REVIEW ARTICLE

A SYSTEMATIC REVIEW ON INTERACTIONS AND EFFECTS OF VARIOUS DENTAL MATERIALS ON MAGNETIC RESONANCE IMAGING

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ABSTRACT

Magnetic Resonance Imaging(MRI) is a non invasive imaging procedure for hard and soft tissue lesions. It is very useful for patients with seizures, tumours, Temporomandibular jointdisorders and Cerebrovascular accidents. However in patients with pacemaker, neurostimulator, fixed metal prosthesis Magnetic Resonance Imaging is contraindicated as these devices may be dislocated or soft tissue burns may occur. In Magnetic Resonance Imaging of the head neck region various dental materials present in the area of interest may cause image artifact. In this systematic review of literature we aim to find out the effect of various dental materials on Magnetic Resonance Imaging and vice versa.

KEY WORDS

Magnetic Resonance Imaging, Dental Materials, Artifact, Metal prosthesis

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INTRODUCTION

Magnetic Resonance Imaging (MRI) is a relatively modern non invasive, imaging modality for diagnosis in medicine and dentistry. It creates three dimensional images using a strong uniform static magnetic field and radio frequency pulses[1]. This is advantageous over the two dimensional images of conventional radiographs using ionizing radiations. In the head neck region MRI is used to detect tumours, Temporomandibular Joint disorders, for seizures and cerebrovascular accidents as they provide high spatial resolution images of hard and soft tissue in various planes. However the presence of substances that can be magnetized in the study area results in MRI image distortion and other medical complications. Patients in whom MRI poses a high risk are individuals with biomedical devices and implants such as pacemaker, cochlear implants, neurostimulators, infusion pumps, fixed metal prosthesis and aneurysm clips. MRI is contraindicated in them as these devices may become nonfunctional resulting in life threatening situations, may be dislocated and soft tissue burns may occur. Various dental materials can also cause complications in MRI of head neck region as well. The susceptibility of dental materials to a magnetic field and their result on images has been sparsely studied and documented. Also material science does not report much about the effect of magnetic field over dental materials. This article tries to review systematically the effect of magnetic field over the dental materials used and their effect on the images produced.

METHODS

This study has been reported as per the PRISMA reporting guidelines (Fig1) PROSPERO at present does not accept scoping reviews, literature reviews or mapping reviews. So, the study could not be registered with PROSPERO.

The study was performed through the search engine PUBMED on international literature. Studies published from January 2000 to April 2022 were considered. The Medical subject headings used were: Effects and artifacts of dental materials on

MESH TERMS	TOTAL RECEIVED PAPER	TOTAL SELECTED PAPER
1. MRI and Dental Amalgam	32	9
2. MRI and Dental Crown	52	14
3. MRI and orthodontic bracket	46	19
4. MRI and titanium dental implants	29	10
5. MRI and composite resin	25	4
TOTAL	**184**	**56**

Table 1- Search result obtained with various Mesh terms

MRI, MRI & dental amalgam, MRI & dental crown, MRI and orthodontic brackets, MRI and titanium dental implant, MRI and composite resin. The literature search was performed by two independent reviewers.

The inclusion criteria were English language publications, Reviews and Clinical research. Case reports, Research on MRI techniques to avoid artifacts, foreign language publications were excluded. Any disagreement regarding study eligibility was sorted through discussion. Only articles pertaining to dental materials were considered.

RESULTS

Table 1 shows the results obtained with various Mesh terms.

With a more direct search heading 'Effect and Artifacts of dental materials on MRI' total articles found were 41 among which 11 were relevant. Therefore finally 56+11=67 articles were included. Careful assessment revealed 12 articles to be repetition. So for final screening 55 articles were selected. After studying the abstract, full text of 15 articles were selected and after analysis one was rejected as it was not original. So 14 articles were extrapolated for this review along with their relevant references.

DISCUSSION

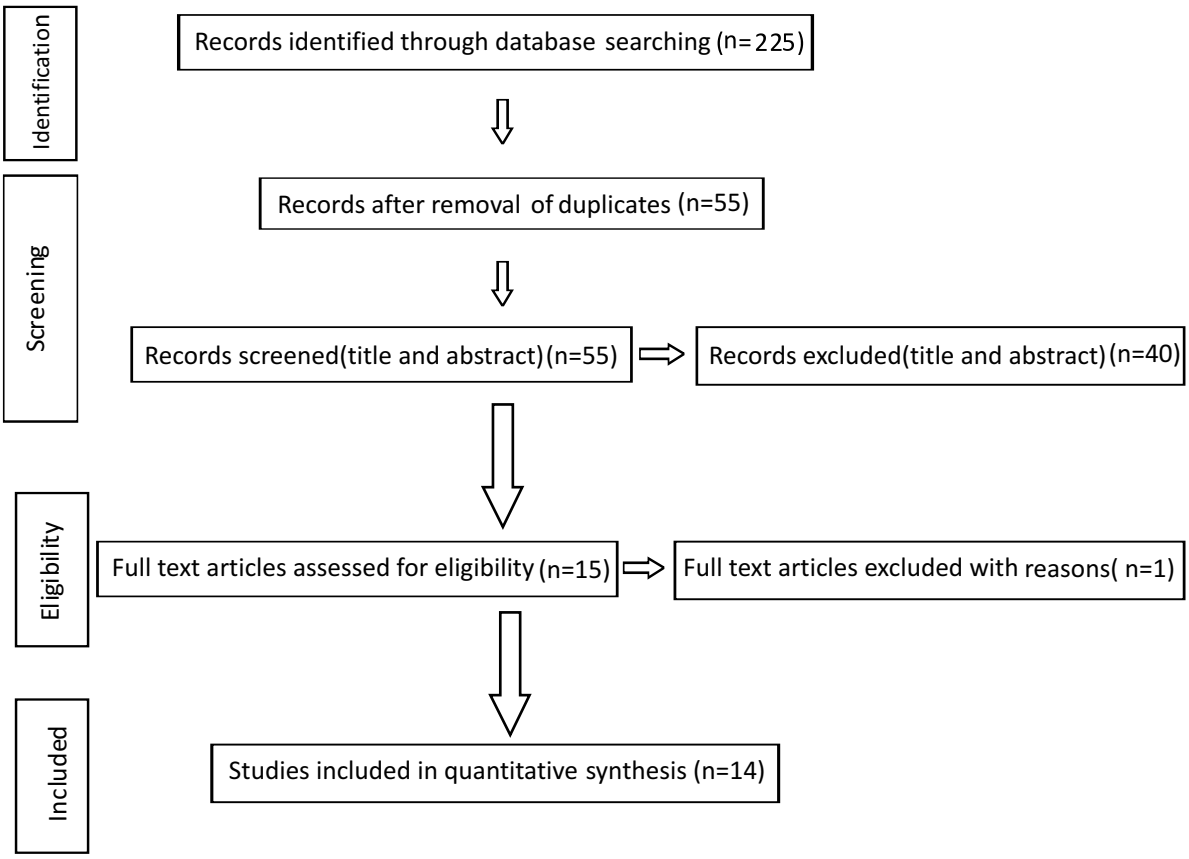
MRI and its mechanism

MRI creates images using a strong uniform static magnetic field and radio frequency pulses. Most MRI machines are large tube head shaped magnets that align atomic particles called protons present in the body especially soft tissues, which in turn produce signals through the induction of radio waves that are picked up by the receiver within MR scanner resulting in the creation of cross-sectional magnetic resonance (MR) images[2,3]. The images are constructed from the rate of decay or relaxation of proton resonance in a plane longitudinal (T1 images) or transverse (T2 images) to the magnetic field plane.

Compatible	Materials presenting no detectable distortions and can be present in the tooth of interest	Resin based sealer Composites(3M ESPE) Glass Ionomer Cements Gutta percha Zirconium Oxide
Compatible I	Produces noticeable distortion but depending on application image may be acceptable	Amalgam Composites (Ivoclar Vivadent) Gold alloy Gold ceramic crown Titanium alloy NiTi alloy wire
Non Compatible	Materials producing strong distortion even when located far from imaging area	Cobalt chromium Stainless steel wires and brackets

Table 2- Classification of dental materials based on magnetic susceptibility[7,40]

FIG-1: PRISMA FLOW CHART



Based on magnetic field strength MRI machines may be LOW FIELD SCANNERS (0.23T-0.3T) or HIGH FIELD SCANNERS (1.5T to 3.0T). Compared to Earth's magnetic force (50μT) a 3.0T scanner is 10.000 times more powerful. ULTRA HIGH FIELD SCANNERS (7.0T-10T) are also available and used for research purpose only[4].

Classification of Dental Materials according to their interaction in the magnetic field

Magnetic susceptibility is an inherent property of matter originating from its electron structure and is the tendency of an article to attract magnetic lines of force[4]. Magnetic susceptibilty artifacts occur at interfaces of substances with different magnetic susceptibilities. Spin dephasing and mismapping artifacts associated with frequency shifts cause signal loss over strong susceptibility gradients[5]. Based on magnetic susceptibility dental materials may be[3,6-10]:-

Diamagnetic - Materials that are repelled by magnets Magnetic field lines are thinned or dispersed and they are least likely to cause an artifact. Eg:- Gold, Silver

Paramagnetic - Materials that are not very strongly attracted by magnets. Slightly magnetized when placed in a strong magnetic field and the magnetic field lines are somewhat concentrated on them. Less likely to cause an artifact. Eg:- Dental Amalgam

Ferromagnetic- Materials that are strongly attracted by magnets. Magnetic field lines are concentrated in them. Causes definite MRI artifacts. Eg:- Stainless steel, Nickel. Chromium oxide, Cobalt, Rare earth magnets.

Types of Unwanted Effects

Interaction between the magnetic field and dental materials can cause the following unwanted effects:-

Artifact Formation - It is defined as the distortion of signal intensity or void that does not have any anatomical basis and do not faithfully represent the tissue components being studied[11,12]. Artifact formation depends on magnetic susceptibility of the metal object causing the artifact, shape, size, position, orientation and number of objects, homogenicity of the alloy and MRI sequence and parameters used[7,13].

Radio frequency heating- Interactions between metallic objects in the human body and MRI can result in radiofrequency (RF) heating[14]. Oral mucosa can withstand temperature rise upto 10˚C beyond which tissue injury can occur[15]. Studies have shown that there is relatively minor RF heating of dental casting material based prostheses under 3.0T MRI. However, orthodontic appliances exhibit heating therefore, a spacer might be required between the appliance and the oral mucosa or the wire should be removed from the bracket before MRI [16].

Magnetically induced displacements- The powerful magnetic field of MRI system will attract the ferromagnetic objects towards the scanner at a very high velocity (projectile effect)[17]. This can cause discomfort or injury to individuals having ferromagnetic prosthesis. Miyata et al. found that the magnetically induced deflection force acting on ferromagnetic keepers was strong. However, they were cemented onto or cast to a dental prosthesis and the strength of the dental cement used for luting was sufficiently strong to prevent dislodgement[18]. So, the fixation of the ferromagnetic prosthesis must be checked before and after MRI due to the possibility of cement degradation.

Factors influencing unwanted effects are Magnetic susceptibility and magnetic permeability, Electrical conductivity of the dental material[7], Tensile strength of the dental material[13] and MRI imaging sequences.[20-22]

The greater the magnetic permeability of a material more is the magnetic field distortion (site of resultant artifact) it will produce[3,13]. Thus alloy composition is important in creating artifacts in MRI. Other important factors include the size and shape of the metallic material as well as its position in the body[8]. MRI without artifacts is possible even in close proximity to dental materials (eg. Amalgam, titanium, precious metal alloys) when they have a low magnetic susceptibility. Unfortunately not all dental materials used currently meet this criteria of low susceptibility[8].

$\mu = 1+x$ {μ= magnetic permeability; x= magnetic susceptibility }

Magnetic susceptibility is synonymous with magnetizability[19]. It is a measure of the extent to which a substance becomes magnetized when placed in an external magnetic field. The magnetization of a material is proportional to the applied field by a dimensionless constant which is magnetic susceptibility or magnetizability (x).

Artifacts in MRI imaging due to various commonly used dental materials

Orthodontic appliances: As found by Costa et al[3] and other researchers 78% of MRI artifacts due to dental appliances is because of the various orthodontic attachments. Niti and stainless steel arch wires are used with stainless steel brackets and since nickel and chromium are both ferromagnetic they cause significant signal distortion. So where possible they should be removed prior to MRI scans. In case removal is not possible their bonds should be checked prior to scan, a non ferromagnetic wire may be placed to keep the brackets together and the plane of scan if possible should be altered to avoid these attachments[23].

Gorgulu S. et al[2] in their studies found that with regard to magnetic field interactions, brackets can be considered "MR safe"; however, it would be safe to replace the wires before MRI. Casetta et al[24] however recommends removal of all stainless steel multibracket orthodontic appliances before cervical vertebrae, cervical region, paranasal sinuses, and head and neck MRI scans. The brain and temporomandibular joint region MRI should not require the removal of such appliances. Ceramic brackets with metal slots and titanium brackets do not always require removal prior to head neck MRI[25,26]. It depends on the area of interest. If the oral cavity itself is under investigation, metal fixed retainers need to be removed[27]. In all MRI scans of the head neck region stainless steel brackets have to be removed.

Dental Crowns: Can be made of Gold/Nickel Chromium/Metal Ceramic/Ceramic/Zirconia. Gold is diamagnetic but gold crown contains traces of ferromagnetic materials. According to Eggers et al.[28] even small amounts of a ferromagnetic substance can cause an extensive blank in the image. Abbaszadeh et. al.[4] in their in vitro study had reported significant distortion due to gold in MRI scans. However, Costa et al[3] , in their study involving MRI scans of epileptic patients with dental devices found dental crowns generated little distortion of the image, only visible in the sagittal plane. Later Tymofiyeva et al[7] classified gold and gold ceramics as MRI compatible.

Precious metal alloys, Nickel Chromium alloy and Cobalt chromium alloys used as metal copings for dental porcelain cause MRI artefacts the area of which increase with the strength of magnetic field[29]. Metal ceramic crowns cause significant signal distortion due to the presence of nickel chromium or cobalt chromium metal copings.

MRI signal distortion is greatest when the material is within 10cm of the area of interest[6]. Therefore there will be little or no impact on image quality due to metal, metal ceramic or preformed metal crowns on MRI conducted in other parts of the body. Also MRI scans of regions other than head and neck are least likely to displace PFMC or other ferromagnetic dental prosthesis as they are distant to the oral cavity[30].

Cortes et al[31] analyzed the impact of Nickel Chromium metal ceramic restorations and found a significant correlation between echo time and artefact area in gradient echo pulse sequence images and suggested that this can be compensated by setting optimized pulse sequences.

Preformed metallic crowns commonly used in paediatric dentistry contain austenitic stainless steel alloy which is the same as that for orthodontic brackets. So as long as they are securely attached they can be considered MRI safe[32]. However where required radiologists may ask for removal of dental restorations containing metal alloys.

Ceramic and Zirconia crowns have gained much popularity. They are considered as MRI compatible.

Xu et al [29] found that artefacts due to Zirconia and casting ceramics were almost absent. But Klinke et al[9] found that Zirconia frame work also caused artifacts like metal based materials on MRI of the lower midface. Infact they also proposed that ingredients like Ytterbium trifluoride, Ferric oxide and lanthanum oxide found on composites as coloring agents caused image disturbances in CT and MRI.

Post and Core- Similar to crowns post and cores composed of cobalt chromium alloy generated severe artifact. Gold palladium alloy post core and zirconia post core produced no effect. Titanium alloy post and cores produced mild artifacts[33].

Dental implants- Made of titanium, a paramagnetic material. Generally induces mild to moderate artifacts compared to other metallic prostheses due to the traces of ferromagnetic iron present[9]. It was observed by Costa et al[3] that titanium implants caused artifacts in all planes resulting in severe blooming that hampered diagnosis but less than orthodontic appliances. Other authors[28,34] however reported that titanium caused only minor artifacts and allowed good visualization. But implant restorations are combined with prosthesis abutments, screws and crowns in clinical settings creating a signal loss[35].

Hilgenfeld T et al[36] observed that precious metals and zirconia crowns are favourable in terms of low artifacts rather than non precious metal crowns when combined with titanium implants. Devge et al[10] also found that implants caused minor artefacts that did not jeopardize scan evaluation. However magnet keepers attached to implants caused major artefacts and are recommended to be removed before MRI scan.

Dental Amalgam - Costa et al[3] in their study found that no artifact in brain MRI is created due to dental amalgam restorations. Dental amalgam alloy has little influence on dental MRI as silver which is the primary component is a diamagnetic material[37]. However MRI may not be safe for dental amalgam.

Shahidi et al[38] found that MRI led to the appearance of thermoelectromagnetic convection which is responsible for the enhancement of the diffusion process, grain boundary migration and vacancy formation resulting in microleakage. Therefore following MRI exposure marginal seal of amalgam restorations need to be checked. Studies have also found increased release of mercury from amalgam restoration following high field MRI[39].

Tooth coloured direct restorative materials - Glass ionomer cements produce no detectable distortion on MRI [7]. Composite resin may cause may cause some artefacts due to the presence of ferromagnetic material in the colouring agent[7].

Endodontic material- Resin based sealers and Gutta percha produce no detectable distortions[40].

So based on magnetic susceptibility dental materials can be classified as shown in Table 2 [7,40]:-

CONCLUSION

Within the scope and limitations of this review the following observations can be made:-

Zirconium oxide, Titanium alloy can be safely used in the oral cavity when MRI interference is concerned.

Orthodontic stainless steel wires and cobalt chromium based dental prosthesis need to be removed before head neck MRI

Composite, Amalgam, Glass Ionomer Cement, Gutta Percha can be considered MRI safe.

As maximum radiation loss occurs when the material is within a radius of 10 cm of the region of interest , careful consideration should be made by the clinician prior to requesting for removal of any dental appliance.

Further evidence based studies into modification of MRI sequences and techniques to best overcome the effect of dental materials in the oral cavity are required.

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