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Compatibility and Safety of MRI with Dental Implant - A Dilemma to Solve

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Abstract: ***The increasing use of MRI (Magnetic resonance imaging) for diagnostic purpose and implants for rehabilitation has necessitate to study the interactions between MRI and dental implants. These interactions could result in unwanted effects which can be heat generation, mechanical displacement and artifacts, which can be a potential source of damage to surrounding oral tissues.This literature review aims to collect and evaluate the present knowledge about the interactions between MRI and dental implant. Dental implants and MRI are most extensively used, most of the dental implants are made of Ti alloy therefore it is critical to know the safety of dental implants during MRI.***

Keywords: MRI, Dental Implant, safety, compatibility

1. Introduction

Dental practitioners are always concerned about the safety of using metallic dental prosthesis in patients due to its possible interactions during diagnostic imaging. Sometime patients are also aware about such interactions and they have query about their safety in scenarios, where they may need to undergo any medical scanning. Therefore for proper patient counselling and their awareness it is imperative for the dentist to have appropriate knowledge about their compatibility.

MRI is a diagnostic tool used universally for soft tissue evaluation. It uses powerful magnetic field, radio waves and a computer, to create images of tissues and organs throughout the body. The powerful magnetic field aligns atomic particles called protons that are present in most of body tissues especially the soft tissues. The applied radio waves then cause these particles to produce signals that are picked up by the receiver within MR scanner. The SI unit of magnetic field is TESLA (T). There are different MR scanners based on magnetic field strength:[18]

Low-field MRI scanners (0.23 T-0.3 T): They are typically identified as open MRI scanners. Low-field MRI scanners have decreased image quality and require a longer scan time compared to high-field MRI scanners.

High-field MRI scanners (1.5 T to 3.0 T): These are typically identified as closed MRI scanners. A 1.5 T MRI scanner provides great image quality, fast scan times, and the ability to evaluate how certain structures in the body function. The 3.0 T MRI scanner is great for visualizing very fine detail, such the vessels of the brain or heart.

Ultra-high field MRI scanners (7.0 T 0 T): It is not widely available and is typically used for research. 1.5T continues to provide most routine exams with enough accuracy to help to diagnose and monitor diseases. When more detailed scans are needed, 3.0T provides these better images in less time. 7.0T, though still new, may be useful with its high SNR, better spatial resolution, and increased T1 dispersion and chemical shifts.

Dental implant is frequently used as a definitive treatment modality for replacement of tooth root which is placed into the bone. Their use in treatment of complete and partial edentulism has become an integral part of dentistry. Dental implants have a number of advantages over fixed partial prosthesis. Most frequently used implants are made of metal such as Titanium (Ti), other materials are ceramics (zirconia, polymers (PEEK) etc. It is a concern of dental practitioner to know the magnetic property of material that are used in fabrication of dental implant.

Types of magnetic material :[19,20]

1) Diamagnetic- diamagnetic substances are those which repelled by magnets and when placed in a magnetic field move from the stronger to the weaker part of the field. For eg. Bismuth, copper etc.
2) Ferromagnetic - are those which are attracted by the magnetic and can be magnetized. e.g. iron, nickel, cobalt
3) Paramagnetic - are those which are attracted by magnets and when placed in a magnetic field move from weaker to stronger part of the field. e.g. aluminium, platinum, titanium

MRI devices use strong magnets, metal implants pose the risk of displacement of implant and radiofrequency(RF) - induced heating of the implant. These effects can damage the surrounding oral tissues and can affect the quality of MR image.

Device movement

There are two types of magnetic field-induced movement of metallic devices: (1) deflection (translational movement), (2) torque (rotational movement). Due to the nature of the deflection force and torque, it is possible to isolate each type

of movement and measure its magnitude separately. Deflection occurs in a region where a spatial magnetic field gradient is present. The deflection force will increase with the magnitude of the gradient. Typically, spatial gradients are greatest near the magnet portal. In contrast, the magnitude of the magnetic torque is proportional to the magnetic field strength. As a result, the torque is largest at the centre of the magnet bore where the field gradient is negligible.

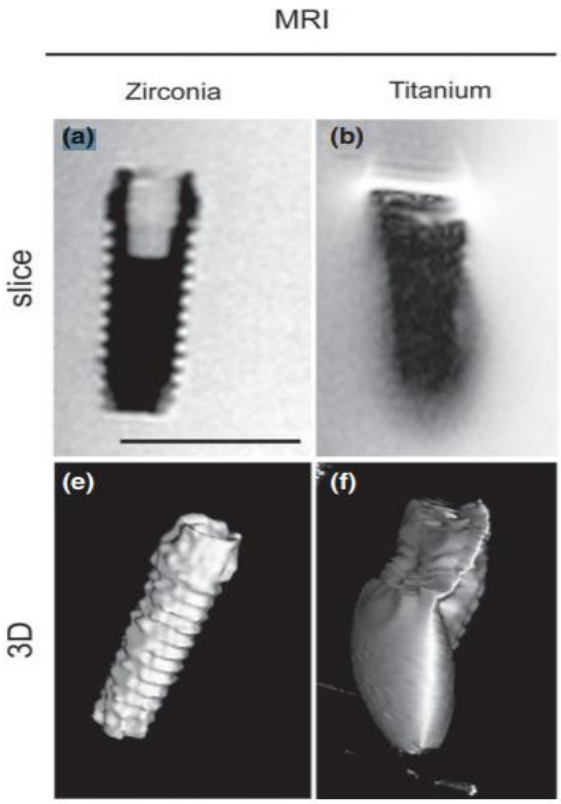
Device heating

Conductive implants, materials, or devices may experience heating by the induction of electromotive forces when subjected to gradient magnetic fields. In addition, heating may be induced by arcing effects, if the device is placed too close to another conductor and sufficient voltage is generated.

Imaging Artifacts

The distortion of MR images by various materials is caused by disruption of the local magnetic field resulting in a change in the position-frequency relationship, which is crucial for accurate image reconstruction. The degree of image distortion depends on the magnetic susceptibility (Ti show low magnetic susceptibility 156.9 × 10−6 to 188.9 × 10−6)[23], shape &position (Larger the size of the material, greater will be the artifact. Maximum area of signal loss will be, when the material is within the radius of 10 cm inside the region of interest.)[21]and orientation of the device (artifact size increases proportional with increase in angle between long axis & magnetic field)[22] in the body, as well as the MR technique(In SE imaging the magnitude of susceptibility artifacts increase with increasing TE.) In GRE imaging susceptibility, specific pulse sequence, and strength of the static and gradient magnetic field.[18] Artifacts are most typically seen as local or regional distortions of the image, as signal voids or as increased noise. For minimizing the amount of susceptibility artifact in an image: (a) Use lower field strength, (b) choose SE over GRE pulse sequence, (c) use short TE, (d) keeping in mind that susceptibility distortions occur along the frequency-encoding readout axis, choose an appropriate axis in relation to the anatomy of interest.

Artifacts of Different Implant Materials in MR Imaging



Imaging of zirconia imaging (MRI) : In MRI zirconia implants are clearly depictable in slice views (a) and 3D renderings (e), while titanium implants (b, f) appear distorted due to strong susceptibility artifacts.[11]

Review

S.NO	NAME OF THE AUTHOR	TYPE OF IMPLANT	MRI SPECIFICATION	RESULT	CONCLUSION
1)	Devge et al (1997) [1]	Implants of Branemark System were tested	The ferromagnetic properties of implant materials are seldom described by the manufacturer. Important factors are alloy composition, size & shape of the metallic material, and its position in body	Artifacts caused by implants were minor and did not jeoparadise scan evaluation, however, magnet keeper attached to implants caused major artifacts	Magnet keepers attached to implants must be removed before an implant patient is referred for MRI examination
2)	Beth A. Schweler et al (1999) [2]	Dental implants	1.5 T MR radiation is used	Safety and compatibility of various implantable medical devices including dental implants show no significant heating, minimum torque, little artifact in case of dental implants if areas are larger than connector	It concluded that medical implantable devices are safe and compatible with MR imaging using 1.5 T MR radiations
3)	Abbaszadeh et al	Ti endosseous	T1 weighted images	Gold produced greatest artifact	the clinical should be aware of

	(2000)[12]	implants, type III gold, dental lathe cut amalgam, S.S. crown, Ag-Pd crown, vitallium bone screw		whereas amalgam and Ti implants produced the least	such artifacts in order to inform the technician to use avoidance measures to minimize the adverse effect of such artifacts on accurate interpretation of MR images
4)	Savane et al (2001)[3]] (article in French)	Ti implants	1.5 T MR unit with 2 commonly used sequences (SE, GRE)	Minor artifacts without distortion	In order to minimize 'ghost images ' Ti and its alloy should be an alternative
5)	Hubálková *et al.* (2002)[4]	15 dental alloys, 4 dental implants, 1 surgical splint & 2 wires for fixation of maxillofacial Fractures		Artifacts were significant: for surgical splints, a spherical artifact of 55 mm in diameter; for wires, up to 22 mm; & for the dental blade implant, a 28 × 20 mm artifact	Although the selected dental appliances are safe when present in patients undergoing MRI, artifacts can substantially influence MRI results.
6)	Shafiei *et al.* (2003) [5]	11 dental casting or implant materials were imaged	1.5 T MRI apparatus with 3 different sequences.	A variety of artifacts with different magnitudes was observed. Only 1 sample, composed mainly of Pa, In, & antimony (Sb), showed no artifacts in any imaging sequences.	Selecting specific dental casting alloys according to their elemental compositions can minimize metal artifacts in MRI; however, Ti alloys currently pose a problem with respect to causing MRI artifacts.
7)	Hubálková et al. (2006)[6]	Dental alloys Ag, Au,Pd, Ni, Co,Ti and other materials	No or very week magnetic field induced 3T & 4T magnetic resonance	Material show Pulsed RF, no detectable heating showed by dental implant (<1 ˚C) Dental implants show no detectable movements.	The dental alloys including dental implants undergoing MR imaging don't represent any health risk.
				Any artifact present in CpTi would depend on impurities of other metal materials eg. Co-Cr,Co-Ni & SS. Dental metals are safe for patient undergoing MR imaging as temp change is up to 0.3˚C. Under 1.5 T MR environment dental implant did not display greater than 2˚ deflection angle.	Dental alloy described do not represent a health risk for patient undergoing MR imaging. Metallic objects fixed in orofacial area basically do not produce any movement in 1.5 MR system.
8)	K. Miyata et al (2012) [7]	Cylindrical implant keeper (GIGAUSS D600, D400, D1000) with coping of casting alloy and the keeper with dental implant (Ti)	3T MRI (Achieva 3.0T Nova Dual & Signa HDxt 3.0T)	RF heating - maximum temperature Implant - 0.4˚C with Achieva 3.0T - 0.6˚C with Signa HDxt Deflection angle measured for keepers were over 90˚ extra weight from 3 to 9 gram required to constrain deflection angle to less than 45˚	Relatively minor RF heating (temperature increase - 0.8˚C) doesn't pose a risk to patient. Keepers are not expected to pose risk such as movement or dislodgement if properly cemented to prosthesis.
9)	Idetal et al (2013)[8] (article in Chinese)	Ti dental implants	1.5T & 3.0T MRI	Rise in temp. of Ti implants to be maximum of 0.4˚C	In this study, however Ti in a human mouth was not directly measured, so we need to attempt to perform MRI on patients with Ti implants.
10)	MARINCAS et al (2013)17	Dental implants	3T MRI	Temp. elevation of less than 1˚C in all studied configuration	Dental implants don't present a risk from RF overheating during an MRI examination at 3T.
11)	Duttenhoefer et al. (2015)[11]	Dental implants	3T MRI, T1 weighted TSE and T2 weighted TSE sequences	Post implantation, while Ti implants induced strong $B_{\circ}$ - field distortion resulting in extensive signal voids, zirconium implants were clearly depicted with only minor distortion.	MRI is valuable imaging modality for zirconium implant but with Ti implant produce pronounced artifacts.
12)	P. Korn et al (2015)[9]	Ti coated polyetherether ketone (PEEK) implanted in mandible of mini pigs	7T Bruker Avance non clinical NMR spectrometer	No image artifact No significant movement of implants seen in the bone of mini pigs.	The developments of this innovation shows desirable results and prove compatibility of dental implant with MRI imaging. But unfortunately it is a animal

					study and require more wast tissue engineering research.
13)	Yacine Noureddine et al (2015)[10]	Dental implants (93), orthopedic(22), vascular prosthesis (2), intrauterine devices (15) & infusion pumps (2)	A whole body 7T MRI system of 230 subjects. 93 out of them had their implant located in orofacial region	No healing No displacement Artifact present due to metallic dental implant close to imaging area of interest	Ti is a biocompatible material and has a low magnetic susceptibility and is there for an advantageous material for MRI In conclusion their initial experience at 7T indicates overly conservative exclusion of all subjects with implant from 7T examinations is not warranted Imaging should only be performed carefully
14)	Oriso et al (2016)[13]	Dental implant	7T & 3T MRI system	Deflection angle for dental implants are minimal ranging from 5˚ to 6.5˚ at 7T & 0.5 to 2˚ at 3T 50 mm implant - increase 1˚ C temperature 7-13 mm implant - 0.8˚C or less	At 7 T osseointegerated implants showed no apparent translational attraction or heating
15)	Smeets et al (2017)[14]	ZrO2, Ti and Ti - ZrO2 alloy implants	3T MR scanner	Ti and Ti-Zr alloy induced an extensive signal void in MRI (strong susceptibility MR signal attenuated up to 14.1 mm from implant) Zr implants were clearly definable with only minor distortion artifacts	MRI allows excellent image contrast and limited artifacts for Zr implants. Ti exhibited pronounced artifacts in MRI closely followed by Ti- ZrO2 alloy
16)	Chockattu et al (2018)[15]				Dental implants are made of non -ferromagnetic materials (titanium) and contain traces of ferromagnetic iron which causes a drop out of signal near metallic surface
17)	Margit - Ann Geibel et al (2018)[16]	Comparison of dental ceramic and Ti implants	3T MR used	Use of MRI for 3D visualization of Ti and ceramic implants UTE & FFE didn't show significant difference in case of ceramic but significant difference observed in case of Ti dental implants as artifact. SD for ceramic SE- 6.4 ± 2% SD for Ti SE - 2157 ± 810 %	All Ti implants cause artifact were quite significant as compare to ceramic implants, but on the basis of safety there is no documentation in this article So, MRI can be used to evaluate the periphery of Ti implants.

2. Material and Methods

This study aims to collect and evaluate the existing knowledge about the safety of dental implant during MRI. A PubMed database search was conducted to identify relevant publication. The following search term including Boolean operators were used:

(Dental AND ((implant OR implant) AND ((MRI))), (Safety of dental implant AND ((MRI))), (compatibility of MRI AND ((dental implant))). This returned 82positive results from 1988 to 2021, all results were scrutinized, and articles were downloaded for further investigation.

Furthermore, the bibliographies of all downloaded articles were screened manually to identify the relevant studies.18articles were found to be relevant for this review, of which majority of articles were in English, 1 article was in Chinese & 1 was in French.

Inclusion criteria: Studies involving dental implants and other medical implants, Dental implants made of any material, articles in all languages, invitro, animal studies, clinical studies and review articles were included. Articles based on MRI and medical implants including dental implants interactions, their safety and potential risk, articles in any language, invitro, animal studies, clinical studies, RCT, metanalysis, and review articles were included in this literature.

Exclusion criteria:

1) Studies in which MRI used for preoperative and postoperative purpose.
2) Dental alloys not used as implant.
3) Not including interaction between dental implant and MRI, were excluded.

3. Result and Discussion

MRI is a non invasive imaging technique which uses strong magnetic field. It is a commonly used diagnostic tool because it has an excellent soft tissue contrast. MRI is widely used for musculoskeletal and cerebrovascular imaging including oral and maxillofacial region for diagnosing, staging and follow up purpose.

Dental implant is a metallic alloy which is used to replace the root of missing tooth, over which prosthesis is placed after osseointegration with bone. It was invented in 1952, from then it is widely used for teeth replacement. Implant provides a strong foundation for permanent or removable replacement teeth that are made to simulate natural tooth. It is most commonly made of Ti, which is an inert and biocompatible metal.

Increasing number of indications for MRI is associated with a growing no. of patients with metal devices present in oral cavity including dental implants. Therefore it is necessary to know the interaction between MRI and dental implant. Three most commonly encountered interactions are : 1) device movement i.e. deflection and torque induced by magnetic field. 2) device heating i.e. heating induced by arching effects.3) imaging artifacts i.e. distortion of MR images by various materials caused by disruption of local magnetic field resulting in a change in the position frequency relationship.

Devge et al (1997)[1]stated that artifacts caused by implants were minor and did not jeopardise scan evaluation. Smeets et al (2017)[15] evaluated MRI allows excellent image contrast and limited artifacts for Zr implants but Ti exhibited pronounced artifacts in MRI closely followed by Ti- ZrO2 alloy. Zr does not show promising results for future because fabrication of surface modifications for zirconia is difficult, CO2 lasers revealed distinct surface alterations to zirconia. Studies showed that Coated or surface-modified zirconia implants showed higher removal torque values than machined zirconia implants. Although a few short-term clinical reports are available and provide satisfactory results, controlled clinical trials with a follow-up of 5 years or longer should be performed to properly evaluate the clinical performance of zirconia implants and to recommend them for routine clinical use. Margit-Amm Geibel et al (2018)[17]reported that all Ti implants resulted in significant artifact formation as compared to ceramic implants, therefore MRI cannot be used to evaluate the periphery of Ti implants.

Beth A. schweler (1999)[2] concluded that medical implantable devices are safe and compatible with MR imaging using 1.5 T MR radiations. Hubálková et al. (2006)[6] described that dental implant show no detectable heating (<1 ˚C) and movement at 3T and 4T MR. (r=these results were in accordance with K. Miyata et al (2012)[7]stated Relatively minor RF heating (temperature increase - 0.8˚C) at 3T doesn't pose a risk to patient. Keepers are not expected to pose risk such as movement or dislodgement if properly cemented to prosthesis. Oriso et al (2016)[13] described that dental implant shows deflection angle ranging from 5° to 6.5° at 7T & 0.5° to 2° at 3T, 50mm implant increases 1°C& 7- 13mm implant increases 0.8°C or less.

According to above studies, MRI shows no significant deflection and RF heating of dental implant at 1.5 T,3T, 5T, 7T & 8T but noticeable artifact occur around periphery of dental implant.

4. Conclusion

Use of dental implant as a prosthesis & MRI as an imaging tool is prevalent now a days. The interaction between these two is device heating & mechanical movement which are negligible but artefacts will be produced. But artifacts only occur in the peripheral region of the implant & are not affecting the surrounding anatomical structures imaging. Most of the studies conducted are invitro in which phantoms are used; therefore there is limited knowledge about the interactions between MRI and dental implant in oral cavity. Based on the information available we can conclude that patient with dental implant can undergo MR imaging safely.

But further studies are needed to test whether the differences in artefact induction reported here will hold true after osseous insertion and in vivo studies are also needed for their justification.

5. Future Scope

The literature review provides evidence that MRI doesn't cause any harmful effect on dental implant and surrounding soft tissue. However there is need for future research on this topic that could help and promote the effective use of MRI in patients with dental implant. The results could provide future guidance and policies for safety of patients with dental implants during MRI.

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