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MRI safety of Dentaurum products

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What is MRI?

Magnetic Resonance Imaging (MRI) is a medical imaging process which, in contrast to all X-ray examinations, does not use ionizing radiation. MRI works with magnetic fields of different strengths and is now the method used more frequently. The main field for the *ultra low-field* appliances is only 0.05 tesla (T), the *low-field* appliances work with approx. 0.5 T. The most frequently used so-called *Standard MRI* uses fields between 1.5 and 3 T. The *high-field MRI* using up to 7 T is for research work only at present.

In all machines, electromagnetic waves of different frequencies are generated (radio frequencies) which "spin" the main field, thereby enabling images to be produced.

What interactions are possible between MRI and dental materials?

Every patient facing an MRI examination wonders if adverse reactions from the magnetic field and the radio frequencies must be expected. Concerns focus on fixed metal appliances, also all dental and surgical objects used in the oral cavity or the skull: fillings, crowns, orthodontic multi-band appliances, dental implants, retainer wires, fracture splints, osteosynthesis plates etc. There are three basic risks [1]:

- Possible temperature increase in metal objects due to the radio frequencies,
- Displacement forces and rotational forces of the objects due to the magnetic main field,
- Deletion of images or distortions due to the magnetizability of the objects (magnetic susceptibility artifacts) or the induction of eddy currents (eddy current artifacts).

The first two of the above-mentioned points have been widely examined and are negligible for dental products [1, 5, 7, 9, 11, 14 - 17, 20, 21, 23]. The third point is, however, of significance since artifacts may render the imaging process unusable. Yet it would be a primitive answer to a complex problem to conclude that this means all metal must be removed from the mouth before an MRI.

Which measures need to be taken depends primarily on the reason behind the need for an MRI. If images of the head/neck region are required, the artifacts arising from fixed metal appliances may impair or prevent an analysis of the images [4, 8, 25]. Radiologists do have some sequences and device settings available to reduce the generation of artifacts. It is, however, not possible to completely prevent them. Not all possibilities available to the radiologist can be used in every case.

In order to avoid the complicated removal of fixed appliances, it is advisable to use metals that are not, or only minimally, magnetizable. This is the decisive property for susceptibility artifacts during an MRI.

In addition, the positioning of the object in the main field of the MRI can influence the extension of the distorted area in the case of the much smaller eddy current artifacts (EC artifacts) [19].

Measures to be taken prior to MRI examinations in the head / neck area

It cannot be assumed that all metal elements in a patient's mouth are known. It can also not be assumed that the metals were chosen under the aspect of minimal magnetizability. It is therefore necessary to remove all metals from the mouth prior to an MRI examination if it is possible for the patient to do so without any problems. This refers to removable dentures and orthodontic appliances. All fixed dental restorations (implants, crowns, bridges, orthodontic appliances) should remain in the mouth since their removal destroys them in most cases. The behavior of the individual materials in an MRI is detailed below.

The following should be noted if a fixed orthodontic appliance (depending on the treatment phase) has archwires made of stainless steel. Steel wires can be expected, despite their original austenitic structure, to show martensitic properties due to their processing [1]. Steel archwires should therefore be removed from the mouth prior to an MRI examination. Archwires made of NiTi can remain in the mouth.

Dental ceramics and acrylics

These materials are not magnetizable and do not therefore lead to artifacts in the MRI image [13, 25]. In their pure form, they are used for final or temporary crowns, bridges and brackets, and dental implants. When used to create a veneer in a particular tooth shade, there is always a metal framework beneath the veneer.

Metals and alloys

A strict differentiation must be made between the magnet properties of individual elements and the alloys made from these elements. Nickel is a good example: as an element, it is highly magnetizable. As part of an alloy, e.g. in stainless steels, it has a low magnetizability.

- Precious metals alloys

Precious metal alloys are not magnetizable and, therefore, do not generate susceptibility artifacts during the MRI [10]. The only exception are palladium-cobalt (Pd-Co) alloys which are used for magnet keepers in subtotal prosthetics. Dentaurum has no products made of precious metal alloys in its product range. CAVE: golden wires rarely consist of a gold alloy. The color usually stems from a titanium nitride coating.

- Titanium and titanium alloys

Titanium materials (e.g. 3.7025, 3.7035, 3.7065, 3.7165) used for the manufacture of implants, meso and suprastructures for implants, crowns, bridges and root canal posts are also not magnetizable. In an MRI, they are therefore not subjected to translational or rotational forces and no susceptibility artifacts occur. However, the typical eddy current artifacts occur with these metals, induced by the alternating fields and gradients in the tomograph. They are significantly smaller than the susceptibility artifacts and affect only the direct surroundings of such implants and screws. A diagnosis within the bonding area to the bone is therefore not possible, and may also impede the exact orientation of close vessels and nerves. For other cases, such products can remain in the mouth.

Studies clearly show that there is no cause for concern that titanium implants may become perceptibly warm and potentially damage tissue under the influence of the 3 Tesla MRT [11]. No such evidence was found even when using the 7 Tesla MRT [17].

Dentaurum offers the following finished products made of titanium or titanium alloys: implants, abutments for implants, cast metals, milled blanks, powder for additive manufacturing, brackets, expansion screws, tomas®-pin, tomas® PI (palatal implant), retainers and the prime4me® RETAIN3R [2, 10, 16, 22, 24].

■ Cobalt-chrome alloys

Where the cobalt content is ≥ 19% and work is carried out at a usual temperature range of < 40 °C, cobalt chrome alloys are not magnetizable [6, 12, 18] and therefore do not lead to susceptibility artifacts during an MRI. Dentaurum offers cast metals, milling blanks, powder for additive manufacturing, brackets, buccal tubes and wires made from these alloys. The eddy current artifacts they cause during an MRI are slightly bigger than for titanium. They can remain in the mouth [2, 13, 22].

■ Nickel titanium, nickel chrome and titanium molybdenum alloys

These alloys are not magnetizable and therefore do not lead to susceptibility artifacts during an MRI. Dentaurum offers cast metals, wires and springs made of these alloys.

■ Stainless steel

Steel is defined as alloys of the iron with carbon. By adding certain metals such as chrome, nickel and, for example, molybdenum, "stainless steels" are created. There are more than 100 types of stainless steel with varying properties. The additions to the alloy have a strong influence on the atomic arrangement which in turn influences the structure or components of the structure of the stainless steel. The typical structure components of the stainless steels are austenite, ferrite and martensite, each of which has a different magnetizability. Austenitic steels are, in contrast to types with martensitic or ferritic structures, not magnetizable. This is true only if the structure of the stainless steel from the austenitic category is fully austenitic and therefore free of ferrite and martensite or other magnetizable phases. Aside from types with higher alloy content, stainless steels may contain some ferrite, usually in single-digit percentages or tenths of a percentage and therefore causing little magnetizability of the material. The ferrite content can be reduced by targeted annealing. Alternatively, the austenite can be stabilized by increasing the alloy content, thereby halting the transformation into ferrite completely or partly. Furthermore it is possible that metastable austenite, by means of cold forming, undergoes a martensitic transformation that is not apparent from the outside, rendering the stainless steels magnetizable. To avoid this "deformation of the martensite", alternative approaches to cold-formed methods need to be found for the manufacture of orthodontic products.

The structure and stability of dental products made of stainless steel are relatively easy to research if the supplier or manufacturer indicates the material number. Unfortunately, manufacturers rarely declare the exact production method of metastable austenite. Even if the exact elementary composition is known, experts can only reliably recognize the magnetic properties of a stainless steel if they are aware of the method of manufacture and the thermomechanical history of the material. If this information is not available, patients with metallic fixed appliances must reckon with having to remove all these objects prior to an MRI, in particular in urgent cases.

Dentaurum uses various stainless steels for the manufacture of brackets, bands, wires and expansion screws for class II appliances and for accessories for the tomas® anchorage system. These are stainless steels with a stable or metastable austenitic structure. Special production processes ensure that martensite does not form. Products manufactured from this material are designed to remain permanently in the oral cavity (see table in annex) and do not generate artifacts in the MRI [2-4].

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Tables

Table 1: Overview of stainless steels used in the dental industry (sorted acc. to consecutive number). Refer to the Materials List at Dentaurum to see which products are manufactured from these alloys.

		Material No.			
No. [1]	**Description**	**DIN***	**AISI / ASTM****	**Short name**	**Structure**
1.000	stainless steel	1.4301	*AISI 304*	X5CrNi18-10	austenite[2]
1.001	stainless steel	1.4303	*AISI 305*	X4CrNi18-12	austenite[2]
1.002	stainless steel	1.4305	*AISI 303*	X8CrNiS18-9	austenite[2]
1.003	stainless steel (dentaflex®, remanium®)	1.4310	*AISI 301 / AISI 302*	X10CrNi18-8	austenite[2]
1.004	stainless steel	1.4401	*AISI 316*	X5CrNiMo17-12-2	austenite[2]
1.005	stainless steel (remanium®)	1.4404	*AISI 316L*	X2CrNiMo17-12-2	austenite[2]
1.006	stainless steel (Noninium®)	1.4456	—	X8CrMnMoN18-18-2	austenite
1.007	stainless steel	1.4460	*AISI 329*	X3CrNiMoN27-5-2	austenite / ferrite[2]
1.008	stainless steel	1.4541	*AISI 321*	X6CrNiTi18-10	austenite[2]
1.009	stainless steel	1.4542	*AISI 630*	X5CrNiCuNb16-4	austenite / ferrite / martensite / precipitates[3]
1.010	stainless steel	1.4435	*AISI 316L*	X2CrNiMo18-14-3	austenite[2]
1.011	stainless steel (dentaflex®)	*1.4310*	AISI 302	—	austenite[2]
1.012	stainless steel (dentaflex®)	*1.4326*	AISI 302 B	—	austenite
1.013	stainless steel (dentaflex®, remanium®)	*1.4301*	AISI 304	—	austenite[2]
1.014	stainless steel (Noninium®)	1.3808	*ASTM F 2581*	X20CrMnMoN17-11-3	austenite
1.015	stainless steel	1.4568	*AISI 631*	X7CrNiAl17-7	austenite / ferrite / martensite / precipitates[3]
1.016	stainless steel	1.4197	—	X20CrNiMoS13-1	martensite
1.017	stainless steel	1.4034	*AISI 420*	X46Cr13	martensite
1.018	stainless steel	1.4571	*AISI 316 Ti*	X6CrNiMoTi17-12-2	austenite[2]
1.019	stainless steel	1.4501	*ASTM A 1082*	X2CrNiMoCuWN25-7-4	austenite / ferrite[2]

[1] Numbering in the Dentaurum Materials List

[2] acc. to DIN EN 10088-3

[3] Phase distribution is heavily dependent on previous thermomechanical treatment

*The steels marked with a DIN materials number correspond generally to the steels marked with an AISI / ASTM materials number. Marginal differences in the permissible tolerances for the chemical composition are possible. The comparative type to the steel used is written in *italics*.

** ASTM materials number if no AISI materials number exists

Table 2: Overview of stainless steels used in the dental industry (sorted acc. to consecutive number). Refer to the Materials List at Dentaurum to see which products are manufactured from these alloys.

No. [1]	Description	Material No. DIN*	Material No. AISI / ASTM**	Short name	Structure
1.014	stainless steel (Noninium®)	1.3808	*ASTM F 2581*	X20CrMnMoN17-11-3	austenite
1.017	stainless steel	1.4034	*AISI 420*	X46Cr13	martensite
1.016	stainless steel	1.4197	—	X20CrNiMoS13-1	martensite
1.000	stainless steel	1.4301	*AISI 304*	X5CrNi18-10	austenite[2]
1.013	stainless steel (dentaflex®, remanium®)	*1.4301*	AISI 304	—	austenite[2]
1.001	stainless steel	1.4303	*AISI 305*	X4CrNi18-12	austenite[2]
1.002	stainless steel	1.4305	*AISI 303*	X8CrNiS18-9	austenite[2]
1.003	stainless steel (dentaflex®, remanium®)	1.4310	*AISI 301 / AISI 302*	X10CrNi18-8	austenite[2]
1.011	stainless steel (dentaflex®)	*1.4310*	AISI 302	—	austenite[2]
1.012	stainless steel (dentaflex®)	*1.4326*	AISI 302 B	—	austenite
1.004	stainless steel	1.4401	*AISI 316*	X5CrNiMo17-12-2	austenite[2]
1.005	stainless steel (remanium®)	1.4404	*AISI 316L*	X2CrNiMo17-12-2	austenite[2]
1.010	stainless steel	1.4435	*AISI 316L*	X2CrNiMo18-14-3	austenite[2]
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1.007	stainless steel	1.4460	*AISI 329*	X3CrNiMoN27-5-2	austenite / ferrite[2]
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1.009	stainless steel	1.4542	*AISI 630*	X5CrNiCuNb16-4	austenite / ferrite / martensite / precipitates[3]
1.015	stainless steel	1.4568	*AISI 631*	X7CrNiAl17-7	austenite / ferrite / martensite / precipitates[3]
1.018	stainless steel	1.4571	*AISI 316 Ti*	X6CrNiMoTi17-12-2	austenite[2]

[1] Numbering in the Dentaurum Materials List

[2] acc. to DIN EN 10088-3

[3] Phase distribution is heavily dependent on previous thermomechanical treatment

*The steels marked with a DIN materials number correspond generally to the steels marked with an AISI/ASTM materials number. Marginal differences in the permissible tolerances for the chemical composition are possible. The comparative type to the steel used is written in *italics*.

** ASTM materials number if no AISI materials number exists

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