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Interactions between metallic and non-metallic alloys of dental crowns in magnetic resonance imaging: an integrative systematic review

Lorenzo Giuseppe Formenti

Tese conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

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Trabalho realizado sob a Orientação de Professor Doutor Pedro Jorge Rodrigues De Carvalho Bernardino

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Lorenzo Giuseppe Formenti

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The Objective feeds on patience as much as it is on Desire

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Resumo

Objetivo: comparar a formação de artefatos de coroas com ligas metálicas nobres, não nobres e livres de metal. O objetivo secundário foi analisar se os exames de RM eram potencialmente perigosos em pacientes portadores de coroas dentárias fixas.

Materiais e métodos: Foi realizada uma pesquisa bibliográfica na base de dados PubMed usando os termos de pesquisa seguintes: (magnetic resonance imaging), (dental materials), (adverse effects), (artifacts), (dental crown). Foram selecionados estudos publicados em língua Inglesa desde 2005 até 2017.

Resultados: As ligas Co-Cro foram as materiais que em todos os estudos criaram maiores volumes de artefatos, juntamente com as materiais Ni-Cro. Em comparação, Ti e outras ligas preciosas criaram menores volumes de artefatos, enquanto restaurações de cerâmica e Zr não criaram nenhum ou muito pouco.

Conclusões: a presença de materiais ferromagnéticos como Ti, Ni-Cro e Co-Cro em áreas a serem scaneadas deve ser avaliada, pois pode produzir grandes artefatos. Os materiais não ferromagnéticos apresentam mínimas forças ou torques desprezíveis quando scaneados por ressonância magnética. O aquecimento da coroa não parece ser significativo ou prejudicial aos pacientes.

Palavras-chave: (ressonância magnética), (materiais dentários), (efeitos adversos), (artefatos), (coroa dentária).

Abstract

Objective: to compare the formation of crown artifacts with noble, non-noble and metal-free metal alloys. The secondary objective was to analyze if MR scans were potentially hazardous in patients carrying fixed dental crowns.

Materials and methods: a literature search was performed on the published database using the following data terms: (magnetic resonsaging imaging), (dental materials), (adverse effects), (artefacts), (dental crown). Studies published in English from 2005 to 2017 were selected.

Results: Co-Cro alloys were the materials that in all studies created the highest volumes of artifacts, along with Ni-Cro restorations. In comparison, Ti and other precious alloys created smaller volumes of artifacts, while ceramic and Zr restorations created none or very little..

Conclusions: the presence of ferromagnetic materials such as Ti, Ni-Cro and Co-Cro in to-be-scanned areas should be evaluated before the actual start of fast MR sequences, as they may produce large artefacts. Non-ferromagnetic materials pose either none or only negligible forces or torques when scanned by MR. Crown heating does not seem to be significant or harmful to the patients.

Keywords: (magnetic resonance imaging), (dental materials), (adverse effects), (artifacts), (dental crown)

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Index of abbreviations

MRI: magnetic ressonance

Co: cobalt

Ni: nickel

Cro: cromium

Fe: steel

Ti: titanium

Au: gold

Ag: silver

Al: aluminium

Pd: paladium

Zr: zirconium

T: tesla

CT: computed tomography

GRE: Gradient echo

SE: Spin echo

UTE: Ultrashort echo time

ET: Echo tim

1 Introduction

Magnetic resonance imaging (MRI), when indicated, is advantageous over other imaging techniques because it provides high spatial resolution images of hard and soft tissues, images are obtained in multiple planes, and does not involve ionizing radiation, unlike intraoral radiographs and computed tomography. This technique has become a common and important life-saving diagnostic tool in recent times for diseases of the head and neck region. [1–3]

MRI creates images using a strong, uniform static magnetic field and radio frequency pulses. When placed in a magnetic field, all substances are magnetized to a degree that depends on their magnetic susceptibility. Variations in magnetic field strength that occur at the interface between dental materials and adjacent tissue can lead to distortions and signal loss, generating an artifact in the image. [1]

An MRI-induced artifact is defined by pixels that do not faithfully represent the tissue components under study. The shape of the artifact depends on the scanner plane. The artifacts have a circular pattern in the axial plane and a "cloverleaf" pattern in the sagittal plane. The severity of the artifact depends on the following factors: the magnetic properties of the metal object causing the artifact, the shape, position, orientation and number of objects , alloy homogeneity, RM sequence, and sequencing parameters used. [4,5]

Other unwanted effects of MRI are radiofrequency heating (a physical effect) and magnetically induced displacement (a mechanical effect) of the dental material. [6]

The main immediate risk associated with MRI is the attraction between the MRI device and metal objects: the magnetic field is strong enough to pull heavy objects towards the scanner with very high velocity (known as projectile effect). [7]

Due to interactions with MRI, metallic objects in the human body can undergo radiofrequency-induced heating. [4]

Patients in whom MRI poses a high risk include those with biomedical devices, cochlear implants, neurostimulators, infusion pumps, and fixed metal prostheses. MRI is contraindicated in such patients because the magnetic field of MRI can cause these devices to become non-functional, thus leading to life-threatening situations, dislocation and soft tissue burns. [4,8]

Today, various types of materials are used in indirect restoration of teeth. Most clinicians use metal crowns due to their desirable properties such as longevity and resistance to high loading. Fixed prostheses such as crowns and bridges can be made from non-noble metal alloys, such as chromium-cobalt (Cro-Co), nickel-chromium (Ni-Cro) and titanium-based (Ti); noble alloys such as gold (Au), platinum (Pt), argent (Ag), aluminum (Al) and palladium (Pd); and “metal free”: ceramics and zirconia (Zr). The properties, specifications, indications and contraindications of these materials are well defined and studied. However, its influence and effect on image quality with MRI must also be known by the dentist. [1]

2 Objective and hypothesis

Our first hypothesis was that major distortion for metals than for non-metals in MRI scans was to be expected.

The main aim of this review is to compare the formation of crown artifacts with noble, non-noble and metal-free metal alloys.

The secondary objective was to analyze if MR scans were potentially hazardous in patients carrying fixed dental crowns.

3 Materials and methods

We used the PRISMA 2020 research strategy as a methodology to address existing knowledge on the subject and write results and discussion of this study.

The MEDLINE database was searched using the PubMed search engine, using different combinations of the words: [DENTAL CROWN], [MAGNETIC RESONANCE], [ARTIFACTS].

The inclusion criteria were:

- *In vivo* and *in vitro* trials that studied the objectives of the review;
- Articles written in English;
- Articles written after 2005.

The exclusion criteria were:

- Articles that did not address the interests of this study;
- Articles that were not fully available online;
- Articles published before 2005
- Systematic reviews.

Data base	Research Equation	Identified Articles	Selected Articles
PubMed	((dental crown[MeSH Terms] AND (magnetic resonance imaging[MeSH Terms])) AND (artifact[MeSH Terms])	66	11

Table 1: research equation

4 Results

Table The MEDLINE database was searched using the PubMed search engine, using the combination of words: [dental crown] AND [magnetic ressonance] AND [artifacts].

The initial search in the available database yielded a total of 66 articles of which 0 duplicate articles were eliminated. On the remaining articles, the titles and abstracts were read seeking concordance with the inclusion criteria of the present study and then 40 studies were discarded because they did not include significant information on MRI scans and interactions with dental crowns. The evaluation of titles and abstracts resulted in the selection of 26 potentially studies of which 15 articles were excluded after full reading concerning the lack of available data. The results of the selection of articles are shown in Figure 1.

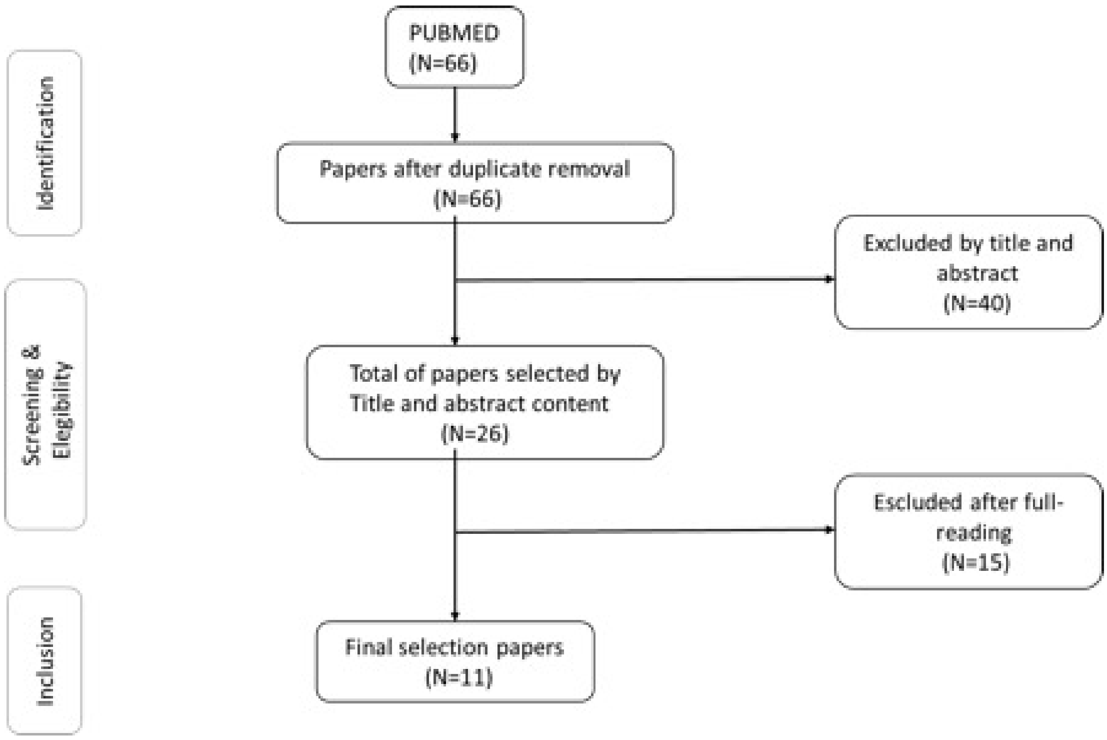

Figure 1: Diagram 1: PRISMA fluxogra

The main results obtained in the articles chosen for review are in the following table:

Table 2: results

Study	Objectives	Tested materials	MRI scan	Results
Matsuura et al. 2005	Compare and analyze the magnetic susceptibility of different materials	Zr Ti Ti alloy Co-Cro	0,5, 1,5 e 3,0 T MRI	The diameters of artifacts caused by pure titanium, titanium alloy and cobalt-based alloy increased in the order of magnetic fields from 0.5, 1.5 to 3.0T. The diameter of the ceramic artifact was not influenced by magnetic field strength, and was the smallest of all biomaterials at all magnetic field strengths. Artifacts caused by biomaterials other than ceramics increase with the strength of the magnetic field.
Raphael et al. (2006)	to compare reviewer confidence and	14 Zr 7 Cro-Co	1.5-T RM scanner	Greater confidence, less variability and greater interobserver agreement in the

	interobserver agreement in the evaluation of MR images of periprosthetic structures around Zr and Cr-Co total knee prostheses.			MRI assessment of periprosthetic structures around Zr knee prostheses
Starcukova et al. (2008)	Magnetic susceptibility, electrical conductivity and artifacts were evaluated for 45 cylindrical standardized samples of dental alloys and amalgam.	precious alloys Ti alloys Ni-Cro Co-Cro	1,5 T RM scanner with different pulse sequences: Gradient echo (GRE) spin echo (SE)	For dental devices, magnetic susceptibility differences are of little clinical importance for diagnostic SE/GRE imaging of the neck and brain, but are significant for orofacial imaging. Alloys of precious metals displayed low magnetic susceptibility and small artifacts. Ti created higher artifacts than precious alloys. Ni-Cro and Co-Cro created significantly higher artifacts than the other groups.

Destine et al. (2008)	To evaluate the artifacts generated by crownshaped dental alloys and a magnetic keeper quantitatively by analyzing digital MRI data	One pre-fabricated magnetic keeper and four clinical dental alloys: Au-Ag-Pd alloy Au alloy, Cro-Co Au-porcelain alloy	1,5 T	Cro-Co showed significantly greater signal intensity
Klinke et al (2012)	The aim of this in-vitro study was to identify and evaluate the artifacts produced by different dental restoration materials in CT and MRI images	44 materials (metal and non-metal)	1,5 T RM CT scan	In MRI, 13 out of 44 materials produced artifacts, while in CT 41 out of 44. Metal based restoration materials had strong influence on CT and less artifacts in MRI images

Tymofiyeva et al. (2013)	to investigate the potential influence of standard dental materials on dental MRI	standard dental materials	1.5 & 3 T scanners com diferentes sequencias de pulso: • GRE • SE	A classification of the materials that complies with the standard grouping of materials according to their magnetic susceptibility (Compatible, Compatible I, Non-Compatible) was proposed. **Compatible I** (material produces noticeable distortions, acceptability depends on application): gold alloy, gold-ceramic crowns, titanium alloy **Non-Compatible (**Material produces strong image distortions even located far from the imaging region)**:** Co-Cr sample
Xu et al. (2015)	To compare five materials commonly used in dentistry, including three types of metals and two types of ceramics, using	Zr Cro-Co Ni-Cro Ceramic alloy	0,35, 1,5 e 3,0 T	Zr showed no significant artifacts when scanned under the three types of MR field strengths. Ceramic artifacts were minimal.

	different sequences of three magnetic resonance (MR) field strengths (0.35, 1.5, and 3.0 T).			All dental precious metal alloys, Ni-Cro alloy dental porcelain and Cro-Co alloy showed varying degrees of artifact under the three magnetic resonance field strengths. Artifact area increases with increasing magnetic field.
Cortes et al. (2015)	clarify how pulse sequences and Sequence parameters affect MR artifacts caused by metal-ceramic restorations	3 Ni-Cro crowns	1.5 & 3T scanners with different pulse sequences: • GRE • IF • ultrashort echo time (UTE) The artifact area in each image was automatically calculated	significant correlation was found between echo time (ET) and artifact area in GRE images. Increased receiver bandwidth significantly reduced the area of artifact in SE images. UTE images produced the smallest artifact area at 1.5 T. Significant difference in the average area of the artifact

			of pixel values within a region of interest	between images at field strengths of 1.5 and 3.0 T
Murakami et al. (2016)	To quantitatively evaluate these embedded artifacts inside a phantom according to the standards set by the American Society for Testing and materials	Al, Ag, Au, Au-Pd-Ag, Ti, Ni-Cro Cro-Co	1,5 T scanner with different pulse sequences: GRE SE UTE	The volumes of artifacts containing Au, Al, Ag and Au-Pd-Ag were significantly smaller than other materials (in which the artifact volume size increased, respectively, of Ti, Ni-Cro, Cr-Co). Significant correlation was found between echo time (ET) and artifact area in GRE images.
Hilgenfeld et al. (2016)	identification of preferable material compositions for implants and supported prostheses with little impact on MR image quality is mandatory.	Zr and Ti dental implants with crowns: • noble alloy metal-ceramics,	3 T scanner	Material composition of dental implants provided with single crowns has a profound impact on artefact volume. In comparison with crowns containing Co-Cro, the MRI artefacts are reduced in precious alloy- and zirconia-based crowns.

		• non-noble alloy metal-ceramics, • ceramics and Zr • Zr		
Blankestein et al. (2017)	Magnetic permeability can predict the size of the artifact. There is no standardized approach to determine the permeability of such bonds. The goal was to establish a reliable approach to determining the size of the artifact caused by dental restorations at 1.5 T MRI.	Co-Cro, Ni-Cro, Ti alloy Ceramic	1,5 T scanner; Ferromaster (instrument for measuring the permeability of objects with a minimum size)	With ceramic, titanium alloy or Co-Cro products, artifact radii smaller than 20 mm can be expected. With the help of a dental magnet, it is possible to make an approximate estimate of the ferromagnetic properties and artifacts that arise as a result. The decisive predictor is the magnetic permeability.

				Permeability measurements with Ferromaster are sufficiently accurate even with small objects.

Off the 11 analyzed studies:

- 3 studies found significant difference in the average area of the artifact between images and field strengths of MRI scan type. They all conclude that artifacts caused by biomaterials other than ceramics increase with magnetic field strength [8,9,10,15,]
- 3 studies scanned with different ET sequences. Both found that lower ET (SE and UTE) significantly lower artifact formation. [1,9,12,]
- 1 study found higher artifacts were generally created by metal containing dental restorations than by metal-free ones [1]
- 8 studies found no or little artifact formation in ceramic or zirconium restoration. Artefact volumes size increased, respectively, from Ti < Ni-Cro < Co-Cro. [10–15,16]
- 1 study suggested a reliable approach to determining artifact size caused by dental restorations at 1.5 T MRI with the Ferromaster. [18]
- 1 study proposed a classification of the materials according to their magnetic susceptibility (Compatible, Compatible I, Non-Compatible).[14]

5 Discussion

5.1 MRI scan type

Magnetic force is measured in tesla (T). MRI uses 1.0-1.5 T, the most powerful MRI scanner uses 3.0 T. Compared to Earth's magnetic force (50 µT); is 10,000 times larger.

Based on the strength of the magnetic field there are[9]:

- Low-field MRI Scanners (0.23T-0.3T): These are commonly 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 (1.5T to 3.0T): These are commonly identified as closed MRI scanners. A 1.5T MRI scanner offers excellent image quality, fast scan times, and the ability to assess how certain structures in the body function. The 3.0T MRI scanner is great for viewing very fine details such as the vessels of the brain or heart.
- Ultra-High Field MRI Scanner (7.0T to 10T): Not widely available and typically used for research.

5.2 Magnetic and electrical susceptibility of dental materials

The magnetic susceptibility of a tissue reflects its ability to acquire its own magnetization when it is subjected to a magnetic field. The acquired magnetization can be concordant (parallel) or discordant (antiparallel) to the external magnetic field. In the first case, the substance is said to have positive magnetic susceptibility and increases the resulting magnetic field, being called paramagnetic. In the second case, it has negative magnetic susceptibility and weakens the resulting magnetic field. [4]

Dental materials can be classified on the basis of magnetic susceptibility as [3]:

- Ferromagnetic: These are the types of materials that are strongly attracted to a magnet. Its permeability is very high in the range of hundreds and thousands. Three sub-types of ferromagnetism are Fe, Co, and Ni.

- Paramagnetic: these are materials that are not strongly attracted to the magnet. They are slightly magnetized when placed in a strong magnetic field and act in the direction of the magnetic field. Its relative permeability is slightly greater than one. Paramagnetic materials have unpaired orbital electrons and become demagnetized once the field is switched off. Examples of such materials are magnesium, tin, platinum, lithium, tantalum, aluminum, molybdenum, etc.

- Diamagnetic: these are materials that are repelled by a magnet. They are slightly magnetized when placed in a strong magnetic field and act in the opposite direction to the magnetic field. Its permeability is slightly less than one. For example, wood, zinc, copper, bismuth, silver, gold, etc., are diamagnetic materials.

The ideal material would have zero electrical conductivity and a magnetic susceptibility identical to that of the observed tissue:

- Higher electrical conductivity facilitates the induction of eddy currents that may lead to artifacts, dental gold might produce distortion because it supports large eddy currents caused by its high electrical conductivity. [10]
- Differences in magnetic susceptibility between the material used and the tissue mislocalization and signal-loss artifacts due to inhomogeneity of the static magnetic field. Furthermore, the greater the magnetic permeability of a material, the more magnetic field distortion (size of the resultant artifact) it will produce. Thus, alloy composition is important in creating artifacts on MRI [4,10]

5.3 Influence of pulse sequence parameters on MRI artefacts produced by metal–ceramic restorations

It was found that the magnitude of susceptibility artifacts in MRI is also related to the type of imaging sequence used:

- Long ET (GRE) sequences are sensitive to the presence of metal, resulting in a dark or black area around the metal on the processed images.
- Shortening the ET can be used to reduce the degree of intravoxel dephasing seen on GRE acquisition. SE and UTE sequences have a pulse that diminishes the phase shifts in the voxel which are caused by local static magnetic field gradients thus making it less sensitive to susceptibility effects. [(1,4)]

One study by Cortes et al. aimed to clarify how pulse sequence parameters at 1.5- and 3.0-T field strengths affect MRI artefacts caused by metal–ceramic restorations. This study assessed multiple pulse sequences to analyze Ni-Cro samples with clinical shapes of metal–ceramic restorations. [(8)]

In Cortes' study, reducing TE in GRE pulse sequences and increasing bandwidth in SE pulse sequences could reduce artefact size up to 40% for our choice of parameters. [(8)]

The study therefore concludes that it is possible to compensate for the effect of higher field strength on MRI artifacts by setting optimized pulse sequences for scanning patients with metal-ceramic restorations. [(8)]

5.4 Artifact size formation of different dental restoration materials

In all studies, dental restorations containing zirconium or ceramic alloys created zero or no artifact volume. [(11,12,13,14,15)] All studies where precious alloys were used (such as Au, Al, Ag and Au-Pd-Ag) created artifacts that were significantly smaller than all the other materials. [(1,10,11,13,15)] Artefact volumes seems to become significant in size, respectively, from Ti < Ni-Cro < Co-Cro in all the studies. [1,11–15,16–18] This is most likely due to the specific ferromagnetic compositions of these alloys. [4]

One study by Tymofiyeva et al. [14] analyzed and classified dental materials into 3 categories according to differences in susceptibility:

- Compatible: when the material produces no detectable distortions on either SE or GRE imaging;
- Compatible I: when the material produces noticeable distortions, acceptability depends on application
- Non compatible: when the material produces strong image distortions even located far from the imaging region.

In the compatible I went precious alloys, gold-metalic, titanium restorations; while Co-Cro restorations together with stainless steel went in the non-compatible category.

One study by Blankestein[18] proposed the use of an instrument to assess the permeability of objects with a minimum size, the Ferromaster. He concluded, differently from Tymofiyeva, that Co-Cro together with Ti and all precious alloys create artifacts radii lower than 20mm, volumes, for the author, negligible when studying a MRI scan.

With the exception of the previous operator-dependent variable, all the studies where concordant on their findings.

It must be stated that none of the above mentioned studies where *in vivo* and that only 2 of them [9,17] used actual teeth crowns and not specimens with cylindrical or spherical shapes, that do not occur in actual dental restorations.

5.5 Safety

According to the literature all non-ferromagnetic materials pose either none or only negligible forces or torques. [19]

Heating will depend on the shape of the material and on the material's electrical conductivity. [20]

6 Conclusions

The extent of artifacts caused by metallic dental devices depends on the magnetic susceptibility and the electrical conductivity of the device, its shape and orientation in the magnetic field, its placement in the oral cavity and on numerous MR measurement parameters, related to the MR scanner specifications, the desired type of contrast, volume of interest, and practical experiment time limitations.

- A non-ferromagnetic material does not significantly elicit artefacts in fast MRI. However, the presence of ferromagnetic materials such as Ti, Ni-Cro and Co-Cro in to-be-scanned areas should be evaluated before the actual start of fast MR sequences, as they may produce large artefacts.

- Shorter ET sequences (SE and UTE) seem to be the proper choice, as this gives the least amount of artefacts.
    - The initial hypothesis in this regard was confirmed: Co-Cro alloys were the restorations that in all studies created higher artifact volumes, together with Ni-Cro restorations. In comparison Ti and other precious alloys created lower volumes of artifacts, while ceramic and Zr restorations created none or very little.

    - Secondary objective: non-ferromagnetic materials pose either none or only negligible forces or torques when scanned by MR. Crown heating does not seem to be significant or harmful to the patients.
- Dental manufacturers and dentists, however, can impact only the device composition, stress state of its crystalline structure and, to a limited extent, its shape, size and orientation.

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