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Artifacts in MRI Due to Dental Restorations: A Narrative Review

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Abstract
Magnetic Resonance Imaging is an advanced non-invasive method to detect the internal structures, differentiate between soft tissues and hard tissues. Unfortunately, the magnetic field and radiofrequency pulses generated within the magnetic resonance imager interact unfavorably with dental materials that have magnetic properties and leads to unwanted effects such as artifact formation. These are a potential source of damage to the oral tissue surrounding the affected dental materials. An MRI- induced artifact is defined by pixels that do not optimally or properly represent the tissue components under study. An MRI-induced artifact is directly proportionate to the ferromagnetic content of a material. Based on currently available evidence this narrative review aims to compile recommendations for dentists and radiologists regarding the artifact caused in MRI of patients with direct and indirect dental restorative materials.

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I. Introduction

Imaging is an essential step of diagnosis in medicine and dentistry. Conventional radiographic methods used in dentistry like intraoral radiographs, orthopantomograms have constraints, since they capture the 2-dimensional image of a 3-dimensional object and radioactivity.(1) Modern imaging techniques include computed tomography (CT), cone-beam CT, magnetic resonance imaging (MRI), ultrasonography, and positron emission tomography. MRI, when indicated, is advantageous over other imaging techniques because it provides better soft-tissue contrast and can differentiate better between hard and soft tissues, the images are obtained in various planes, it is non-invasive and does not use ionization. MRIuses a strong uniform static magnetic field for image formation When placed in a magnetic field, all substances are magnetized depending on their magnetic susceptibility.(2) Variations in the magnetic field strength at the interface between dental materials and the adjacent tissue can also cause spatial distortions and signal loss, resulting in artifact formation in the image.3Presence of metal objects in the field of views such as dental restorations, orthodontic bands, surgical plates, and pins can cause this type of artifacts. The metal materials highly impair the x-ray beam resulting in incorrect diminished values of objects behind the metal. However, information on the extent of dental restorations to induce unwanted effects in MRI is not readily available.(3)

In the MRI, images are formed using a strong uniform magnetic field and radiofrequency pulses. The substances when placed in a magnetic field are magnetized at various degrees depending on their magnetic susceptibility. The MRI image quality can be markedly degraded by artifacts caused by dental materials.This limits their usefulness as diagnostic tools. Artifacts might mask a pathology (e.g. tumors, inflammatory tissues) or obscure the anatomy of the area examined and make it difficult to diagnose. Many studies have investigated

the artifacts generated by metals and dental restorative materials used in dentistry on MRI.D B Hinshaw Jr et al. discussed artifacts that were caused by some materials commonly used in dental restorations, mainly stainless steel materials, such as metal pins and posts.(5) Fache JS et al. Evaluated artifact production in MRI due to various dental materials. Their study analyzed and compared the magnetic susceptibility and artifact caused by different dental materials. They concluded that the size of an artifact and magnetic permeability of the dental materials are related.(6) New PF et al. investigated the intensity of MRI artifacts in dental amalgam. Starcukova et al. showed that MR imaging without artifacts is possible only if they are made of materials with low magnetic susceptibilities such as amalgam, precious alloys, and titanium. However, they mentioned that not all dental materials in the current use meet this criterion of low magnetic susceptibility.(7) Although the previously mentioned studies have described the effects of metallic objects on MRI interpretation, a few have addressed the effect of non-metal-based materials on MRI image quality.

Although the magnetic susceptibility values of dental restoration such as multiple metal crowns, dental amalgam, composite, and glass ionomer cement are not sufficiently available. This narrative review aims to compile, based on the currently available evidence, recommendations for dentists and radiologists regarding the artifact caused in MRI of patients with dental restorations. The reporting of this review conforms to SANRA (Scale for Assessment of Narrative review Article) guidelines, a brief appraisal for the assessment of nonsystematic reviews.(8)

II. Methodology.(9)

An Internet search was conducted to find relevant articles published from year January 2000 to September 2020 regarding the artifacts in MRI due to dental restorations. The used search engines were Cochrane, Google Scholar, PubMed/Medline, Web of Science, and Scopus. The keywords were selected based on Medical Subject Heading (MeSH). The keywords searched were MRI artifacts, dental restorations, composite resin restorations, dental amalgams, glass ionomer cement, full metal crowns, and metal-ceramic crown restorations. More than 350 articles were initially found. The study was included if it provided information to at least one of the dental restorations known to cause MRI artifacts. The original research articles and review articles were collected and evaluated one by one. Each article was read at least twice, and the information was summarized. Other keywords were searched for more general evidence (such as the MRI artifacts in dentistry, artifacts due to dental restoration). Inclusion criteria were English language, Artifacts due to amalgam, glass ionomer cement, composite resins, full metallic crowns, metal-ceramic crown, and zirconia crown restorations. As an exclusion strategy, Artifacts in MRI due to reasons other than restorations were excluded. Many studies have exhibited the role of dental restorations in MRI artifacts. The search resulted in 31 articles. The total number of papers that met the inclusion and exclusion criteria for this review was 17.The summary of these studies is presented in Table 1.

Table 1: Summary of included articles

Sl. No.	Name of authors	Name of articles	Dental restorative materials studied.	MRI specifications
1.	Mazumdar P et al(10)	Artifacts in MRI due to dental restorations: Fact or myth	Composite resin, Co Cr full metal crown, metal ceramic crowns, Glassionomer cement.	T1-weighted MR imaging.
2.	Chockattu SJ et al(8)	Unwanted effects due to interactions between dental materials and magnetic resonance imaging: a review of the literature	Dental amalgam, Composite resins, Ni-Cr metal-ceramic restorations	T1-weighted MR imaging.
3.	Thomas K et al(4)	Artifacts In Magnetic Resonance Imaging and Computed Tomography Caused By Dental Materials	Al, silver alloy (Ag), type IV gold alloy (Au), gold-palladium silver alloy	1.5 & 3 T MRI scanners; GRE, SE & UTE pulse sequences.
4.	Tymofiyeva et al.(11)	Influence of dental materials on dental MRI.	Co cr alloy, All metal crown, Composite restorations	1.5 T MRI apparatus; in axial, coronal, & sagittal planes; T1-weighted SE sequence (TR/TE) & T2-weighted TSE sequence were used.

5.	S M J Mortazavi et al.(12)	Effect of magnetic resonance imaging on microleakage of amalgam restorations:	Dental amalgam	3 T–T1WI & T2WI images.
6.	Taniyama T et al.(13)	Metal artifacts in MRI from non magnetic dental alloy and its FEM analysis.	Co cr alloy, All metal crown	1.5 T MRI apparatus; in axial, coronal, & sagittal planes;
7.	Holton A et al.(14)	Comparative MRI compatibility of 316 L stainless steel alloy and nickel-titanium alloy stents	Amalgam restoration	T1-weighted MR imaging.
8.	Eggers G et al.(15)	Artefacts in magnetic resonance imaging caused by dental material.	Ni-Cr metal-ceramic restorations	3 T–T1WI & T2WI images.
10.	O Buef et al.(16)	Correlation between magnetic resonance imaging disturbances and the magnetic susceptibility of dental materials.	Dental Au, amalgam, S.S., Ti, Ag-Pa,	1 T; T1 and T2 weighted and proton-density images.
11.	Abbaszadeh K et al.(17)	Effect of interference of metallic objects on interpretation of T1-weighted magnetic resonance images in the maxillofacial region.	Co Cr, Ag-Pa, & vitallium	T1-weighted MR imaging.
12.	K S Oikarinen et al.(18)	Visibility of foreign bodies in soft tissue in plain radiographs, computed tomography, magnetic resonance imaging, and ultrasound.	4 samples of different sizes of fractured tooth crown, pieces of amalgam, glass, asphalt, composite, dry wood, and stone (embedded in soft tissue)	1 T; T1 and T2 weighted and proton-density images.
13.	Destine Det al.(19)	Metallic artifacts in MRI caused by dental alloys and magnetic keeper.	1 pre-fabricated magnetic keeper and 4 clinical dental alloys (Au-Ag-Pa, casting Au alloy type 3, Co-Cr, Au porcelain alloy); in total, 2 metal crowns & 5 magnetic keepers were analyzed	1.5 T MRI apparatus; in axial, coronal, & sagittal planes; T1-weighted SE sequence (TR/TE) & T2-weighted TSE sequence were used.
14.	Cortes LF et al.(20)	Artifacts in brain magnetic resonance imaging due to metallic dental objects.	Ni-Cr metal-ceramic restorations (i.e., dental crowns & fixed bridges) and cylindrical reference specimens	1.5 & 3 T MRI scanners; GRE, SE & UTE pulse sequences.
15.	Hua X Ket al.(21)	Comparison of magnetic resonance imaging artifacts of five common dental materials.	3 metals and 2 ceramics, fabricated to same size and thickness of incisor crown	Different sequences of 3 MRI field strengths: 0.35, 1.5 & 3 T–T1WI & T2WI images.
16.	Murakami S et al.(22)	A standardized evaluation of artefacts from metallic compounds during fast MR imaging.	7 metallic dental materials: Al, silver alloy (Ag), type IV gold alloy (Au), gold-palladium silver alloy (Au-Pd-Ag), Ti, Ni-Cr & Co-Cr alloy	T1weighted SE

17.	Lan G et al.(23)	Pu W, Haili H. Contrastive analysis of artifacts produced by metal dental crowns in 3.0 T magnetic resonance imaging with six sequences.	Crowns of Co-Cr, Ni-Cr, Ti alloy & pure Ti	3 T MRI with 6 sequences: T1weighted SE, T2 weighted-inversion recovery, T2 star GRE, T2 weighted-FSE, T1 weighted-fluid attenuate inversion recovery, and T2 weighted-imagin

III. Discussion

The MRI is a non-invasive method of diagnosis with the principle of using non-ionizing radiofrequency electromagnetic radiation in the presence of controlled magnetic fields. It produces high-quality cross-sectional images of the body.(24) MRI technique has evolved through the years. In 1973 Lauterbur produced the first nuclear magnetic resonance image.

Patients with dental restorations may require magnetic resonance imaging (MRI). MRI of the head and neck is used to evaluate the progress of degenerative diseases and the cause of any subsequent symptoms, or to evaluate pathologic conditions related to the brain, midface, and pharynx.(4)

Working principle of MRI

According to the book "MRI: Principles and Artifacts" by R. Edward Hendrick (1993) MRI creates detailed images of organs and tissues within the body using a strong uniform static magnetic field and radio waves.(25)

i. 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.

ii. Modern MRI machines use magnets with a field strength of 0.5–2 tesla (T). Most MRI machines use radio wave induction to produce signals. It has large tube-shaped magnets that align the water molecules in the body for producing signals. This creates cross-sectional magnetic resonance (MR) images.

When a patient with dental restorations undergoes MRI, the following problems can be encountered:(5)

i. Movement/dislodgement of dental materials (leading to accidents) because of a high magnetic field.

ii. Artifacts in MRI due to these dental materials.

iii. Thermal heating of materials due to radio waves (although negligible for dental materials).

Artifact formation in MRI

An artifact may be defined as a distortion of signal intensity or void that does not have any anatomic basis in the plane being imaged. It can also be defined as the pixels that do not exactly represent the tissue components being studied.(26)

Factors affecting the severity of artifact formation.(26)

a) The magnetic properties of the metal object that causes the artifact.

b) The shape, position, orientation, and the number of objects.

c) The homogeneity of the alloy, and the sequence parameters used in MRI.

Artifacts can be classified into different types such as image-processing artifacts, patient-related artifacts, radio frequency (RF)-related artifacts, external magnetic field artifacts, gradient-related artifacts, errors in data, flow-related artifacts, and magnetic susceptibility artifacts. The magnetic susceptibility artifacts reflect the ability of a substance to be magnetized, especially by a metal.(27)

MRI is based on the dependence of the resonance frequency of a hydrogen (H) nucleus on the strength of the magnetic field to which the nucleus is exposed. Any intrinsic or extrinsic effect distorting the magnetic field results in spatial distortion of the image. The distortion of the magnetic field shifts the resonant frequency of the H nuclei at that point.

Potential sources of artifacts in MRI due to dental restorations:(28)

a) Distortion of the static magnetic field due to differences in the magnetic susceptibility of materials and body tissues

b) Eddy currents induced by alternating gradients and radiofrequency magnetic fields. The image distortion occurs due to eddy in the applied magnetic field. Eddy current artifacts are caused due to metallic objects in the magnetic field.

Depending on the magnetic field, three major types of alloys can be identified.(29)
i. Ferromagnetic substances are strongly attracted by a magnetic field. Three sub-types of ferromagnetism are iron (Fe), cobalt (Co), and nickel (Ni).
ii. Paramagnetic substances, which have unpaired orbital electrons and become demagnetized once the field is switched off.
iii. Diamagnetic substances, which have few unpaired orbital electrons and therefore induce weak magnetic fields.
Ferromagnetic substances are strongly attracted by a magnetic field and thus have a high potential for causing MRI artifacts. Diamagnetic substances have a very weak and negative susceptibility to the magnetic field and paramagnetic materials have positive susceptibility and augment the external field, but both are far less likely to cause artifact.

The presence of ferromagnetic metals in some of the dental materials causes magnetic field inhomogeneity. The metal-based materials create their magnetic field and alter precession frequencies of protons in the adjacent tissues. An induced magnetic field influences the tissues adjacent to ferromagnetic components of the metal. Therefore they fail to generate a useful signal. However, in various literature, it was shown that not only metal-based dental materials cause susceptibility artifacts, but also non-metal materials can cause artifacts and disturbances in the MRI images.

Dental amalgam, composite resin, glass ionomer cement, full metal, metal ceramics, zirconia, and gold restorations are the most used materials in dentistry. The present review evaluated the artifacts on MRI records caused due to different dental restorations.

i) Glass-ionomer cement (GIC)
No detectable distortions on MR imaging were found in GIC restorations. They are classified as compatible with MRI (the material produces no detectable distortions).(15) In a study done by Mazumdar P et al, it was found that teeth restored with glass ionomer cement restorations were not the source of artifacts.(10)

ii) Composite resin

Tymofiyevaet al. found that the composite resins of some manufacturers were compatible on MRI, whereas other brands were compatible I (the material produces noticeable distortions, with the acceptability depending on the application; $3 < \Delta x < 200$ ppm). Ingredients such as ytterbium trifluoride, ferric oxide, and lanthanum oxide (coloring agents) cause image disturbances in MRI because they are ferromagnetic.(11)

A study done by Mazumdar P et al, stated that teeth restored with composite resins restorations were not the source of artifacts.(10) Another study done by Thomas K showed no artifacts in the case of composite resin restorations. It was concluded that rare earth elements such as Ytterbium trifluoride found in composites caused artifacts in MRI.(4)

iii) Dental amalgam

Dental amalgam is composed of several metals (silver, tin, copper, zinc, platinum, palladium, and mercury), with silver being the major component. Dental amalgam alloy has little influence on dental MRI because silver is a diamagnetic (non-ferromagnetic) metal. However, MRI is not completely devoid of any effects on amalgam restorations. Yilmaz et al. studied the effects of a 3 T magnetic field on amalgam restoration materials with different ratios of silver content (40%, 50%, and 70%), and found no significant differences in microleakage between the amalgam types (non-gamma-2 spherical amalgam versus non-gamma-2 admixed amalgam)whereas Mazumdar P et al. found that dental amalgam restorations generated little or no image distortion in the sagittal plane.(10),(30)

Indirect restorative materials
i) Gold crowns

The metals commonly used to manufacture crowns are gold, palladium, nickel, and chromium. Although gold is a diamagnetic substance, gold alloys contain traces of other ferromagnetic metals. According to Eggers et al., even small amounts of a ferromagnetic substance can cause an extensive blank in the image. This compositional difference accounts for discrepancies in study results regarding artifact formation with gold crowns.(15) Abbaszadeh et al. found significant image distortion in MRI; however, Fache JS et al. found that the impact of eddy currents was negligible, as a piece of dental gold studied in vitro, and extensive gold

restorations in the mouth of a volunteer revealed no distortions on the MRI scanner.(6),(17) Tymofiyeva et al. classified gold alloy and gold-ceramic crowns as compatible I, with the acceptability depending on the application.(11)

ii) Ceramic and metal-ceramic crowns

Tymofiyeva et al. classified gold-ceramic crowns as compatible I. Precious metal alloys, nickel-chromium alloy, and the cobalt-chromium ceramic alloy used as metal copings for dental porcelain display MRI artifacts. The artifact area increases with the strength of the magnetic field.(11) Mazumdar P et al analyzed that metallic Ni-Cr crowns have shown significant distortion is present in more than one tooth. The artifacts produced by metals correlate with variables like composition and number of metal crowns. Extensive metallic artifacts in the oral cavity and other areas (TMJ, posterior cerebral fossa, maxillary sinus), were produced in patients with multiple metal-ceramic crowns. Patients having seven to ten metal-ceramic crowns were a potential source of artifacts in MRI that made image interpretation impossible. The major artifact was found in patients with multiple metal (Ni-Cr) crowns. The artifact was faint or limited in patients with less than three metal-based crowns.(10)Hua Xi Kou et al.found that zirconia and casting ceramics presented almost no or faint artifacts.(21) In contrast, the study byK S Oikarinen at al. found that ceramic (zirconium dioxide) led to the same effect as metal-based materials on MRI of the lower mid-face.(18)Wedge-shaped specimens ($1 – 3.5 \times 9 \times 16$ mm) of the ceramic materials IPS Empress and Ducera gold showed artifacts less than 15 mm, while Cergo and Vita Omega 900 showed artifacts between 15 and 30 mm, and zirconium dioxide showed artifacts larger than 30 mm (the same as metal alloys).(31)

Artifacts elimination methods.

To deal with the distortion for imaging near metals, various techniques have been proposed. These techniques can be categorized into two and three-dimensional approaches. The slice encoding for metal artifact correction (SEMAC) technique, which includes the VAT gradients, is based on two-dimensional multi slice SE imaging and uses additional slice encoding to deal with the through-plane distortion. The multi-acquisition variable resonance image combination (MAVRIC) technique is based on the three-dimensional acquisition and acquires multiple images with a different center of excitation frequency to deal with a broad field perturbation. These techniques have different approaches of reducing the image artifact including the through-plane distortion, but all are revealing that MRI near metal prostheses is possible in imaging. The combination of the MAVRIC and SEMAC technique is known as MAVRIC-SL. Also, metal artifact reduction sequence (MARS), WARP (Siemens Healthcare, Munich, Germany), and slice encoding for metal artifact correction are recommended to reduce the size and intensity of susceptible artifacts resulting from magnetic field distortion. Other methods of artifact correction involve pulse sequence optimization, post-processing hardware improvement, and scan parameter. The orientation of the metallic object, an alloy used, and magnetic field strength, as well as the use of metal-suppression techniques, can be intended to reduce the artifacts caused due to metallic crowns.(32)

IV. Summary

As MRI is becoming widely used in dentistry, it is critical that dental practitioners are aware of the potential of dental materials to cause adverse interactions during MRI imaging. Dental practitioners must be acquainted with the composition of direct and indirect restorative materials in order to anticipate complications and take precautions prior to MRI in patients with the aforementioned dental materials. In order to anticipate complications and take precautions prior to MRI in patients with the aforementioned dental materials. The influence of other dental work in the mouth like wire splints, metallic orthodontic braces, implants may be studied for more complete knowledge.

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