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RESEARCH ARTICLE

Microleakage beneath orthodontic brackets in high field magnetic resonance imaging (MRI) AT 1.5 & 3 Tesla

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Objectives: The aim of the present study was to evaluate the effects of 1.5 T and 3 T MRI on the adhesion between the orthodontic brackets and the teeth by evaluating the microleakage between the enamel, adhesive and brackets interfaces.
Methods: 58 extracted human premolars which were received a standard bracket bonding procedure were randomly divided into three groups; control group (n = 20; no MRI), 1.5 T MRI group (n = 19; 20 min MRI exposure of 1.5 T) and 3 T MRI group (n = 19; 20 min MRI exposure of 3 T). The teeth were kept in distiled water for 2 weeks, and thereafter subjected to 500 thermal cycles. Then, specimens were sealed with nail varnish, stained with 0.5% basic fuchsin for 24 h, sectioned and photographed under a stereomicroscope. Microleakage was scored with regard to the adhesive–enamel and bracket–adhesive interfaces at the occlusal and gingival levels. Statistical analysis was accomplished by Kruskal–Wallis and Bonferroni–Dunn tests.
Results: All of the groups exhibited statistically similar microleakage scores in the adhesive–enamel interface along occlusal margins ($p>0.05$, $p = 0.331$). The mean microleakage scores along gingival margins in the 3 T MRI group was significantly higher compared to the control group both in the adhesive–enamel and bracket–adhesive interfaces ($p<0.05$, $p = 0.019$ and $p = 0.020$ respectively). The microleakage scores along the gingival margins were also significantly higher than the occlusal margins in the 3 T MRI group ($p<0.05$, $p = 0.029$).
Conclusions: 3 T MRI may weaken the adhesion between the enamel and the stainless steel orthodontic brackets.
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Introduction

MRI is a non-invasive technique that uses a magnetic field and radio waves to obtain detailed images of tissues and organs.[1] Compared to dental radiographs or CT, MRI provides images with higher contrast resolution in soft tissues without radiation exposure.[2] Patients undergoing orthodontic treatment benefit from MRI for various head and neck pathologies.[3] Today, 1.5-Tesla (T) and 3 T high field MRIs are frequently used due to high resolution and signal-to-noise ratio (SNR) in images.[4–8] The term "high-field MRI" is used when the scanner's field strength is 1 T or above. Benefits of high-field scanners include shorter scan times as well as the ability to see smaller details of body.[4–8]

There are many studies on the various interactions of orthodontic brackets and wires with MRI.[9–11] It is known that there is a temperature increase of 1–2°C in

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metal dental materials due to MRI.[12] A similar temperature increase occurs in metal orthodontic brackets such as stainless steel, but clinically, MRI applications are considered to be safe for patients in terms of temperature increase.[10,11,13] Also; metallic devices produce a signal void that is visible in the image as a black spot.[14] Orthodontic brackets in the oral region was previously reported to cause MRI-induced image artefact even in distant parts of the body; and also to produce significant geometrical distortion of the images[15] On the other hand, it is known that the magnetic field attracts metal objects during examination resulting in patient injury and damage to the device.[16] Although stainless steel orthodontic brackets are one of the most important components of MRI-induced magnetic moment concerning the head and neck region,[17] according to the general opinion, it is not necessary to remove the brackets most of the time, considering the region wanted to be examined by MRI and the regions where the brackets are located.[2,9,15]

The strength of the adhesion between the brackets and the teeth affects the success and quality of the orthodontic treatment and is also important in terms of patient safety. The adhesion between brackets, tooth and adhesive was previously evaluated by the assesment of the shear bond strength of the brackets after MRI.[13] Assesment of the microleakage between brackets, tooth and the adhesive is an other reliable method for the evaluation of the adhesion between the brackets and teeth.[18,19] It has been reported that the increase of the adhesion between the brackets and the tooth surface minimise the potential for microleakage.[19] Therefore, the aim of the present study was to evaluate the effect of 1.5T and 3T MRI on the adhesion between orthodontic brackets–enamel and adhesive–enamel surfaces by the assesment of microleakage.

Methods and materials

This study was approved by the Ethics Committee of the Medical School of Akdeniz University (App. No: 240). Written informed consent was obtained from patients for the use of their extracted teeth in this study.

To determine adequate sample size G*Power 3.1.9 (Faul, Erdfelder, Buchner, & Lang, 2007) was used. Based on the Arıkan et al's[18] study a minimum sample size of 48 teeth was required to provide 80% power with 5% α and effect size $f = 0.514$. 60 freshly extracted for orthodontic purposes, non-carious human premolars were collected. Teeth with developmental defects, cracks, hypoplastic areas or irregularities of the enamel surface were excluded. Before the starting of the procedure, the teeth were cleaned of calculus, debris and soft tissue remnants and each tooth was polished with pumice and rubber cups for 30 s. The teeth stored in distilled water until the bonding procedure. All of the teeth received the following standard bracket bonding procedures.

A 37% phosphoric acid gel (3M Dental Products, Minnesota) was used for acid etching for 15 s. The teeth were rinsed with water and for 15 s and dried with an oil-free source for 15 s. A metal upper premolar bracket (American Orthodontics Mini Master Brackets 0.022 MBT Compatible) was bonded to each tooth with Transbond XT bonding system (3M Unitek, Monriva, California) according to the manufacturer's instructions and cured with the same curing unit (10 s with Ortholux LED Curing Light). The average bracket surface area of the bracket base was determined 12.4 mm^2.

Specimens were stored in distiled water for 2 weeks at 37°C, after which thermal cycling was performed at 5°C to 55 °C for 500 cycles with a dwell time of 30 s and a transfer time of 10 s, in accordance with ISO/TR 11405 recommandations.[20] The thermal cycle was used to stimulate clinical conditions and to enhance human applicability of bonding agents. After bracket bonding and thermal cycling procedures the specimens were randomly seperated into one control group and two experimental groups of 20 teeth each. Samples of each group were fixed in acrylic resin block with sticky wax. Two teeth were lost during the experiments; hence, the study was finalized with 58 teeth. The groups received the following MRI procedures.

(1) **Control group** ($n = 20$): specimens in the control group underwent the same bracket bonding and microleakage assessment procedures but MR images were not obtained.
(2) **1.5T MRI Group** ($n = 19$): MRI was performed with a 1.5T MR unit (Magnetom Avanto; Siemens Heathineers, Erlangen Germany) by applying a head imaging protocol (axial T_1 weighted thin-section imaging before and after the administration of contrast material, axial T_1- and T_2 weighted fast spin echo imaging, T_1 weighted imaging, magnetisation-prepared rapid acquisition gradient-echo imaging, T_2 weighted imaging, T_2 weighted fluid-attenuated inversion recovery imaging, and T_2 weighted coronal and sagittal fast spin echo imaging) with a head coil (Nova 1Tx/32Rx, Siemens Healthineers) and exposure to a static and varying magnetic field for approximately 20 min.
(3) **3-T MRI Group** ($n = 19$): a 3T MR unit (Magnetom Spectra; Siemens Heathineers, Erlangen Germany) was used to perform MRI for approximately 20 min with the same protocol used for 1.5T imaging.

24 h after MRI protocols, the specimens were prepared. Before dye penetration, the apices of the teeth were sealed with sticky wax, and the specimens were coated with two consecutive layers of nail varnish up to 1 mm from bracket margins. Specimens were then immersed in 0.5% basic fuchsin solution (Wako Pure Chemical Industry, Osaka, Japan) for 24 h. After thorough rinsing with distiled water, the samples were air-dried and, each specimen was sectioned longitudinally with a low-speed diamond disk (Isomed Buehler, Lake Bluff, Illinois)

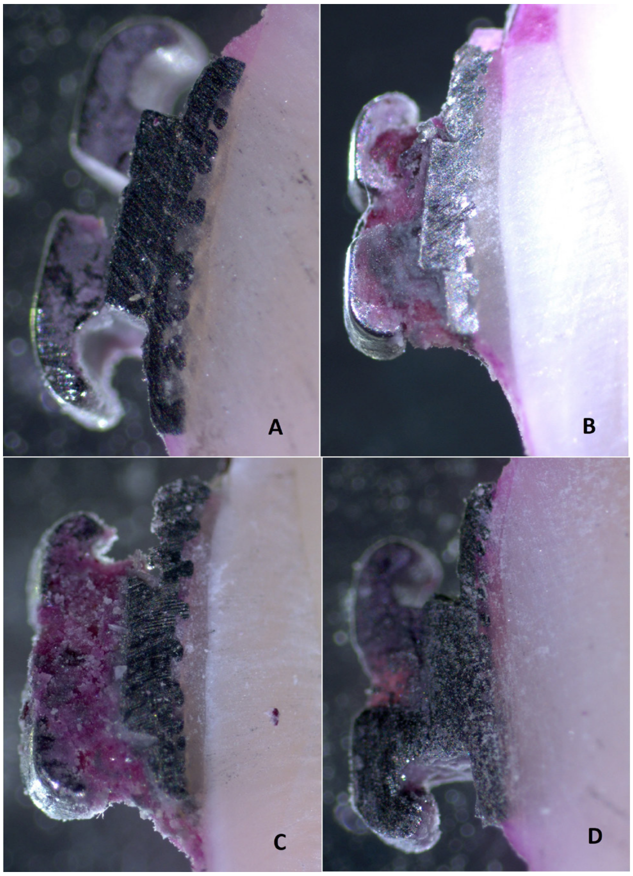

Figure 1 Samples of microleakage scores; (A) Score 0, (B) Score 1, (C) Score 2 and (D) Score 3

with water coolant in the buccolingual direction. The most-stained half of the tooth was used to evaluate the microleakage. All sections were examined by two investigators under a stereomicroscope (Zeiss Stemi, CarlZeiss/GmbH, Germany) at X16 magnification in a blinded fashion. Microleakage was determined at the occlusal and gingival levels along both interfaces (adhesive–enamel interface and bracket–adhesive interface). Scoring was made according to the following criteria[21] (Figure 1).

Score 0: no dye penetration between the bracket–adhesive or adhesive–enamel surface (Figure 1A).

Score 1: dye penetration restricted to 1 mm into the bracket–adhesive or adhesive–enamel surface (Figure 1B).

Score 2: dye penetration into the inner half (2 mm) of the bracket–adhesive or adhesive–enamel surface (Figure 1C).

Score 3: dye penetration into 3 mm of the bracket–adhesive or adhesive–enamel surface (Figure 1D).

In cases of disagreement between scoring, consensus was obtained by using the greater score.

Statistical analysis

The descriptive findings were presented with mean ± standard deviation (SD) for the continuous data. The normality assumptions were controlled by the Shapiro–Wilk test. Wilcoxon signed-ranks test was used for non-parametric comparison of paired data. Comparison of microleakage scores among study groups was performed using Kruskal–Wallis test and Bonferroni–Dunn test was used as a post-hoc test for significant cases. Statistical analysis was made using IBM SPSS Statistics for Windows, v. 23.0 (IBM Corp., Armonk, NY). Two-sided p values <0.05 were considered statistically significant.

Table 1 Comparison of the microleakage scores between adhesive–enamel interfaces

	Variables (mean ± SD)		
Groups	*Gingival*	*Occlusal*	p*a*
Control (n:20)	0.45±0.83[a]	0.4 ± 0.68	$Z = -0.105$ $p = 0.917$
1.5 Tesla MRI (n:19)	0.79 ± 0.54[ab]	0.47 ± 0.51	$Z = -1.732$ $p = 0.083$
3 Tesla MRI (n:19)	1 ± 0.75[b]	0.63 ± 0.6	$Z = -1.811$ $p = 0.070$
	KWH = 7.960b p = **0.019**	KWH = 2.209b *p* = 0.331	

SD, standard deviation.
Same letters in a column denote the lack of statistically significant difference.
[a]Wilcoxon signed-rank test.
[b]Kruskal–Wallis test with post-hoc Bonferroni–Dunn test.

Results

Table 1 demonstrates the microleakage scores of the adhesive–enamel interfaces at the occlusal and gingival levels. All of the groups exhibited statistically similar microleakage scores in the adhesive–enamel interface along occlusal margins (p>0.05, p = 0.331). Although the microleakage scores along the gingival margins was higher than the occlusal margins both in the 1.5 T and 3 T MRI groups, the differences were not statistically significant (p>0.05, p = 0.083 and p>0.05, p = 0.070 respectively). The mean microleakage scores along gingival margins in the 3 T MRI group (1 ± 0.75) was significantly higher compared to the control group (0.45 ± 0.83) (p<0.05, p = 0.019). There was no significant difference in microleakage scores at the gingival margin between the 1.5 T MRI group and the control group.

Table 2 presents the microleakage scores of the bracket–adhesive interfaces at the occlusal and gingival levels. 3 T MRI group (1.05 ± 0.71) exhibited statistically significant higher values of mean microleakage scores of the bracket–adhesive interfaces along gingival margins compared to the control group (0.45 ± 0.6) (p<0.05, p = 0.020). There was no statistically significant difference between the groups in terms of the microleakage scores of the bracket–adhesive interfaces along the occlusal margins (p>0.05, p = 0.278). The microleakage scores along the gingival margins (1.05 ± 0.71)

Table 2 Comparison of the microleakage scores between bracket–adhesive interfaces

	Variables (mean ± SD)		
Groups	***Gingival***	***Occlusal***	**p***a*
Control (n:20)	0.45±0.6[a]	0.35 ± 0.59	$Z = -0.513$ $p = 0.608$
1.5 Tesla MRI (n:19)	0.63 ± 0.6[ab]	0.32 ± 0.48	$Z = -1.732$ $p = 0.083$
3 Tesla MRI (n:19)	1.05 ± 0.71[b]	0.58 ± 0.61	Z **= −**2.179 p **= 0.029**
/+	**KWH = 7.810**b p = **0.020**	KWH = 2.564b *p* = 0.278	

SD, standard deviation.
Same letters in a column denote the lack of statistically significant difference.
[a]Wilcoxon signed-rank test.
[b]Kruskal–Wallis test with post-hoc Bonferroni–Dunn test.

were significantly higher than the occlusal margins (0.58 ± 0.61) in the 3T MRI group ($p<0.05$, $p = 0.029$). However, there was no significant difference between the mean microleakage scores of gingival and occlusal levels for control and 1.5T MRI groups ($p>0.05$, $p = 0.608$ and $p>0.05$, $p = 0.083$ respectively).

In all groups, there was no statistically significant difference between the microleakage scores of adhesive–enamel and bracket–adhesive interfaces for gingival ($Z = 0.426$, $p>0.05$, $p = 0.670$) and occlusal margins ($Z = -1.291$, $p>0.05$, $p = 0.197$).

Discussion

During conventional fixed orthodontic treatment; stainless steel brackets and metallic archwires are usually used. Patients undergoing orthodontic treatment may need MRI for any reason. In this cases, although no clear guidelines are available, removal of the fixed orthodontic appliances (brackets and archwires)[22,23] or only archwires[1] was recommended by some authors for patient safety. In fact, the removal of orthodontic appliances, even for a few hours or days, is costly, time consuming and uncomfortable for both the clinician and the patient.[13] The studies investigating the interaction between the MRI and orthodontic appliances generally focused on image artefacts and the increase in the temperature of the brackets and archwires. As a general rule, the more distance between the brackets and the desired anatomic location to be imaged, the less the void and artefact and the less distortion.[9,24] It is also known that a 1–2°C temperature increase occurs in metal orthodontic brackets, but clinically, MRI applications are considered to be safe for patients in terms of temperature increase.[10,11,13]

Displacement of metallic orthodontic devices in the oral cavity is another aspect of the interaction between the orthodontic treatment and MRI. Some studies evaluated the risk of displacement in MRI by measuring deflection angles and translational forces.[25,26] The maximal forces observed were 0.3N, and the deflection angles reached maximum 45°; so the authors reported that 1.5T and 3T MRI can be used safely in terms of the risk of detachment and displacement of the orthodontic brackets when respecting the usual recommendations.[25,26] Sfondrini et al[13] investigated the shear bond strength for the evaluation of the adhesion between the orthodontic brackets and the enamel surface after MRI. The values were considered to be clinically acceptable, between 5 and 50MPa, representing the theoretical limits for an orthodontic material to sustain musticatory forces without risk of enamel lost.[27] No published study has evaluated the microleakage after MRI for the assesment of the adhesion between the brackets and teeth. In the present study, the microleakage between the adhesive, teeth and the orthodontic brackets was preferred not only for the evaluation of the displacement and detachment risk of the brackets but also the likelihood of formation of white spot lesions on the enamel at the adhesive–enamel interface after MRI.

Wang et al[17] revealed in their study that the magnetic moment differs in transverse and longitudinal directions. In their study, it has been emphasised that the magnetic moment may vary in different bracket types and in different head positions of the patients in 1.5T brain MRI. Therefore, although acrilic blocks were used instead of phantom head model in the present study, samples in both groups were tried to be placed on MRI devices in the same direction and trying to imitate the clinical position during brain MRIs. The fact that more microleakage was observed in the gingival margin than occlusal in both 1.5T and 3T MRI in the present study may indicate the directional effect of the electromagnetic moment of MRI on the stainless steel brackets. Also, the easier angulation of the curing light at the occlusal margin might be another possible reason for this difference. In addition, the phase-encoding direction process, which is used to regulate vertical and horizontal radiofrequency in order to prevent artefact formation, may play an important role in the formation of microleakage difference in the gingival and occlusal margins.[28] While more microleakage was observed in the brackets in 3T MRI compared to the control group, the same significant difference was not observed for 1.5T MRI, which may affect MRI preferences in those undergoing orthodontic treatment.

Sfondrini et al[13] showed that MRI did not affect the adhesion between the brackets and the teeth that would impair primary stability. The absence of primary instability of the brackets in both MRI groups in the current study indicated that the results were consistent with the literature. However, Sfondrini et al[13] removed the brackets from teeth after MRI procedure and scored according to the surface where the composite was left remain. They concluded that MRI increased the amount of composite removed from the enamel, but did not create a significant difference with the control group.[13] Although the authors attributed this MRI-induced bond change to the effect of heat, this method may have caused uncertainties in demonstrating the weakening effect on the bond strength of the composite due to magnetic moment. In present study, the brackets were not removed from the teeth after MRI, and microleakage was measured using basic-fuchsin with a stereomicroscope by taking a vertical section from the teeth. The significant difference in microleakage of 3T MRI compared to the control group can be considered as a clinically remarkable finding. The fact that brackets attached to extracted teeth caused significantly more microleakage than the control group in only one 3T MRI imaging suggests that the primary stability of the bracket may be impaired in patients receiving repeated head-neck MRIs or in cases where the weakness of the composite bond will increase due to long-term use (especially individuals in the last stages of orthodontic treatment). Therefore, it would be appropriate to evaluate patients undergoing orthodontic treatment in terms of bracket stability before and after MRI.

From the orthodontic point of view, microleakage presents the likelihood of formation of white spot lesions on the enamel at the adhesive–enamel interface.[19] Since the microleakage scores were found to be statistically higher in 3T MRI group in the present study, the risks of enamel demineralization, white spot lesions and dental caries formation should also be considered especially in patients who have to undergo repeated MRIs during their orthodontic treatment.

In the present study, the effect of 3T MRI on bracket stability was found to be more suspicious than 1.5T MRI in terms of patient safety. This result should be taken into account by medical practitioners and radiologists as well as dentists. Especially in cases where the image quality in brain MRI does not make a clinically significant difference between 1.5T and 3T MRI applications, choosing the appropriate imaging device may be important for patient safety.

One of the limitations of the present study was that the extracted teeth were placed on an acrylic block and placed in the MRI device. This may not have provided clinically relevant conclusions about the direction of the magnetic moment. Taking the bracket and teeth into MRI using a phantom model could provide a more realistic simulation of the direction of the magnetic moment.

Another limitation was that 1.5T and 3T MRI were performed only once. It might be possible for the microleakage to differ significantly in the 1.5T MRI as in the 3T MRI with repeated magnetic resonance imagings. This may be the subject of a future study.

Conclusion

All of the groups exhibited microleakage between either the adhesive–enamel interface or the bracket–adhesive interface. The mean microleakage scores along gingival margins in the 3T MRI group was significantly higher compared to the control group both in the adhesive–enamel and bracket–adhesive interfaces.

3T MRI may weaken the adhesion between the enamel and the stainless steel brackets. In those undergoing orthodontic treatment, care should be taken in determining the MRI protocol and patient safety due to orthodontic brackets.

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Contributors

EBG contributed to methodology, validation, investigation, resources, writing – review & editing, visualization; SS contributed to investigation, writing – original draft; AK contributed to supervision, review & editing.

Conflict of Interest Statement:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics approval

This study was approved by the Ethics Committee of the Medical School of Akdeniz University (App. No: 240).

REFERENCES

1. Görgülü S, Ayyildiz S, Kamburoglu K, Gökçe S, Ozen T. Effect of orthodontic brackets and different wires on radiofrequency heating and magnetic field interactions during 3-t mri. *Dentomax-*

illofac Radiol 2014; **43**(2): 20130356. https://doi.org/10.1259/dmfr.20130356
2. Ozawa E, Honda E-I, Parakonthun KN, Ohmori H, Shimazaki K, et al. Influence of orthodontic appliance-derived artifacts on 3-t mri movies. *Prog Orthod* 2018; **19**(1): 7. https://doi.org/10.1186/s40510-018-0204-6
3. Camporesi M, Bulhoes Galvão M, Tortamano A, Dominguez GC, Defraia N, et al. Ceramic brackets and low friction : a possible synergy in patients requiring multiple mri scanning. *J Orofac Orthop* 2016; **77**: 214–23. https://doi.org/10.1007/s00056-016-0027-3
4. Cheng CH, Huang HM, Lin HL, Chiou SM. 1.5t versus 3t mri for targeting subthalamic nucleus for deep brain stimulation. *Br J Neurosurg* 2014; **28**: 467–70. https://doi.org/10.3109/02688697.2013.854312
5. Bastiaansen JAM, Piccini D, Di Sopra L, Roy CW, Heerfordt J, et al. Natively fat-suppressed 5d whole-heart mri with a radial free-running fast-interrupted steady-state (fiss) sequence at 1.5t and 3t. *Magn Reson Med* 2020; **83**: 45–55. https://doi.org/10.1002/mrm.27942
6. Chow N, Hwang KS, Hurtz S, Green AE, Somme JH, et al. Comparing 3t and 1.5t mri for mapping hippocampal atrophy in the alzheimer's disease neuroimaging initiative. *AJNR Am J Neuroradiol* 2015; **36**: 653–60. https://doi.org/10.3174/ajnr.A4228
7. Zijlmans M, de Kort GAP, Witkamp TD, Huiskamp GM, Seppenwoolde J-H, et al. 3T versus 1.5t phased-array mri in the presurgical work-up of patients with partial epilepsy of uncertain focus. *J Magn Reson Imaging* 2009; **30**: 256–62. https://doi.org/10.1002/jmri.21811
8. Kim J, Chang K-H, Na DG, Song IC, Kim SJ, et al. Comparison of 1.5t and 3t 1h mr spectroscopy for human brain tumors. *Korean J Radiol* 2006; **7**: 156–61. https://doi.org/10.3348/kjr.2006.7.3.156
9. Poorsattar-Bejeh Mir A, Rahmati-Kamel M. Should the orthodontic brackets always be removed prior to magnetic resonance imaging (mri)? *J Oral Biol Craniofac Res* 2016; **6**: 142–52. https://doi.org/10.1016/j.jobcr.2015.08.007
10. Almuqbel MM, Leeper GJ, Petelo JF, Page TJ, Melzer TR. MRI artefact in the rectum caused by ingested orthodontic brackets. *Radiography (Lond)* 2018; **24**: e48-50. https://doi.org/10.1016/j.radi.2017.10.002
11. Regier M, Kemper J, Kaul MG, Feddersen M, Adam G, et al. Radiofrequency-induced heating near fixed orthodontic appliances in high field mri systems at 3.0 tesla. *J Orofac Orthop* 2009; **70**: 485–94. https://doi.org/10.1007/s00056-009-9923-0
12. Oriso K, Kobayashi T, Sasaki M, Uwano I, Kihara H, et al. Impact of the static and radiofrequency magnetic fields produced by a 7t mr imager on metallic dental materials. *Magn Reson Med Sci* 2016; **15**: 26–33. https://doi.org/10.2463/mrms.2014-0122
13. Sfondrini MF, Preda L, Calliada F, Carbone L, Lungarotti L, et al. Magnetic resonance imaging and its effects on metallic brackets and wires: does it alter the temperature and bonding efficacy of orthodontic devices? *Materials (Basel)* 2019; **12**(23): E3971. https://doi.org/10.3390/ma12233971
14. Shafiei F, Honda E, Takahashi H, Sasaki T. Artifacts from dental casting alloys in magnetic resonance imaging. *J Dent Res* 2003; **82**: 602–6. https://doi.org/10.1177/154405910308200806
15. Zachriat C, Asbach P, Blankenstein KI, Peroz I, Blankenstein FH. MRI with intraoral orthodontic appliance-a comparative in vitro and in vivo study of image artefacts at 1.5t. *Dentomaxillofac Radiol* 2015; **44**(6): 20140416. https://doi.org/10.1259/dmfr.20140416
16. Shellock FG. Biomedical implants and devices: assessment of magnetic field interactions with a 3.0-tesla mr system. *J Magn Reson Imaging* 2002; **16**: 721–32. https://doi.org/10.1002/jmri.10207
17. Wang ZJ, Rollins NK, Liang H, Park YJ. Induced magnetic moment in stainless steel components of orthodontic appliances in 1.5 t mri scanners. *Med Phys* 2015; **42**: 5871–78. https://doi.org/10.1118/1.4930796
18. Arikan S, Arhun N, Arman A, Cehreli SB. Microleakage beneath ceramic and metal brackets photopolymerized with led or conventional light curing units. *Angle Orthod* 2006; **76**: 1035–40. https://doi.org/10.2319/110905-392
19. Kustarci A, Sokucu O. Effect of chlorhexidine gluconate, clearfil protect bond, and ktp laser on microleakage under metal orthodontic brackets with thermocycling. *Photomed Laser Surg* 2010; **28 Suppl 2**: S57-62. https://doi.org/10.1089/pho.2009.2626
20. ISO Technical Report 11405. *Dental Materials: Guidance on Testing of Adhesion to Tooth Structure*. Geneva: International Organization for Standardization; 1994.
21. Arhun N, Arman A, Cehreli SB, Arikan S, Karabulut E, et al. Microleakage beneath ceramic and metal brackets bonded with a conventional and an antibacterial adhesive system. *Angle Orthod* 2006; **76**: 1028–34. https://doi.org/10.2319/101805-368
22 . Costa AL, Appenzeller S, Yasuda CL, Pereira FR, Zanardi VA, Cendes F. Artifacts in brain magnetic resonance imaging due to metallic dental objects. Med Oral Patol Oral Cir Bucal 2009;14(6):278-282.
23. Blankenstein FH, Asbach P, Beuer F, Glienke J, Mayer S, et al. Magnetic permeability as a predictor of the artefact size caused by orthodontic appliances at 1.5 t magnetic resonance imaging. *Clin Oral Investig* 2017; **21**: 281–89. https://doi.org/10.1007/s00784-016-1788-1
24. Elison JM, Leggitt VL, Thomson M, Oyoyo U, Wycliffe ND. Influence of common orthodontic appliances on the diagnostic quality of cranial magnetic resonance images. *Am J Orthod Dentofacial Orthop* 2008; **134**: 563–72. https://doi.org/10.1016/j.ajodo.2006.10.038
25. Kemper J, Klocke A, Kahl-Nieke B, Adam G. Orthodontic brackets in high field mr imaging: experimental evaluation of magnetic field interactions at 3.0 tesla. *Rofo* 2005; **177**: 1691–98. https://doi.org/10.1055/s-2005-858762
26. Yassi K, Ziane F, Bardinet E, Moinard M, Veyret B, et al. Evaluation of the risk of overheating and displacement of orthodontic devices in magnetic resonance imaging. *J Radiol* 2007; **88**: 263–68. https://doi.org/10.1016/s0221-0363(07)89813-1
27. Scribante A, Contreras-Bulnes R, Montasser MA, Vallittu PK. Orthodontics: bracket materials, adhesives systems, and their bond strength. *Biomed Res Int* 2016; **2016**: 1329814. https://doi.org/10.1155/2016/1329814
28. Eo T, Shin H, Jun Y, Kim T, Hwang D. Accelerating cartesian mri by domain-transform manifold learning in phase-encoding direction. *Med Image Anal* 2020; **63**: 101689. https://doi.org/10.1016/j.media.2020.101689