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MRI AND DENTISTRY- A CONTEMPORARY REVIEW

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ABSTRACT

Magnetic resonance imaging (MRI) is one of the most powerful diagnostic tools in radiology and diagnostic science. Magnetic Resonance Imaging is a highly sensitive and specific imaging modality that is being used in radiology and diagnostic science. It poses very little risk to the patient and it does not emit any ionizing radiation, nor is it an invasive procedure. It is a non-invasive procedure and the images can be highly sensitive and specific. The system does not use ionizing radiation and there is little risk associated with application of magnetic field to the majority of people.

KEY WORDS: Magnetic resonance imaging (MRI), radiology and diagnostic science.

INTRODUCTION

Imaging in orthodontics is emerging at an astonishing speed due to the development of three-dimensional (3-D) imaging modalities. After their development in the 1990s, custom-built craniofacial machines began to appear on the market in the early 2000s. Other sophisticated imaging, with a variety of applications to the maxillofacial dental and skeletal regions, has followed. In dentistry, Dentist currently have the option to image their patients with a multitude of imaging modalities, which include computed tomography (CT), cone beam computed tomography (CBCT), cephalometric head films, panoramic films, intraoral and extraoral photography, soft-tissue laser scanning, stereo-photogrammetry, and magnetic resonance imaging (MRI).[1-4]

Magnetic resonance imaging (MRI) is one of the most powerful diagnostic tools in radiology and diagnostic science. It is a non-invasive procedure and the images can be highly sensitive and specific. The system does not use ionizing radiation and there is little risk associated with application of magnetic field to the majority of people. MRI can be used for assessment of intra-cranial and extra-cranial lesions, like rhabdomyosarcoma, optic nerve glioma, neuroblastoma, and retinoblastoma. It is also useful in cases of trauma to soft tissues, TMJ pathologies and salivary gland tumours. Cranial lesions can be life threatening and require repeated MRI scans to evaluate the progress of the patient. Despite these imaging characteristics, MRI has the shortcoming of being expensive, and inappropriate for claustrophobic patients.[5]

History

The term "magnet" is believed to be named after the shepherd magnus, who was credited with making the discovery around 1000 B.C. He found magnetite (magnetic oxide of iron (Fe_3 O_4) which was subsequently known as lode stone or lead stone (i,e stone that points the way).[1] The first important scientific work on this subject was by an eminent doctor, William Gilbert, in 1600 A.D, he published a book in latin titled "On the lodestone, magnetic bodies, and on the great magnet -the earth". Unfortunately no significant study of magnetism was made for a century after the publication of Dr.Gilbert's book. The 18th Century witnessed a growing popular interest in Magnetism and electricity among, the Europeans, particularly the French and Germans. The first electro static machine, which could produce strong electric charge was invented in 1705 by Francis Hauks bee, curator of experiments at the Royal Society of London. The multitalented Benjamin Frank Lin performed some significant experiments in the field and is credited with promulgating terms such as charge, discharge, electric shock, positive, negative and battery.[1,2] In 1820, Hans Christian Dersted, a professor of physics at the University of Copenhagen, Denmark, was first to describe the association between an electric current and a magnetic field. Within a few years, the properties of elector magnetism were worked out by numerous Cont. Scientists ulminating in James clerk Maxwell's elector magnetic theory - which is regarded as the crowwing glory of the 19^{th} Century physics -subsequently proven by Wilhelm conrad Röntgen. In 1920's and 1930's, saw a period of intense experimentation on the magnetic properties of nucleus, particularly hydrogen, because it has a simple nucleus consisting of a single proton. Dutch physicist, pietor zeeman - observed that magnetic fields affects atomic phenomena. Intrinsic magnetic moment of an atom was demonstrated by Otto stern and walter gerlach in 1929. Isidor Rabi and colleagues showed that electric charges in nuclear particles were asymmetrical, their work led to the first direct measurement of Nuclear magnetic resonance. The Nobel prize for physics was awarded to stern in 1943 and Rabi in 1944 for their work on atomic and nuclear magnetic phenomena. In 1952, Felix bloch and Edward purcell were awarded the nobel prize for physics for study on the measurement of the magnetic moment of the proton. In 1971, Raymond Damadian showed experimently that NMR signals varied according to the water content of different tissues, specifically discriminating between tumors and normal tissues. About the same time, the first crude NMR images were produced by Dr.Paul C.Lauterbur. In his original paper he called this new imaging technique "Zeugmatography". The initial MR images took hours to acquire and were very poor in quality because the NMR signals were too weak.[3,4] 1974, researchers at the University of Aberdeen, U.K obtained fairly reasonable MR images of a mouse. 1980, the Nothingham group produced the first clinically acceptable images of the human brain. The first commercial company to invest in and build an MR scanner was EMI, the CT pioneer. With the introduction of NMR to clinical imaging, the word "nuclear" was dropped as it raised connotations of "nuclear warfare" or "nuclear power plant". It was feared that the lay public would not distinguish one nuclear from the other. Hence the present day term MRI and MR spectroscopy (MRS).

The Magnetic Resonance Imaging Process

The MR imaging process can be divided into a few simple steps.[4]

1. The patient is placed in a magnetic field and essentially becomes a magnet.
2. A radio wave is sent in.
3. The radio wave is turned off.
4. The patient emits a signal
5. The signal is received and used for reconstruction of the picture.

The important hardware components of a typical MR machine can be added to this simple frame work. The patient is placed in the main magnet, which produces an external magnetic field, made more uniform by smaller "shim" coils. Transmit radio frequency (RF) coils send radio waves into the patient while receiver (rf) coils receive the signals emitted from the patient, these coils are also known as surface coils e.g. Head, body, spine, T.M.J. Image processing and display are done by a computer.

Physical Principles of the M.R.I.

1. Tissues and Nuclear Magnetism

MR images obtained in clinical practise are based on the hydrogen nucleus. Hydrogen is by far the most abundant nucleus in the human nucleus (10^{19} nuclei / mm^3). It has the highest tissue conc (100 mmol / kg) and the strongest magnetic moment (or strength and direction of the magnetic field of any element). These properties allow the signal produced by hydrogen to be more than 1000 times stronger than that of any other element. In clinical MRI, differentiation between normal and diseased tissues relies on detections of their relative water (and hence hydrogen) content. The nucleus of an atom consists of neutrons which have no charge, and protons which have a positive charge. The proton spins continuously around its own axis. A moving electric charge produces its own magnetic field. Therefore each proton has its own local magnetic field aligned along two poles, similar to a bar magnet, also known as a magnetic dipole. Nuclei with an even number of protons and neutrons the dipoles pair up and cancel out each other's magnetic effect. Contrast this situation with that of an odd no of protons or neutrons resulting in a net magnetic dipole moment. Besides hydrogen (which has a single proton), the other nuclei that have "odd" combinations and are therefore theoretically suitable for MRI, include sodium 23 (11 protons, 12 neutrons), phosphorous - 31 (15 protons, 16 neutrons) and potassium - 39 (19 protons, 20 neutrons). When a patient is placed inside an MR machine, the external magnetic field (Bo), causes magnetic dipoles to align with the field, resulting in a net tissue magnetisation (Mo). This net tissue magnetisation is difficult to measure because it is aligned in the same direction as the much stronger external magnetic field. The wobbly type of proton spin motion in a strong magnetic field, often likened to the moment of a spinning top, is called precession. The rate of proton rotation is known as (precession) or Larmor frequency - and is dependent on the type of nuclide and strength of the external magnetic field. The larmor equation allows calculation of the precession or (Larmor) frequency. When an RF pulse of the correct larmor frequency is applied to a nucleus, the nucleus absorbs energy resulting in a change in direction of the magnetic dipole movement. This phenomenon is known as resonance, giving the term nuclear magnetic resonance. The direction of the net tissue magnetisation can be altered according to the amplitude and duration of the applied RF pulse. Tipping the tissue magnetisation exactly 90" from the z axis produces the maximum amount of magnetisation in the transverse (or xy) plane. A receive will placed in this plane would be able to measure the net transverse magnetisation (Mxy) much more than in the longitudinal plane (Mo). The RF pulse is applied only as a brief burst. After the RF pulse (or wave) is switched off, the longitudinal magnetisation (M_2) increases (or recovers), while the transverse magnetisation (M_{xy}) decreases (or decays) as the protons gradually realign along the Bo direction. The T_1 relaxation time is defined as the time required for recovery of 63% of the magnetisation along the longitudinal direction (i.e.B_6) after a 90° RF pulse. The T_1 recovery rate of a hydrogen proton varies in different tissues due to diverse macromolecular environments. The T_1 relaxation time of a tissue reflects the degree of transfer of RF energy from the recovering spinning protons to the surrounding tissue lattice. Hence, the T_1 relaxation time is also known as the spin - lattice relaxation time. Closely coupled tissues such as fat have short relaxation times "loose" tissue such as CSF have long T_1 relaxation time. Following the 90°RF pulse, the dipoles oriented in the transverse plane start to decay. Initially processing at the same rate and in the same direction, the individual dipoles then gradually become out of phase with one another (known as spin - spin interactions). The dephasing process enclose with act transverse magnetisation of zero. The time taken for (M_{xy}) to decay to 37% of its original value is the T_2 relaxation time. The T_1 relaxation time reflects the internal local field strength of a particular tissue. Solid tissues such as muscle with a fixed molecular structure and strong local magnetic result in rapid dephasing of dipole movements and therefore gives rise to short T_2 relaxation times.[1-3,5]

Liquids, whose molecules are mobile, produce weaker local field strength have longer T_2 relaxation times. Fat which has a short T_1 appears white or bright an T_1 weighted the imaging scans. Because most pathologic processes result in an increase in the amount of free or bulk water, T_2 weighted images are used to detect disease and performed before T_1 sequences.

HOW MR IMAGES ARE GENERATED

All the H^+ protons in a patient precess at the same frequency (Larmor), excited by the same RF pulse, with no way of distinguishing among the sources of the signals emitted by different parts of the body. The secret of localising the source of MR signals from a specific site in the patient's body was unlocked by Dr.Paul C.Luterber in 1973. He proposed adding a weaker magnetic fields the gradient field, to the stronger main magnetic field. The gradient field is a non - uniform magnetic field that is strong at one end and gradually becomes weaker at the other end. It is produced by gradient coils and can be applied in any direction, this multidirectional ability gives MRI the capability of forming multiplaner images. The gradient field when superimposed on the main magnetic field modifies its strength. According to the Larmor equation, where proton frequency is directly proportional to magnetic field strength. There would be a gradient of different precession frequencies. The RF pulse can be customised to precisely the required range of frequency called band width, thus forming the basis for slice selection in MRI. The smaller the band width the smaller the slice and vice versa. The other method would be to increase the steepness of the gradient, thereby increasing the variation in precession frequencies, and giving thinner slices. To further localise the source of signals another gradient field is applied in a different direction, (e.g the Y axis). The second gradient (also known as frequency encoding or read out gradient) divides the slice of tissue into many strips of progressively increasing frequencies in the Y direction. Switching off the gradient in this direction will cause the protons in different portions of the slice to get out of phase with one another.

This gradient known as the phase - encoding gradient further localises the signal source. Application of three different gradients results in generation of a mixture of signals. These signals are analyzed by a computer using the fourier transformation, and the MR images can thus be reconstructed. The most commonly used MR technique in Clinical imaging is the Spin - Echo (SE) pulse sequence. The SE pulse consists of a 90° pulse followed after some delay by a 180° pulse, which results in the detection of the T_2 component. In clinical practise, the external magnetic field is usually supplied by a super conductive magnet. Field strengths vary from 0.1 to 2.0 Tesla, generally for clinical MR imaging optimal range is between 0.5 and 1.5 tesla. Tesla is a measure of energy, in this case magnetic field strength.[2,3,4]

MAGNETIC RESONANCE CONTRAST AGENTS

The signal intensity emitted by a tissue can be altered by injecting contrast agents. These agents change the signal intensity of tissues by altering T_1 or T_2 relaxation times. Contrast enhancement is mainly determined by vascularity and the interstitial vascular space of the tissue involved. In the jaws they are added to study the presence of enhancement within a lesion or RIM enhancement at the margin of a lesion such as Odontogenic cyst or Tumor. MR contrast materials are classified into ferromagnetic, paramagnetic and super magnetic categories, the paramagnetic being the most popular & useful. Paramagnetic contrast agents have the greatest relaxation as protons in water molecules. The only paramagnetic agent is the lanthanide known as Gadolinium diethylene thiamine pantothenic acid (Gd-DTPA), which shortens T_1 & T_2 relaxation times.[3,4]

Fat Suppression

Kitagawa et al have diagnosed the utility of fat suppression in the imaging of oral maxillofacial lesions. It is especially useful when using (Gd - DTPA). As fat has high signal intensity on T_1 weighted images, fat suppression technics can be divided into relaxation - rate dependent methods & chemical shift methods (Widely used, introduced by Dixon).

Information Provided with each M.R.I.

Varies with brand of the machine, models & software.

Demographic Data

Depending on the software, the patients Name, Age & Sex along with the date & time of examination are provided. The name of the radiology clinic, as well as of the radiologist and the referring physician may be included.

Machine Settings

In contrast to plain radiography, the machine settings are indicated. Strength of the magnet in Tesla units. Compare & contrast T_1 & T_2 - weighted images. Hydrogen proton densities for the type of tissue being examined (bone for eg.) T_2 sequence are done first to study pathology, then T_1 followed by contrast studies.

Patient Orientation

The patient's left & right sides are identified. It is important to note L/R side labelling to know what side is being studied.

M.R.I. Sequence

Faster scans can be used to study tissues in their functional state and are called functional M.R.I.'s Some methods employed are

1. GRASS [**G**RADIENT **A**CQUISITION IN **S**TEADY **S**TATE]
2. FLASH [**F**AST **L**OW **A**NGLE **SH**OT]
3. FISS [**F**AST **I**MAGING IN **S**TEADY **S**TATE]
4. FAST [**F**OURIER **A**CQUIRED **S**TEADY **S**TATE **T**ECHNIC]
5. FSEI [**F**AST **S**PIN **E**CHO **I**MAGING]

BASIC CONCEPTS OF ANALYSING MRI

Although a dentist or a Radiologist interpret Radiographs, MR images are analysed because they represent a computation of data analysed by a Radiologist. In the MR images of the Jaws, the extent margin and to some degree, composition of contents of an Abnormal Area can be analysed with some accuracy. Many clinicians compare MRI findings with plain radiographs to determine the histologic nature of the abnormality. In the future, using software (Analytical) the molecular composition of an Area can be analysed for specific disease processes and histologic diagnosis.[3,4]

Applications of MRI in Various Branches of Dentistry

ORTHODONTICS

The accuracy of clinical diagnosis of normal and abnormal disc position has been reported to be 73% with M.R.I. The M.R.I. Scanning can be used to determine the relationship of the Disc to the condyle. The location of reference points in 3 dimensions for Radiographic Cephalometry can be done with M.R.I. with respect to imaging of the human skill.[5] The availability of 3-D, Reconstruction of data from CT & MRI scans provide. The most realistic means of visualising structures. MRI can be used to collect growth data without exposing the patient to radiation hazards.[5] MRI can be used to assess tongue volume correctly**.** They are superior to cephalometries and other imaging techniques for the estimation of oropharynx and hypopharynx sizes.

Shellock FG and Curtis JS reviewed and summarized various studies pertaining to the safety aspect of performing MR imaging in a patient with respect to the ferromagnetic qualities of a metallic implant, material, or device. Of the sixteen different dental devices and materials tested (including stainless steel, chrome alloy, dental amalgam, palladium, platinum, silver points and titanium alloys), twelve had measurable deflection forces but only three (stainless steel, dental amalgam and silver points) represented a potential problem for patients during MR imaging because they were magnetically activated devices. Various factors influenced the risk of performing MR imaging in a patient with a ferromagnetic implant or device, including the strength of the magnetic field, the relative degree of ferromagnetism of the device, the mass of the object, the configuration of the object, the location and orientation of the object in situ, and the length of time the object has been in place. These factors should be carefully considered before subjecting a patient with a ferromagnetic object to MR imaging, particularly if the object is in the vicinity of a vital structure where movement or dislodgement could injure the patient.[6,7]

Sadowsky PL, Bernreuter W, Lakshminarayanan AV and Kenney P evaluated the effects of a variety of orthodontic appliances on MR scans, particularly scans for the head and TMJ regions.

Their study consisted of two parts, the first part of the study was conducted on a phantom with fixed appliances, and the second part of the study was conducted on a group of patients undergoing fixed appliance treatment. Two types of artifacts were evident on the phantom images: distortion and alteration of signal intensity (brightness). The presence of the archwire caused much greater artifact interference than the bands and brackets alone. The MR scans of the patients also indicated that the orthodontic appliances produced significant artifacts, especially in the areas closest to the appliances. The mouth and the facial regions including the maxillary sinus and also the frontal and temporal lobes of the brain were not clearly visualized.[8]

TMJ Disorders

The effects of orthodontic treatment on Temporomandibular Joint (TMJ) are still subject to doubts and discussions. The use of complementary exams has always been a constant in the evaluation of this interrelation and can be exemplified by conventional radiographic examinations that were widely used to assess the implications of orthodontic treatment on the TMJ. However, this modality of imaging examination has limitations, because the TMJ is one of the structures of the human body more difficult to be well visualized radiographically due to overlapping of several adjacent bony structures. Thus, the effects of orthodontics on TMJ structures are still controversial. With the advent of imaging examinations with specificity, sensitivity and greater accuracy in the reproduction of articular anatomic structures, such as magnetic resonance imaging (MRI), computed tomography and cone-beam volumetric computed tomography as well as 3D reconstruction methods, this interrelationship can be evaluated with greater exactness. Added to this fact, there was accomplishment of clinical studies with designs and more rigorous methodological criteria, generating higher levels of evidence. The correct occlusal relationship as a result of orthodontic treatment is not obtained at the expense of non-physiological positioning of both the condyle and the articular disc. Thus, when orthodontics is used correctly does not cause adverse effects in the TMJ. The application of forces during certain orthodontic mechanics, especially orthopaedic situations, can cause alterations in condylar growth and bone structures of the TMJ.[8,9]

Thus, the mechanics application should be performed properly and the professional must have knowledge of these impacts. In some studies by analysis of imaging examinations, it was observed that there were improvements in situations of pre-existing TMD at the beginning of orthodontic therapy. However, these data are only suggestive and more randomized clinical trials are necessary to obtain more precise conclusions. Further randomized controlled clinical trials, with longitudinal and interventional nature are necessary, for the determination of more precise causal associations, within a context of a scientific evidence based dentistry.

Slice thickness, slice gap & field of view: All are inter related which affects the spatial resolution of the image. For the Jaw, slice thickness of 5-6 mm with a gap of 1.6 to 2 mm has been suggested by Van Rensberg & Nostje' In the TMJ, slice thickness of 3 mm with 0.5mm slice gap has been suggested by Brooks. Field of view represents a zooming in the area of interest to appear enlarged and separate from adjacent structures. Field of view of jaws is set at 24 -2 8 cm, and is limited to 10 cm for the TMJ.[3,4]

Endodontics: The accuracy of MRI is as similar to CT. MRI scan are not affected by artifacts caused by metallic restorations like Amalgam, metallic extracoronal restorations, which can be major problem with CT technology.[10,11] MRI may be useful to access the nature of endodontic lesions and for planning periapical surgery. But on the other side MRI have few drawbacks. These include the poor resolution compared with simple radiographs and long scanning times, in addition to the greater hardware cost and limited access only in dedicated radiology units. The dental hard tissues such as enamel and dentin cannot be differentiated from metallic restorations; all the appear radiolucent. It is for those reasons that MRI is of limited use for the management of endodontic disease.[12-14]

Prosthodontics and Implantology: Coward et al. conducted a study on comparison of prosthetic ear models created from data captured by computerized tomography, magnetic resonance imaging, and laser scanning. The study concluded that all 3 methods of imaging would be of value in further studies, not only for the fabrication of complex shapes such as prosthetic ears, but also for other facial prostheses.[15]

Coward et al. conducted another study on comparison of prosthetic ear models created from data captured by computerized tomography, magnetic resonance imaging, and laser scanning. They concluded that the dimensional measurements on the stereolithographic models were similar to those from the original source. Only small differences were apparent between the surface topography of the CT, MRI, and LS models. MRI may be particularly appropriate to fabricate a prosthesis because it involves no radiation for the patient and internal form can be reproduced. The use of this technique in clinical practice requires further study.[16]

BIO EFFECTS AND SAFETY CONSIDERATIONS

Although, there is no known Biohazard Associated with M.R.I. it is contraindicated in patients having electrically, magnetically or mechanically activated implants such as cardiac pacemakers and infusion pumps. The potential risks associates with performing MRI in patients with Ferromagnetic implants or materials related to the induction of electric currents, heating and the misinterpretation of an artifact as an abnormality and the possibility of movement or dislodgement of an implant. Studies indicate that patients with metallic implants (Dental implant) or materials can safely undergo M.R.I.[7]

MRI & PREGNANCY

F.D.A. requires that M.R.I. devices indicate that the safety of M.R. imaging when used to image fetus and infants "Has not been established". Although M.R.I. is not considered hazardous to the Fetus, a cautionary Approach to M.R.I. during pregnancy is recommended till additional investigation provides more information. M.R.I. is indicated in pregnant women if other non ionising forms of diagnostic imaging are inadequate (Ultrasound for eg.) or if the examination provides more information that would otherwise require exposure to ionising and radiation (X rays, C.T.)[1,2,7]

PATIENTS WITH CLAUSTROPHOBIA, ANEXITY, EMOTIONAL OR PHYSICAL STRESS

Emotional or psychologic reactions may occur in patients before or during M.R.I, the most common reason being the restrictive dimensions of the interior of the scanner. Certain newer generation M.R.I. systems offer a more open design, which reduces the incidence of psychologically related problems. A patient who is well informed about specific aspects of M.R.I. examination including the expected level of gradient noise, the internal dimensions of the scanner and the duration of the examination, usually tolerates an MRI scan without distress.[1,7]

RELATIVE DISADVANTAGES

1. Spatial Resolution of MR is lower and examination time longer.
2. Examination is not conveniently extended from one organ to another or from one part of the body to another.
3. Contact involvement arising from bone tissue are not always demonstrable.
4. Patients with pacemakers must be excluded.
5. It is not easy to subject seriously ill patients, those connected to support apparatus or those under G.A. to an MR Examination.

Advantages

1. It enables differentiation among various types of normal and abnormal tissues, with clarity that is unmatched by any other imaging technique.
2. Multiplanar anatomical display.
3. Avoidance of ionising radiation hazard.
4. Relative lack of side - effects.
5. High patient acceptability.
6. Greater tissue contrast
7. The fact that parenteral contrast is not required to reveal blood vessels.
8. Ease with which views in any place are obtained.
9. The absence of artifacts due to bone or air.

MR SPECTROSCOPY

MR Spectroscopy studies involves other elements than hydrogen. Commonly used elements are sodium, phosphorous, carbon and fluorine.Sodium is of interest as it passes out of damaged cell membranes to increase in concentration in necrotic tissues. Sodium MRS is a sensitive tool for the diagnosis of infarct and neoplasia. Phosphorous plays a critical role in many biochemical processes; Ratio of organic to inorganic phosphorous in patients with muscle dysfunction. MR Spectroscopy is useful for study of Skeletal muscle physiology. Tumours and the healing or grafts. Its applications will lead to a better understanding of changes in muscle functions of patients with temporomandibular disorders.[1,2,5,7]

CONCLUSION

1. Generally, it is agreed that MR was the most important innovation in Diagnostic imaging in the 1980's.Its immense value in the diagnosis of CNS pathologies, in particular is beyond doubt.
2. Its utility in many extraneurological contexts needs to be carefully examined and compared with that of longer established diagnostic methodologies.
3. The costs of MR, its intrinsic limitations, and as yet unsettled problems of hazards should be weighted.
4. Despite the diverse image acquisition technologies currency available, standards have to be adopted in an effort to balance the anticipated benefits with the associated costs and risks.

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