Radiofrequency heating and magnetic field interactions of fixed partial dentures during 3-tesla magnetic resonance imaging

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Objective. This study evaluated the heating and magnetic field interactions of fixed partial dentures in a 3-Tesla (3T) magnetic resonance imaging (MRI) environment.

Study design. Three substructure materials (Co-Cr, Ni-Cr, ZrO_2) were used to fabricate twelve 4-retained bridges and 12 crowns. Specimens were evaluated at 3T for radiofrequency heating and magnetic field interactions. One-way analysis of variance (ANOVA) test was used to compare continuous variables of temperature change. Significance was set at $P < .05$. Translational attraction and torque values of specimens were also evaluated.

Results. None of the groups exhibited excessive heating (mean temperature change, < 1.4°C), with maximum increase at the end of the T-1. Moreover, in all groups, only relatively minor magnetic field interactions that would not cause movement in situ were observed.

Conclusion. The study findings indicated that patients with fixed partial dentures (single crown or bridge) fabricated from Co-Cr, Ni-Cr, and zirconia substructures may safely undergo MRI at up to 3T. (Oral Surg Oral Med Oral Pathol Oral Radiol 2013;116:640-647)

Magnetic resonance imaging (MRI) is a diagnostic imaging technique that uses static and time-varying magnetic fields (MFs) to provide tissue images through the magnetic resonance (MR) of nuclei.[1] MRI provides essential support for clinical diagnosis of soft tissue and blood flow in both medicine and dentistry.[2] The greatest advantage of MRI is its ability to provide multiplanar imaging of every part of the body without moving the patient.[3] Moreover, unlike computed tomography (CT) scans and traditional radiographs, MRI scanning is harmless to the patient, as it uses strong MFs and non-ionizing electromagnetic fields in the radiofrequency range.[4]

When placed in an MF, all substances are magnetized to a degree that varies according to their magnetic susceptibility.[5,6] Due to differences in the magnetic susceptibility of human tissue and dental alloys, metallic dental restorations may produce serious artifacts, especially in maxillofacial imaging. Metallic materials can be classified according to their degree of magnetic susceptibility as ferromagnetic (materials that have a large, positive susceptibility to an external magnetic field), paramagnetic (materials that have a small, positive susceptibility to magnetic fields), or diamagnetic (materials that have a weak, negative susceptibility to magnetic fields). Whereas ferromagnetic metals such as iron, cobalt, and nickel strongly amplify the MF, paramagnetic metals such as chromium, manganese, and aluminum only slightly amplify the MF, and diamagnetic metals such as copper, gold, zinc, lead, and carbon slightly weaken the MF.[7-9] Various materials that are used in the oral cavity for prosthetic treatment are considered ferromagnetic.[10,11]

The term *MR environment* encompasses the static, gradient, and radiofrequency (RF) electromagnetic fields that may affect implants and other devices used in the body.[11] The most immediate risk associated with the MR environment is the attraction created by the MR device between the magnet and ferromagnetic metal objects.[12] In addition to producing artifacts, metallic objects in the human body may also undergo heating, displacement, and rotation during MRI because of the electromagnetic field. During imaging, an RF pulse is used to excite

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Statement of Clinical Relevance

MRI safety and the compatibility of dental alloys must always be considered before an MRI procedure. In this study, measurement of RF heating and MF interactions revealed that none of the alloys commonly used in fixed prosthodontic treatments posed danger for the patient during 3T MRI.

protons by an exchange of energy. The body absorbs some of this energy, and heating occurs in tissue.[1] Thus, accidents and injuries may occur with high MFs.[12] The American Society for Testing and Materials (ASTM) International and the US Food and Drug Administration (FDA) use 3 terms to define the safety of medical devices in MRI: *MR safe*, *MR conditional*, and *MR unsafe*.[13] *MR safe* refers to devices or implants that are completely non−magnetic, non−electrically conductive, and non−RF reactive, eliminating all of the primary potential threats during an MRI procedure. *MR conditional* refers to devices that may contain magnetic, electrically conductive, or RF-reactive components that may safely be operated near an MRI system. *MR unsafe* refers to devices that are strongly ferromagnetic and pose a clear and direct threat to persons and equipment within the magnet room.[13,14]

Dental treatment today involves a wide range of alloy products such as crowns, bridges, denture frames, implants, posts, pins, orthodontic brackets, wires, and amalgam,[8] and many studies have investigated artifacts generated by these materials.[7-9] MRI may also cause movement or heating of metal objects present in the body that can lead to potential health risks for patients undergoing examination. It is well known that removable dentures should be removed before MRI, as the powerful MF of the scanner can induce them to move suddenly and with great force toward the center of the MR system, causing harm to the patient as well as the device.[10]

MRI safety and the compatibility of dental alloys must always be considered before an MRI procedure[15]; however, as developments in technology have occurred, some materials now used in fixed partial dentures—such as cobalt-chromium (Co-Cr) metal substructures produced by direct metal laser sintering (DMLS) and zirconia (ZrO_2) crowns—have not been tested for MRI safety. DMLS is an additive metal fabrication technology that involves the use of a focused, high-powered Yb-fiber optic laser[16] to melt and fuse metal powder into solid parts that are built up from individual layers.[17] Zirconium dioxide (zirconia, ZrO_2) ceramics have superior mechanical properties, high flexural strength, and high fracture toughness, and over the past decade they have come into increasing use for copings and frameworks of fixed restorations.[18] The aim of the present study was to evaluate changes in temperature and MFs of fixed partial dentures fabricated from Co-Cr, Ni-Cr, and ZrO_2 in a 3-tesla MRI (3T MRI) environment and to estimate the safety of these alloys for patients undergoing 3T MRI examination.

MATERIALS AND METHODS

Preparation of specimens

A total of 36 non-carious freshly extracted human maxillary premolar teeth were selected and stored in physiologic saline solution (Isolyte 1000 mL, Eczacıbası-Baxter, Istanbul, Turkey). Cylindrical PVC rings (2 cm diameter × 3 cm length) were produced using a milling machine (Tezsan, Tos-Mas 165, Gebze, Turkey). Freshly poured autopolymerizing acrylic resin (DuraLay; Reliance Dental Mfg. Co., Worth, IL, USA) was injected into the PVC rings, and tooth specimens were embedded in the resin perpendicular to the horizontal plane 2 mm below the cementoenamel junction. After polymerization, the PVC rings containing the tooth specimens were horizontally clamped onto the rotary segment of a lathe (Tezsan, D-110, Gebze, Turkey), and the specimens were shaped using a diamond blade at 40,000 rpm under water-cooling to obtain semiconical specimens with diameters of 5 mm at the cervical level and 4 mm at the occlusal level, a crown height of 4 mm, 5° angled axial walls, and a chamfer-type finish line. Then 24 of the 36 PVC rings were fixed together in pairs using cyanomethylmethacrylate glue to obtain 12 sets of double-rings with a distance of 2 cm between tooth specimens. These double-rings were used in the fabrication of 4-unit fixed partial dentures with 2 pontics (Figure 1a), whereas the 12 single-rings were used in the fabrication of single crowns (see Figure 1b). Three types of restorative materials (Co-Cr, Ni-Cr, ZrO_2) (Table I) were used in fabrication, for a total of 6 experimental groups ($n = 12$), as follows: Co-Cr Crown (C-CoCr), Ni-Cr Crown (C-NiCr), Zirconia Crown (C-Zr), Co-Cr Bridge (B-CoCr), Ni-Cr Bridge (B-NiCr), and Zirconia Bridge (B-Zr).

Fabrication of restorations

Co-Cr restorations (Groups C-CoCr and B-CoCr) were fabricated using a DMLS system (M2 Cusing, Concept Laser GmbH, Lichtenfels, Germany). Tooth specimen surfaces were scanned directly using an optical scanner (Activity 102, Smart Optics Sensortechnik GmbH, Bochum, Germany), and restorations were digitally designed using three-dimensional (3D) computer-aided design (CAD). Metal substructure retainers were designed with a thickness of 0.5 mm, and pontics were designed with an occlusogingival height of 0.5 cm and a buccolingual width of 0.8 cm. After DMLS, Co-Cr bridges and crowns were annealed in an argon atmosphere at a controlled temperature in line with the manufacturer's recommendations.

Ni-Cr restorations (Groups C-NiCr and B-NiCr) were fabricated using conventional casting techniques. Casting wax was modeled onto prepared tooth specimens, and the modeled patterns were sprued, invested, and cast in an induction machine (Fornax, Bego, Bremen, Germany).

Zirconia restorations (Groups C-Zr and B-Zr) were fabricated using the 3D CAD data obtained for the