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Disturbing effect of different dental materials on the MRI results: preliminary study

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The influence of different dental materials used for conserving reconstruction of teeth on the magnetic resonance imaging assessed on the basis of changes in NMR proton relaxation T1 of the physiological environment represented by the physiological salt solution has been studied. The dental materials studied varied in a wide range of chemical compositions: composites (Silux Plus made by 3M Dental, Tetric Cream made by Ivoclar-Vivadent), pH controlling composite (Ariston pHc made by Vivadent), hybrid glass ionomer (Vitremer made by 3M Dental), compomer (Hytac made by ESPE), amalgamate without the gamma phase (Septalloy made by Septodont), chemo-cured phosphate cement (Agatos made by Chema-Elektromet), phosphate cement with addition of silver (Argil made by Spora-Dental). The reference standard was a 0.9% physiological solution of NaCl. The relative deviations of the spin-lattice relaxation time vary from –18.5% to +24.0%. From the point of view of magnetic resonance imaging, the materials significantly disturbing the tomographic images are the amalgamate Septalloy-Septodont and glass ionomer Vitremer-3M Dental, while the composite Tetric Cream-Vivadent has insignificant effect.

Key words: *dental materials, MRI, spin-lattice, relaxation time T*

1. Introduction

Nuclear Magnetic Resonance tomography, known also as Magnetic Resonance Imaging or MRI based on the magnetic properties of hydrogen or carbon nuclei has become a widely used non-invasive method of imaging human organism tissues for diagnostic purposes. The method in safer and more accurate than the conventional method based on radiological technique (Computed Tomography), permitting evaluation of the soft tissues thanks to the use of contrasting materials. The use of MRI eliminates the risk of absorbing too high a dose of ionising radiation and improves the possibilities of differentiation of soft tissues especially in the head. As the basic condition of the use of MRI is the presence of water in a tissue studied it is particularly suitable for imaging soft tissues.

The proton spin-lattice relaxation time T_1 is the basic parameter of MRI, although this method can also use the proton spin-lattice relaxation time T_2 dependent or diffusion dependent images or T_1- or T_2-weighted images after injection of a contrasting agent. The T_1 time-dependent images are most often used as they ensure good imaging of details of the anatomical structures as well as they are better correlated with water content than T_2-dependent and differences between T_1 values for tumor and normal tissues are correlated with differences in the volume fraction of extracellular fluid volumes and in the amounts of membrane and fibrillar surface area in the cells. The T_1 times are constant and specific of different tissues: e.g. the body fluids blood and lymph are characterised by low T_1 values, while the fat tissue or proteins by high T_1 values. Moreover, T_1 values characterising the organs such as the liver<spleen<kidney<heart<lung, change in good accordance with the free water contents in these organs determined by thermal analysis [1]. It is well known that cancer tissue development in the initial stage corresponds to a shortening in the

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T_1 relaxation time because of the characteristic increase in degree of hydration of the tissues, which is followed in a later stage by an increase in the T_1 time [2], [3], which has been used for diagnostic purposes and makes the basis for cancer tissue imaging. The information provided by CT is based on the differences in the amounts of the radiation dose absorbed by tissues of different types so is limited to anatomical data, while MRI provides information on biophysical and biochemical structures of particular tissues but also allows, e.g., angiography without a contrasting agent [4], [5] and functional investigation of the brains, thus localization of regions responsible for particular functions [6], [7]. Moreover, MRI of the head and neck, especially near or at the spine and at the bottom rear part of the scull is not obscured by so many artefacts as CT recording, so MRI is the method of choice. MRI is widely used for diagnostic purposes of conditions of the central nervous system [8], [9] tumours [10], [11] and in ophthalmology [12]. MRI was allows for the assessment of geometrical parameters in muscles stabilizing vertebral column [13], [14].

There have been fewer reports on the use of MRI in diagnosis of hard tissues, because of significant distortions, [15]–[19]. In dentistry, MRI is mostly applied for anatomical and pathological diagnosis [19]–[21]. Attempts have been made to use MRI for diagnosis of changes in the oral cavity and temporo-mandibular joints, but for this purpose special techniques of visualization are needed [22], [23]. A technique for contrast-enhanced dental MRI is described that enables 3D visualization of the oral cavity, including the jaw and teeth. Since teeth are MRI-invisible, the basic principle of this technique is that the teeth and jaw can be observed indirectly through contrast with a surrounding MR-visible medium. Attempts have been taken to apply MRI for assessing the degree of demineralization of enamel and dentin in caries disease and further for evaluation of the effects of remineralization therapy [18]. The ^{1}H -NMR and ^{13}C -NMR spectra are also applied in investigation of human saliva whose buffering properties help protect against teeth caries [24]–[26].

One of the main problems in MRI imaging are the artifacts related not only to the presence of low-hydrated tissues, but also to the presence of foreign materials such as alloys and implant materials. According to literature reports [17], [18], MRI has limited applications for the patients having some ferromagnetic material objects in their bodies (implants, surgical clip, cardiac peacemaker, prostheses, metal pins used for conserving dental reconstruction, etc). Moreover, certain materials used in dental treatment can disturb the MRI image. Literature has reported the disturbing influence of ferromagnetic materials (metal, silver amalgamate) as well as titanium (Ti), nickel-chrome alloy (Ni-Cr), cobalt-chrome alloy (Co-Cr), stainless orthodontic wire, cobalt-chrome orthodontic wire, and dental magnetic attachments [27], [28]. Their presence originates artefacts, signal voids characteristic of magnetic materials, a linear high intensity image and distortion at their boundary [29]. Results on metal artefacts from titanium alloys in spin-echo sequences are contradictory; some authors have reported that titanium had no significant effect [30], [31] while others claim that titanium alloys produce high- to moderate-magnitude artefacts [27], [32]–[35]. New sequences or signal manipulations give only partial solution of the problem of artefacts appearing in the vicinity of metallic materials [36], [37].

The disturbing effect of metal-containing materials such as amalgamate has been well documented in literature on MRI [15], [16]. It is well known that ferromagnetic substances are strongly attracted by a magnetic field and thus have high potential from MRI artefacts, [30]–[32], [36], [37]. Although presently the majority of materials used for medical purposes such as dental implants, orthopaedic screws, and aneurysm clips are made of non-ferromagnetic materials such as titanium, it has not been possible to eliminate the artefacts caused by their presence in the MRI imaging. Moreover, the imaging of the tissues near the metallic objects is still a problem as in the vicinity of them the MRI signal often disappears [38], [39].

As yet no attempts have been made to explain the effect of different materials used for reconstruction of the hard tooth tissues on the MRI images. The choice of the material to be used is made on the basis of the colour, optical properties, the interaction on the oral cavity tissues and physic-chemical properties such as volume changes, solubility, sorption, electric thermal and mechanical properties [35]. Presently used final reconstruction materials include: composites, classical and hybrid glass ionomeric cements and compomers [35]–[40], which have phased out silver amalgamates, but little is known on their possible disturbing effect on MRI imaging, so on the T_1 relaxation time.

The aim of the study is to check the possible effect of different dental materials used for reconstruction of tooth tissue on the value of the proton spin-lattice relaxation T_1 time, which is the fundamental parameter used in MRI.

2. Materials and methods

The study was performed on the following materials: composite Silux Plus made by 3M Dental, Tetric Cream made by Ivoclar-Vivadent, pH controlling composite (Ariston pHc made by Vivadent), hybrid glass ionomer (Vitremer made by 3M Dental), compomer (Hytac made by ESPE), amalgamate without the gamma phase (Septalloy made by Septodont), chemo-cured phosphate cement (Agatos made by Chema-Elektromet), phosphate cement with addition of silver (Argil-made by Spora-Dental) representing different groups of materials most frequently used in the conservation dentistry.

Samples of the final hardened form of materials studied of 2.0 cm^3 in volume were placed in special plastic containers filled with a 0.9% solution of NaCl (physiological salt known to make about 4% of human organism) isotonic to human body fluids.

The spin-lattice relaxation time, T_1, was measured by a ^{1}H-MRI spectrometer made at the laboratory at the Institute of Physics, AMU, using a standard inversion recovery technique. The proton spin-lattice relaxation time in the laboratory frame, T_1, was measured on a pulse spectrometer operating at 60 MHz and a temperature of 37 °C. Because of a weak signal, 4–8 runs were accumulated. The estimated (on the basis of repeating the measurement as well as fit quality) average error of the measured T_1 values did not exceed 3%. The temperature was stabilized within 0.5 deg in all measurements using a nitrogen gas flow. The reference standard (phantom) was a 0.9% solution of NaCl.

3. Results

The spin-lattice relaxation times T_1 measured for the phantom sample of physiological salt and the physiological salt in the presence of the dental materials studied are given in Table 1. In order to estimate the disturbing effect of a given dental material on the T_1 time the T_1 values were averaged for three independently prepared samples of each dental material. The differences between the T_1 of the phantom sample in the presence and in the absence of a given dental material were determined (ΔT_1) and the results (in %) are given in Table 1 and Fig. 1. The relative deviations of T_1 time vary from –18.5% to +24.0%, they are the greatest for amalgamate Septalloy (+24.0%) and hybrid glass ionomer Vitremer (–18.5%), while the smallest for microhybride composite Tetric Cream (0%) and cement Argil (–1.8%) (Table 1).

Table 1. The dental materials studied, spin-lattice relaxation times T_1 and relative deviations of the spin-lattice relaxation time ΔT_1

No.	Dental material		Material type	T_1 (s)	ΔT_1 (%)
1	Reference	0.9% NaCl	Physiological salt	3.642	0
2	Composites	Silux-plus	Microfiller composite light-cured	3.496	–4.1
3		Tetric-ceram	Microfiller composite light-cured	3.498	0
4		Ariston pHc	Hybrid composite ph controling composite light-cured	3.657	+6.3
5	Glass ionomer	Vitremer	Hybrid glass ionomer light-cured	2.951	–18.5
6	Compomer	Hytac	Compomer light-cured	3.681	+3.6
7	Phosphate cement	Agatos	Phosphate cement chemo-cured	3.483	–5.0
8	Phosphate cement with addition of silver	Argil	Phosphate cement with addition of silver chemo-cured	3.548	–1.8
9	Amalgamate	Septalloy	Amalgamate without the gamma phase	3.886	+24.0

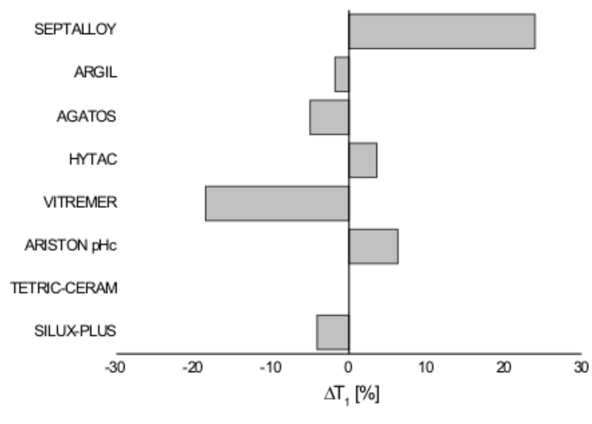

Fig. 1. The relative deviations of the spin-lattice relaxation time ΔT_1

The dental materials used differ in chemical composition which definitely affects the T_1 time values. On the basis of the results collected Table 1, the dental materials studied can be divided into two groups: Argil, Silux-Plus, Agatos and Vitremer cause a shortening of T_1 time, while Hytac, Ariston pHc, and Septalloy cause its elongation. Both groups influence the MRI image obtained on the basis of T_1 time measurements. Only Tetric-Ceram, a micron composite (small particle hybrid), very hard and cured by visible light of the wavelengths 400–500 nm, the most insoluble and durable of the composite fillers studied has no effect on the T_1 time.

4. Discussion

4.1. An elongation of T_1 time in Hytac, Ariston pHc, and Septalloy

According to the results presented in this work, the presence of amalgamate (Septalloy) causes a large increase (by about 24%) in the relaxation time T_1, which confirms the results of other authors. This result is in agreement with that of Zeze et al. [26], who reported no artefacts from alloy (Au), Casting Gold M.C. Type IV, gold-silver-palladium alloy (AU-Ag-Pd), or silver alloy (Ag), but the presence of artefacts, signal void characteristic of magnetic materials caused by titanium (Ti), nickel-chrome alloy (Ni-Cr), cobalt-chrome alloy (Co-Cr), stainless steel orthodontic wire, cobalt-chrome orthodontic wire, and dental magnetic attachment (as a keeper).

In the presence of composite material Ariston pHc being a condensed, hybrid light cured composite resin responding to the pH of the oral cavity and used as an alternative to silver amalgamate in class I and II cavities according to Black in primary teeth and class V cavities in permanent teeth the T_1 relaxation time is elevated, thus it shows the same type of behavior as that in the presence of amalgamate, but the effect is almost 4 times weaker.

It is surprising that Hytac which belongs to the poly-acid modified resin composites, is a compomer exhibiting close chemical relationship to composite resins and water-absorbing composite that contains some glass ionomer components, disturb the T_1 time to an insignificant degree (Table 1). According to Al-Fawaz et al. [40], Hytac has the highest surface microhardness value among the hybrid ionomers, whereas Vitremer shows the lowest microhardness level. Hytac, absorbing water to a much lower degree, has a low degree of hydration, which explains the T_1 behavior.

4.2. A shortening of T_1 time in Argil, Silux-Plus, Agatos and Vitremer

Interesting results were obtained for glass ionomers, whose presence was found to cause a significant decrease in the T_1 time. Glass ionomers are water-based and show hydrophilic properties determining their binding to dentin. They are made of the powder phase (aluminium-silicon glass) and the fluid phase (water solution of polymers and copolymers of acrylic acid). These materials settle as a result of metal salt bond formation between the aluminium ions Al^{+3} and calcium ions Ca^{+2} and the acid residues of the polymers. Hybrid glass ionomers are of classical composition of the fluid phase which contains monomer, poly-acid and water [38]. An exemplary modern material of this type is Vitremer (3M Dental) composed of the power phase (fluoride-aluminium-silicon glass) and the fluid phase (water solution of the modified polyalkene acid). The shortening of T_1 relaxation time in the presence of glass ionomers is thus a results of their chemical composition that is the presence of in-built water. According to Carr et al., a similar shortening of T_1 time is caused by the acrylic materials which do not produce artefacts in the MRI imaging [17], [41].

A four times smaller change in T_1 than caused by Vitremer was observed for the phosphate cement composed of the powder phase containing mainly zinc oxide and fluid phase with phosphoric acid as the main component Agatos, containing no silver. A shortening of the T_1 relaxation time of the same order was observed to be caused by a composite material Silux-Plus – a light cured material included to represent micro-filled resin composites.

The phosphate cement (Argil) containing silver (the so-called cement) was found to cause only very small (about 2%) decrease in the T_1 relaxation time, Table 1.

4.3. No changes in the T_1 time in Tetric Ceram

From the point of view of the MRI imaging, by far the best materials are composites as they do not affect the T_1 value. We have studied two composites of different size fillers: the micro-hybrid Tetric Ceram, producing no changes in T_1 time and the composite with a microfiller Silux Plus, producing a slight shortening of T_1 time by 4.1%. The composites are known to show a small contraction on polymerations, low water sorption, the thermal expansion coefficient close to that of the tooth, low water sorption, high wear resistance and high strength of binding to enamel and dentin. Water sorption of micro-hybrid composites is 0.3–0.6 mg/cm^2, while that of composites with microfillers is 1.2–2.2. mg/mc^2 [38]. The much higher water sorption of the latter materials is due to the presence of organic matrix. The difference in the water sorption may explain why Silux Plus caused a shortening of T_1 time, while Tetric Ceram did not.

The best of the materials studied proved to be the micro-hybrid composite with ceramic component Tetric Ceram. The use of this material for dental restoration should give no disturbances in MRI imaging.

The type of disturbance to the MRI imaging caused by a dental material is determined by the material properties. The hydrophobic ones (Ariston pHc, Hytac) similarly as metallic ones (amalgamates like Septalloy) extend the T_1 time, while the hydrophilous materials (Vitremer Agatos, Silux-Plus, Argil) shorten this time. Composites such as Tetric Ceram have practically no effect on T_1.

5. Conclusion

It has been shown that some dental materials used for reconstruction of hard tooth tissues, first of all such as the silver amalgamate or hybrid glass ionomer, can falsify the value of the T_1 relaxation time of the surrounding tissues and therefore, the results of the MRI imaging, leading to errors in diagnosis of pathological changes in the head. The material established to cause practically no changes in the T_1 time is the micro-hybrid composite with a ceramic component Tetric-Ceram.

It is known that extension [42] or sometimes shortening [2], [3], [43], [44] of T_1 time of a tissue in the range 20–115% relative to the T_1 time of a healthy tissue, follows from changes in the degree of hydration of tissues, which makes the basis for cancer diagnosis [42], [45], [49]. The relaxation times of various kinds of tissues are directly proportional to the water content. It is known that immature or invasive tissues have a higher water content, average cell size or reduced amount of rough and smooth endoplasmic reticulum than the mature or noninvasive varieties [41], [45]–[48]. Sometimes changes in T_1 time can be detected at very early stages of chemical carcinogenesis [49]. In view of the above, the effect of dental materials used for reconstruction of teeth on the T_1 value of the surrounding tissue is essential, in particular in MRI imagining of the head. The falsifying effect of dental materials may lead to erroneous results of MRI imagining and incorrect determination of the extension of infiltration of tissues, so may have important effect on the diagnosis, on specification of the region to be subjected to radiotherapy and on choosing the range of surgical removal of tumour. To the best of our knowledge the effect of the new dental materials on the T_1 time, so on the MRI imagining, has not been studied yet, and the results can be of importance in medical therapy.

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