RESEARCH

Effect of orthodontic brackets and different wires on radiofrequency heating and magnetic field interactions during 3-T MRI

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Objectives: To evaluate the heating and magnetic field interactions of fixed orthodontic appliances with different wires and ligaments in a 3-T MRI environment and to estimate the safety of these orthodontic materials.

Methods: 40 non-carious extracted human maxillary teeth were embedded in polyvinyl chloride boxes, and orthodontic brackets were bonded. Nickel–titanium and stainless steel arch wires, and elastic and stainless steel ligaments were used to obtain four experimental groups in total. Specimens were evaluated at 3 T for radiofrequency heating and magnetic field interactions. Radiofrequency heating was evaluated by placing specimens in a cylindrical plastic container filled with isotonic solution and measuring changes in temperature after T_1 weighted axial sequencing and after completion of all sequences. Translational attraction and torque values of specimens were also evaluated. One-way ANOVA test was used to compare continuous variables of temperature change. Significance was set at $p < 0.05$.

Results: None of the groups exhibited excessive heating (highest temperature change: $<3.04^\circ\text{C}$), with the maximum increase in temperature observed at the end of the T_1 weighted axial sequence. Magnetic field interactions changed depending on the material used. Although the brackets presented minor interactions that would not cause movement *in situ*, nickel–titanium and stainless steel wires presented great interactions that may pose a risk for the patient.

Conclusions: The temperature changes of the specimens were considered to be within acceptable ranges. With regard to magnetic field interactions, brackets can be considered “MR safe”; however, it would be safe to replace the wires before MRI.

Dentomaxillofacial Radiology (2014) **43**, 20130356. doi: 10.1259/dmfr.20130356

Cite this article as: Görgülü S, Ayyıldız S, Kamburoğlu K, Gökçe S, Ozen T. Effect of orthodontic brackets and different wires on radiofrequency heating and magnetic field interactions during 3-T MRI. *Dentomaxillofac Radiol* 2014; **43**: 20130356.

Introduction

MRI is a technique that uses a magnetic field (MF) and radio waves to create detailed images of organs and tissues within the body. Most MRI machines are large tube-shaped magnets that align the water molecules in

the body. These aligned particles produce signals with the induction of radio waves and thereby cross-sectional MR images are created.¹ MRI can be used for the assessment of intracranial and extracranial lesions, particularly those involving soft tissue.² MRI at 3.0 T was introduced for clinical imaging with the promise of high signal-to-noise ratio, spatial resolution and temporal resolution.³ 3-T MRI is being increasingly used for clinical purposes in paediatrics to assist overcoming the

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Received 30 September 2013; revised 11 November 2013; accepted 14 November 2013

unique anatomical, physiological and behavioural challenges while imaging children.⁴ The increased spatial resolution improves the capacity to image small patients and, specifically, smaller structures such as the inner ear, brachial plexus, biliary system and the vascular system.^{3,4}

When placed in an MF, all substances are magnetized to a degree that varies according to their magnetic susceptibility.^{2,5} Owing to differences in the magnetic susceptibility of human tissue and dental alloys, metallic dental restorations may produce serious artefacts, especially in maxillofacial imaging. The term “MR environment” encompasses the static, gradient and radiofrequency (RF) electromagnetic fields that may affect implants and other devices used in the body.^{6,7} The most immediate risk associated with the MR environment is the attraction created by the MR device between the magnet and ferromagnetic metal objects.⁷ In addition to producing artefacts, metallic objects in the human body may also undergo heating, displacement and rotation during MRI owing to the electromagnetic field.^{1,7} According to many investigators, the presence of an orthodontic appliance in a patient’s mouth presents a potentially hazardous situation because of MF interactions in the MR environment. The use of MRI in orthodontics is rare, but it has been used to image the temporomandibular joint during functional appliance treatment.⁸ However, there is little evidence that fixed appliances need to be removed prior to taking MRI scans to prevent artefacts due to metallic implants being produced. Moreover, there is insufficient evidence to suggest that brackets and bands are dislodged during MRI scans, which may lead to possible tissue damage.⁹

In orthodontics, many different metallic alloys such as nickel (Ni), titanium (Ti) and stainless steel are used as brackets, tubes, and arch or ligature wires for fixed treatment. The main concern for the orthodontist is whether the removal of brackets, tubes or wires in patients is necessary during treatment because of their harmful effects at 3-T MRI. Therefore, the aim of this study was to evaluate the thermal effects and the risk of displacement induced by 3-T MRI on certain metallic devices used in orthodontics.

Methods and materials

Preparation of specimens

A total of 40 non-carious freshly extracted human maxillary teeth were selected and stored in physiological saline solution (Isolyte® 1000 ml; Eczacıbası-Baxter, Istanbul, Turkey). They were randomly divided into four groups ($n = 10$). For each group, rectangular polyvinyl chloride (PVC) boxes (2 cm width $\times$ 8 cm length $\times$ 2 cm depth) were produced using a milling machine (Tos-Mas™ 165; TezSan, Gebze, Turkey). First, all teeth in each group were fixed to the bottom of the PVC box perpendicular to the horizontal plane, with a few drops of hot pink wax in contact, side-by-side, and later freshly poured autopolymerizing acrylic resin (DuraLay™; Reliance Dental Mfg Co., Alsip, IL) was injected into the PVC boxes, 2 mm below the cemento-enamel junction. Following polymerization, the acrylic block was removed from the PVC box and the buccal sides of each tooth were etched with 37% orthophosphoric acid. After the bonding process, 0.018-inch Roth slot metal brackets (Ormco, Orange, CA) were fixed with composite resins in all groups. For a total of four experimental groups (each containing 10 teeth in acrylic blocks), different types of arch and ligature wires (NiTi, stainless steel, elastic) were used, and the following groups were prepared: (a) 0.014-inch NiTi arch wire and elastic ligature (NiTi-e); (b) 0.014-inch NiTi arch wire and continuous stainless steel ligature wire (NiTi-css); (c) 0.014-inch stainless steel arch wire and elastic ligature (SS-e); and (d) 0.014-inch stainless steel arch wire and continuous stainless steel ligature (SS-css) (Figure 1).

MRI and measurements

Heating of orthodontic materials was assessed using an infrared thermometer (Testo 845®; Testo Inc., Sparta, NJ) following scanning in a 3-T MRI scanner (Philips Achieva® 3 T X-Series; Royal Philips Electronics, Amsterdam, Netherlands).¹⁰ In total, four MRI scans were performed. The boxes which contain fixed orthodontic

Figure 1 The study groups: (a) Ni-Ti arch wire and elastic ligature, (b) Ni-Ti arch wire and continuous stainless steel ligature wire, (c) stainless steel arch wire and elastic ligature, (d) stainless steel arch wire and continuous stainless steel ligature.

appliances were placed parallel to the long axis of the coil of the MRI device¹¹ in an 8 × 2 cm concave cavity on the surface of an 8 × 4 cm cylindrical plastic container that was fixed to the bottom of a 19 × 8 cm cylindrical container at a distance of 1 cm from its inner walls (Figure 2). Both containers were filled with 2 l of 0.9% isotonic NaCl solution (Mediflex®; Eczacibasi-Baxter, Istanbul, Turkey) at 22 °C.

Before imaging, the temperature of both the solution and the specimen (outside the container) was measured using an infrared thermometer (Time 1). Measurements were performed at five points: contact point of the 1st and 2nd teeth, contact point of the 3rd and 4th teeth, contact point of the 5th and 6th teeth, contact point of the 7th and 8th teeth and contact point of the 9th and 10th teeth. The temperature of the scan room, specimens and solution was maintained at 18 ± 0.1 °C.

Using a standard head and neck coil, specimens and plastic containers were placed on the bench of the 3-T MRI device for the imaging procedure. Specimens were scanned with T_2 weighted (T_2 W) turbo spin echo in the axial and coronal planes, T_1 weighted (T_1 W) inversion-recovery (IR) turbo spin echo-based sequencing in the axial plane and T_1 three-dimensional sequencing in the sagittal plane. Technical parameters for 3-T MRI are shown in Table 1.

Total scanning time of sequences was approximately 20 min. RF power output gain was adjusted manually. MRI was performed in the following sequence: T_2 W-axial, T_2 W-flair axial, T_2 W-axial, diffusion, T_2 W-coronal

and T_1 three-dimensional sagittal. The temperature of each specimen outside the container was measured again following T_1 W-axial imaging (Time 2). The position of the container was maintained during measurement, and plastic tongs were used to hold the specimens to ensure that the measurements were not affected by human body temperature. Imaging continued following the measurements, and, after the completion of all sequences of MRI, the container was removed from the MR device coil and the temperature of the specimens was recorded immediately outside the solution (Time 3).¹⁰

The statistical software program SPSS® for Windows v. 15.0 (SPSS Inc., Chicago, IL) was used for statistical analysis. Descriptive statistics were presented as the mean, standard deviation, minimum-maximum and 95% confidence intervals. A one-way ANOVA test was used to compare continuous variables of temperature change, with a confidence level set at 95%. A *post hoc* Tukey test was used to compare the groups, as ANOVA results were found to be statistically significant. A *p*-value of <0.05 was considered statistically significant.

Magnetic field interactions

Following temperature measurements, specimens were evaluated for translational attraction and torque.

Translational attraction: The attraction of each specimen [0.018-inch Roth slot bracket, NiTi arch wire (8 cm length, 0.014 inch), stainless steel wire (8 cm length, 0.014 inch)] to the static MF was measured using the American Society for Testing and Materials (ASTM) F2052-02 deflection angle method.¹¹ Each specimen was suspended from the 0° indicator of a plastic protractor by a 6-0 silk surgical thread (weight: 0.009 g, <1% of the specimen weight). Surgical threads were attached to the centre of bracket and to the centre of the wires.¹⁰ The inner surface of the bracket was positioned horizontal to the bench. Deflection angles were assessed at the point of highest spatial magnetic gradient for the 3-T MR scanner (690 G cm⁻¹, 71 cm distant from the isocentre). Deflection from the vertical was measured to the nearest 1°. Measurements were repeated three times, and the average value was calculated and recorded.

Torque: Torque induced by the MF was qualitatively assessed according to the method described by Shellock et al.^{12,13} A millimetric grid scale was attached to the bottom of a clear plastic container. Specimens were placed in the container (brackets were placed face-down and perpendicular to the static MF), and the container was positioned such that the specimen was aligned at the centre of the scanner, where it would be subjected to the maximum torque force.¹⁰

To evaluate any alignment or rotation of the specimens relative to the static MF, the test apparatus was inserted in the coil, and the specimen was observed. Then, the apparatus was removed from the coil, and the specimen was rotated 45°. Thereafter, the apparatus was reinserted and the specimen was observed again. This process was

Figure 2 A specimen that was placed in the cavity of the plastic container that was filled with isotonic saline solution.

Table 1 Technical parameters for 3-T MRI

Parameters	T ₂ W-TSE (axial)	T ₁ W-IR-TSE (axial)	T ₂ W-TSE (coronal)	T ₁ -3D (sagittal)
FOV (mm)	230 × 184	230 × 184	230 × 184	250 × 250
Voxel size (mm)	0.5 × 0.7 × 2	0.5 × 0.7 × 3	0.5 × 0.7 × 2	1 × 1 × 1
Slice thickness (mm)	4	4	4	<1
No. ACQ (slices)	24	24	28	155
TE (ms)	80	20	80	3.7
TR (ms)	3000	2000	3000	8.1
Scan time (min:s)	02:18	02:28	02:18	07:14
WFS (pix)/BW (Hz)	2.244/193.4	2.402/180.8	2.144/202.5	2.244/193.4
SAR/local head	<57%/1.8 W kg ⁻¹	<57%/1.8 W kg ⁻¹	<89%/2.9 W kg ⁻¹	<14%/1.4 W kg ⁻¹
SAR whole body/level (W kg ⁻¹ per normal)	<0.1	<0.1	<0.1	<0.1
NSA	1	1	1	1
Flip angle	90–120 °	90–120 °	90–120 °	8 °
B1 ms (μT)	1.8	1.8	1.8	0.6

ACQ, number of acquisitions; BW, body weight; FOV, field of view; IR, inversion recovery; NSA, number of signals average; SAR, specific absorption rate; T₁-3D, T₁ weighted three-dimensional; T₁W, T₁ weighted; T₂W, T₂ weighted; TE, echo time; TR, repetition time; TSE, turbo spin echo; WFS, water–fat shift.

repeated eight times to complete a 360 ° rotation of each specimen. Torque was qualitatively assessed for each specimen using the following scale¹⁴: 0, no torque; 1, mild torque (slight change of orientation, no alignment to the MF); 2, moderate torque (gradual alignment to the MF); 3, strong torque (rapid and forceful alignment to the MF); 4, very strong torque (very rapid and forceful alignment to the MF).

Results

Radiofrequency heating

A temperature rise was observed in all groups from the beginning of 3-T MRI (Time 1) until the completion of all sequences (Time 3). However, this change in temperature was not >3.04 °C according to the mean values

as shown in Table 2. Also, for all groups, the maximum rise in temperature occurred between Time 1 and completion of T₁W-axial sequencing (Time 2), which was also statistically significant for all groups ($p < 0.05$). A slight rise in temperature was also observed between Time 2 and Time 3 in all groups ($p > 0.05$). The *post hoc* Tukey test revealed that statistical significance was owing to the NiTi-css group.

Between the four groups, the maximum rise in temperature was found for the NiTi-css group, both between Time 1–Time 2 and Time 2–Time 3. The greatest difference between Time 1 and Time 3 was 3.04 °C for the NiTi-css group, and this value was also the maximum temperature difference between all groups.

As a result, overall RF heating for the groups (from Time 1 to Time 3) was statistically significant ($p < 0.05$). RF heating was statistically significantly higher for the

Table 2 Statistical results of the temperature changes

Groups	Mean (°C)	Standard deviation (°C)	95% confidence interval for mean (°C)	Minimum (°C)	Maximum (°C)	p-value ^a
Time 2						
NiTi-e	19.62	0.19	19.38–19.85	19.40	19.90	
NiTi-css	20.58	0.25	20.25–20.90	20.30	20.90	<0.001
SS-e	19.46	0.24	19.16–19.75	19.20	19.80	
SS-css	19.66	0.15	19.47–19.84	19.50	19.80	
Time 3						
NiTi-e	20.00	0.14	19.82–20.17	19.90	20.20	
NiTi-css	21.04	0.13	20.87–21.20	20.90	21.20	<0.001
SS-e	20.04	0.13	19.87–20.20	19.90	20.20	
SS-css	20.12	0.14	19.93–20.30	19.90	20.30	
Difference Time 1–Time 2						
NiTi-e	1.62	0.19	1.38–1.85	1.40	1.90	
NiTi-css	2.58	0.25	2.25–2.90	2.30	2.90	
SS-e	1.46	0.24	1.16–1.75	1.20	1.80	<0.001
SS-css	1.66	0.15	1.47–1.84	1.50	1.80	
Difference Time 1–Time 3						
NiTi-e	2.00	0.14	1.82–2.17	1.90	2.20	
NiTi-css	3.04	0.13	2.87–3.20	2.90	3.20	<0.001
SS-e	2.04	0.13	1.87–2.20	1.90	2.20	
SS-css	2.12	0.14	1.93–2.30	1.90	2.30	

NiTi, nickel–titanium; NiTi-css, NiTi arch wire and continuous stainless steel ligature wire; NiTi-e, NiTi arch wire and elastic ligature; SS-css, stainless steel arch wire and continuous stainless steel ligature; SS-e, stainless steel arch wire and elastic ligature.

^ap-values belong to one-way ANOVA results.

NiTi-css group than for other groups ($p < 0.01$). RF heating was not statistically significant for the NiTi-e, SS-e and SS-css groups compared with the NiTi-css group ($p > 0.05$) (Table 2).

Magnetic field interactions

Average deflection angles were 13° for brackets, 62° for NiTi wire and 71° for stainless steel wire. The qualitative torque score for brackets indicated a slight change (1, mild torque) of orientation, with no alignment to the MF. However, the qualitative torque score for NiTi and stainless steel wire indicated a significant change (2, moderate torque for NiTi wire; and 3, strong torque for stainless steel wire) of orientation, with serious alignment to the MF (Table 3).

Discussion

In the present study, the results of the tests applied for the measurement of RF heating and MF interactions revealed that none of the brackets that are commonly used in fixed orthodontic treatments posed any danger to the patient during the 3-T MRI, but the wires should be removed before imaging for the safety of the patient.

The indications for MRI within the dental and maxillofacial region for various reasons continue to evolve.⁹ In general terms, the removal of fixed orthodontic appliances is advised prior to MRI of the dento-maxillofacial region to prevent artefacts.² However, there is insufficient evidence to suggest that brackets and bands are dislodged or overheated during MRI scans, which may lead to possible tissue damage.⁹ For the safety of patients, radiology centres recommend the removal of not only removable but also fixed orthodontic appliances. However, this is impractical, expensive and time consuming for both the patient and the orthodontist. Metal-based materials create their own MFs. Tissues adjacent to ferromagnetic components are influenced by the induced MF of the metal and, as a result, do not generate a useful signal.^{5,14} Not only do ferromagnetic dental alloys used in dental practice cause distortions in cranial MRI but RF heating and displacement of materials in the oral cavity are important in terms of MRI safety.^{2,5,15,16}

Most brackets currently used are made of austenitic stainless steel containing 18% chrome and 8% Ni.¹⁷ In general, for fixed orthodontic treatment, NiTi and stainless steel arch wires are widely used with stainless steel brackets in clinical practice. The present study examined RF heating and MF interactions of NiTi and stainless

steel arch wires with elastic or stainless steel ligatures during 3-T MRI. In all groups, 0.018-inch Roth slot metal brackets were used. The maximum temperature rise was measured in the NiTi-css group as 3.04°C , and the minimum temperature rise was observed in the NiTi-e group as 2.00°C between Time 1 and Time 3. The temperature rise was similar between the groups NiTi-e, SS-e and SS-css and was not $>2.12^\circ\text{C}$. These temperature rises do not affect the pulpal or mucosal health of the oral cavity. In other words, according to the results of the present study, metallic fixed orthodontic appliances do not constitute any threat in terms of RF heating during 3-T MRI. In the previous studies, which aimed to measure RF heating during MRI, artificial teeth were used¹⁸ or the orthodontic appliances were inserted directly into gelled phantom models.^{19,20} In the present study, to simulate actual clinical conditions, 40 human teeth were used for the application of brackets and wires.

ASTM 2181-02a is a standard testing method developed for measuring RF-induced heating near a passive implant during MRI. This method assumes that the devices to be tested will be located entirely inside the body and notes that, in certain cases, it may be appropriate to incorporate materials of different conductivity within the phantom.¹ Medical devices such as dental implants, orthopaedic implants, stents and neurostimulators are covered by a high volume of muscular tissue and numerous blood vessels, while fixed orthodontic appliances are not located entirely within the body but are located over orofacial tissue that is in close proximity to the MR coil, and if the patient opens his or her mouth during imaging, the restorative device may come into direct contact with the MF.

In the present study, in line with ASTM 2181-02a data, instead of a gelled phantom material, a 0.9% saline solution was used owing to the difficulties and expense involved in preparing different phantom models with heat sensors for each group. However, round plastic containers were used to mimic the head shape, as indicated in ASTM 2181-02a. Previous similar studies performed using pure saline solution found lower temperature changes when compared with gelled phantom models.^{10,21} However, Hasegawa *et al*²⁰ tested maxillary full arch fixed orthodontic appliances with brackets, molar bands and stainless steel wire for RF heating using a gelled phantom model and indicated that the temperature change was approximately $+2.61^\circ\text{C}$. Shellock and Crues²² also indicated that only minor temperature changes occur in association with conventional MR procedures involving metallic objects. Therefore, heat generated during an MR procedure, involving a patient with a passive metallic appliance, particularly if small, does not seem to be a substantial hazard.⁹ We found that the value of the maximum temperature rise was not hazardous for the vital tissue, in line with existing data in the literature. In a recent study,¹⁰ the authors tested fixed prosthodontic substructures that were manufactured from different metallic alloys in terms of RF heating during 3-T MRI, and they found that ceramic veneered metallic substructures do not create any potential risk for 3-T MRI.

Table 3 Magnetic field interactions of orthodontic materials during 3-T MRI

Groups	Deflection angle	Torque
Bracket	13°	1
NiTi wire	62°	2
Stainless steel wire	71°	3

NiTi, nickel–titanium.

In the present study, deflection angle measurements ranged from 13° to 71°. The maximum deflection angle was found for the stainless steel wire, whereas the minimum deflection angle was found for the bracket. According to ASTM International 2052-02,¹¹ a deflection angle <45° indicates that the magnetically induced deflection force is less than the force of gravity, and it can be assumed that the device does not pose any risk during MRI. Thus, it can be concluded that, although the brackets represent no risk during 3-T MRI, NiTi and stainless steel wires do pose a risk.

Qualitative torque measurements were in accordance with deflection angle measurements. Maximum changes of orientation and alignment to the MF were measured for stainless steel wire (Score 3) and brackets presented the least (Score 1). Therefore, it can be concluded that, while the NiTi and stainless steel wires pose a potential risk for patients in a 3-T MRI environment, with respect to MF interaction, brackets can be assumed safe. Our findings for the deflection angle and qualitative torque

measurements are also compatible with the existing data in the literature.^{20,23} The present study differs from previous similar studies^{18–20,23} in that we examined not only the RF heating but also the MF interactions during 3-T MRI by using natural human teeth. It should be noted that this study did not evaluate the changes on the bonding strength of the brackets or changes in the amount of force applied by wires.

Conclusion

The temperature changes of the specimens in the present study were considered to be within acceptable ranges. However, MF interactions of the specimens differed from each other. Although NiTi and stainless steel wires posed a risk for patients during 3-T MRI, brackets represented no risk. Thus, it was concluded that, although the brackets may be considered “MR safe”, it would be safer to replace the wires before MRI.

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