulator, about 13 people with severe spinal cord injury had respective spinal cord MRIs and the retained tissue of key sections of the spinal cord (anterior, posterior, right, left, and total cord) was examined. Voluntary motor regulation was tested throughout conservative and liberal bottom limb abduction and ankle dorsiflexion efforts after epidural stimulator installation and before any training. The capacity

to apply force and move was not connected to any neuroimaging measure. Prevented tissue of particular spinal cord locations significantly correlated with certain aspects of motor control, such as antagonist (negative correlation) muscle activation amplitude throughout dorsiflexion of the left ankle and patterns of electromyographic coordination all through straight lumbar spine flexion. The actuality that the quantity and position of pardoned tissue of the spinal cord at the site of the lesion were unrelated to the potential to develop the volitional movement of the lower limb may imply that supraspinal inputs via spared regions of the spinal cord which differ between individuals can contribute in the creation of lower limb voluntary control output of motor prior to any mentoring once epidural activation is made available [75].

An initial MRI scan for individuals with cervical spine injury provides important predictive information on the recovery of the neurological system. According to the literature available, there seems to be a statistically significant association among extradural observations of the greatest possible compression of the spinal cord, intradural MRI outcomes of length of cord edema, intramedullary internal bleeding, and durations of intramedullary hemorrhage, and recovery of neurological in trauma patients cervical spine injuries. These indicators are mostly prognostic, and the surgical methodology and fixing principles must be focused on some other considerations such as the patho-anatomy of neurological state, ligamentous and osseous structures, and damage mechanism rather than just on the findings of MRI findings [76]. The pathophysiological mechanisms that occur after spinal cord injury are extremely complicated, and our understanding of such pathways is inadequate. This is demonstrated by the delayed progress of presently available neuroprotective treatments compared to the revitalization of quick trauma and other therapeutic therapies. Magnetic resonance scanning plays a crucial role in the detection of such injuries. It helps in the diagnosis of injury in various stages after the use of various drugs to know the effectiveness of diverse measures employed for the treatment of spinal cord injury [77].

In multiple sclerosis (MS), spinal cord imaging is critical for identifying and diagnosing the disease progression. The axonal loss leads to atrophy of spinal cord degeneration, and the degree of axonal loss corresponds with pathogenicity and prognosis. As a result, measurements of axonal destruction are frequently used as a biomarker to track illness development. To new technological advances, an increasing number of descriptive and analytical MRI Imaging modalities have been investigated in an ongoing effort to provide valid and accurate modern diagnostic biomarkers in The spine imaging ole in the prognosis of various techniques [78].

Certain quantitative Spinal Cord Magnetic Resonance imaging parameters in multiple sclerosis vary over the course of 5 years, demonstrating continuous tissue changes. Subject-specific spinal cord MRI scale change trajectories between 2 to 5 years are substantially associated and hugely important to obey impairment. These results indicate that when analyzing longitudinal Spinal cord-MRI data, individual dynamics of change should be taken into consideration and that quantifying brief alteration is indicative of widely prescribed impairment [79].

Diffusion Kurtosis Imaging (DKI) offers undeniable benefits, including more traditional diffusion. Magnetic Resonance Imaging as evidenced by a growing variety of clinical implementations and software platforms commonly used in brain imaging. However, DKI is still widely underused in neonatal Spinal Cord (SC) imaging due to its intrinsically high technological requirements. DKI's exceptional responsiveness to – anti-gaussian diffusion makes it ideal for identifying complex, subtle, quick microstructural changes happening in this

region at this early and essential development period, which are not detectable with merely DKI [80].

Oh *et al*. set out to replicate the clinicoradiologic contradiction by correlating the magnetization transfer ratio of the spinal cord with clinical impairment levels in multiple sclerosis patients. Their study divided a large group of Multiple sclerosis patients among four categories based on high- and low loads measured with conventional MRI and lower and higher levels of disabilities. They discovered that the values magnetization transfer ratio measured through the entire cord images of cross-sectional at the C3-4 rate was dramatically lower inside the lower and mid subgroup than in the relatively low subgroup since there was no considerable difference in the two elevated subgroups [81].

A novel artificial neural technique described here can significantly decrease the time for reliable myelin water fraction computation, making myelin water fraction imaging increasingly viable and easy [82]. The longer scan duration, discomfort of the patients, and increased price are the key barriers to adding spinal cord scan of MRI as a standard technique in multiple sclerosis imaging. These challenges might be overcome by employing many quick parametric MRI quantitative approaches, including MRI synthetic via stimulation of the Bloch equation [83]. A hybrid imaging approach that incorporates susceptibility-loaded imaging with T2W FLAIR was already utilized to reveal microvascular anomalies in Multiple sclerosis brain lesions. This method employs an iron contrast agent, i.e., ferumoxytol, to enlarge tiny arteries and improve the visibility of vein anomalies within multiple sclerosis brain lesions that would otherwise be undetectable [84].

A promising new biomarker, net sodium concentration, was discovered to be higher in the spinal cord of relapsing-remitting multiple sclerosis patients when compared with untreated. MR spectroscopy can measure it, so it might be useful in the coming years [85].

There has also been growing interest in monitoring the effects of multiple diseases adjusting treatments for injured tissue and incidence of tissue injury mostly in the central nervous system. Although gathering spinal cord MRI data is still not required for monitoring methods, multiple investigations have revealed that a considerable number of multiple sclerosis patients may have undiagnosed spinal cord lesions. According to studies, asymptomatic spinal cord lesions are prevalent in 27 percent to 53 percent of clinically isolated syndrome patients and 25 percent to 32 percent of Relapsing-remitting multiple sclerosis patients. They are related to greater age at illness beginning during the last group. For a significant number of patients, they are the only evidence of the progression and activity of diseases [86].

Even though the myelin water fraction is myelin-specific, it does not directly image the myelin. In this context, ultra-short echo time sequences offer the ability to imagine the myelin proton (extremely brief T2) in the spinal cord white matter, although this method has received little attention in the multiple sclerosis population [87-90].

11. Genetic Damaged by MRI Imaging

MRI is clinically advanced and considered one of the strongest non-invasive approaches for diagnoses of diseases and doesn't require ionizing radiation that harms the body. In 2009, OECD collected health data from approximately 30 countries [91]. The USA has greater than 7950 MRI scanners and ranks, and it lies at the first position in the world, spanning more than 50,000 populations in the world. It was evaluated that near about 200

million MRI scans were done worldwide [92]. There is no evidence of direct adverse effects from patients that have been reported yet. It was evaluated that the strong magnetic field and heat produced by RF causes triggers arrhythmia and shocks, that's why it has been contradicted for the patients with implant-able electronic or conducting objects, including cardiac pacemakers and cardiac ventricular defibrillators, in past some cases with these issues have been reported.

Furthermore, new medical devices such as cardiac pacemakers have been developed that are unaffected by MRI, and hence they are very safe for MRI carried out at 1.5 T. It is possible to have MRI-safe implantable electronic objects and pacemakers in the coming few years [93-97]. The technical developments in MRI systems have increased the static magnetic field strength for better diagnosis [98-101]. The investigations have been carried out to check the interactions between associated genetic risks to the patients working in the MRI scanner and the electromagnetic fields formed by MRI systems, and many of them suffer from carcinogenesis, genetic damage, and other health issues, who are in contact with MRI scanner daily for few hours. Furthermore, it was investigated that MRI exposure causes cancer due to the powerful electromagnetic radiations leading to genotoxicity. Although the record of MRI scan was overall good from the safety point of view, it still requires further investigations [102]. The interactions of electromagnetic radiations produced by MRI are shown in Fig. 7.

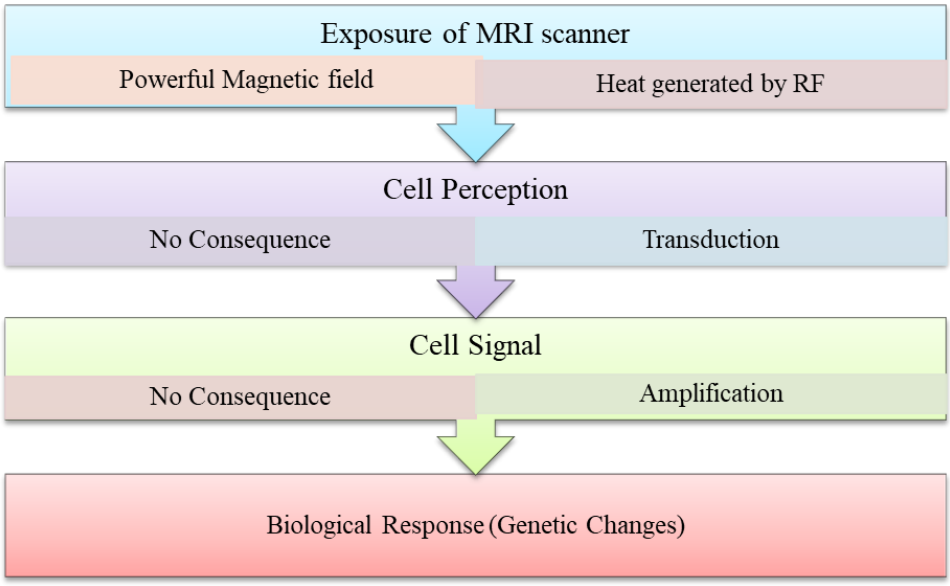


Figure 7. Interactions of electromagnetic radiation and biological cells leads to genetic changes and carcinogenesis.

12. MRI Utilization in National Trends During Ongoing COVID-19 Pandemic

Luxenburg *et al.* investigated that the rate of MRI scans decreased during the first wave of COVID-19. The decline was observed in April 2020, and a nearly 47.5% relative drop occurred compared to April 2019, while approximately 42.2% drop occurred compared to 2018. There was a notable incline of the waves and then come back to nearly pre-pandemic levels, with a slight decline, during the second wave of the pandemic compared to the last year. Moreover, the ratio of MRI examinations between the Northern periphery and the Tel-Aviv inclined from 2.89 to 3.94 from April 2019 to April 2020, respectively. In the first ten months of the COVID 19 pandemic, there was a decrease of just 1 % in MRI utilization in the region of Jerusalem metropolitan where the COVID 19 cases were maximum [103].

13. Advantages and disadvantages of MRI Imaging

There are numerous advantages of MRI imaging as Rf pulses produced by MRI imaging do not cause any harmful effects; hence, they are safe for children and ladies. MRI is a non-invasive diagnostic tool. MRI image processes can distinguish between nearby soft tissues, and by altering the pattern of RF pulses, the contrast between various tissues has been manipulated. MRI imaging can produce high-quality direct oblique and coronal images that are not produced by radiography and CT scan. The differentiation is possible between acute, chronic transit, and fibrous phases parallel with histopathological changes. No artifact is required with the dental filling. Manipulations of images are possible by MRI imaging. Intramedullary spread is useful in this case [104]. Although MRI technique has proved a blessing in the health care sector to improve the quality of life and act as a very important approach in the diagnosis of various diseases by taking the images of body cells and tissues even though these techniques possess some disadvantages [104]. However, They cause claustrophobia in the patients as they have to stay in closed places and large magnets for more than an hour. MRI equipment is not cost-effective and is expensive to operate and maintain. Still, there is a need for the development of hardware and software. Due to the powerful magnetic field and heat produced by electromagnetic radiation are not considered good for patients with implants, including cardiac pacemakers and other artificial heart valves. The distortion of MRI images occurs by metal. The surgical stents or clips cause hindrance in the images of the patients. The strongest magnetic field creates problems with the equipment sitting despite the sophisticated nature of the shielding. All metallic objects, teeth, air, and bones appeared black. As a result, differentiation becomes quite difficult while they are noisy. Different agents often cause allergy in the patient, and there is a chance of skin infection at the injection site. It is not possible to distinguish between malignant or benign tumors, resulting in a false positive report.

14. Conclusions

MRI imaging replaced many promising technologies and is highly acceptable for clinical implementations. However, it still requires further investigations to overcome the lack of consistency, and significant methods were adopted to reduce their harmful effects to a greater extent arising from electromagnetic radiations of RF. It is a somewhat complex technology with several clinical indications for diagnosing internal tissues, organs, and maxillofacial abnormalities. They are not used in dentistry in a routine, and their appropriate uses can improve the quality of images and act as an appropriate tool for patient care. They play a very important role in diagnosing spinal cord injuries for successfully carrying out surgical operations. The introduction of 3-D imaging increases the utilization of this imaging technique even further. Furthermore, MRI scanning during the crucial period of COVID- 19 waves revealed adjustment to the new normal. In devise for a later national crisis, reasonable and convenient data of MRI uses can act as a “sensor” for an extensive array of interventional diagnostic and medical activities.

Funding

This research received no external funding.

Acknowledgments

The authors are grateful to all who contributed to this article in the data collection, analysis and interpretation.

Conflicts of Interest

The authors declare no conflict of interest.

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