Clinical Significance
In prosthodontics, MRI is often used to examine the temporomandibular joint and implant position. However, artifacts can be produced with some metals. This study examined the artifacts generated by certain metals in this field under MRI.

Abstract
Purpose: To evaluate the artifacts generated by crown-shaped dental alloys and a magnetic keeper quantitatively by analyzing digital MRI data.
Methods: One pre-fabricated magnetic keeper and four clinical dental alloys (gold-silver-palladium, casting gold alloy Type 3, cobalt-chromium, gold porcelain alloy) were selected. Twenty metal crowns and 5 magnetic keepers were analyzed. The samples were placed in an acrylic phantom (150 mm × 150 mm × 150 mm) filled with agar, and then placed in the MRI apparatus. Various image slices were selected from the center (0 mm) to 70 mm at steps of 5 mm. The distribution of the signal intensity in the region of interest was calculated using ImageJ software and the mean coefficient of variation of each specimen was obtained. Statistical analysis was performed by Dunnett's test (p < 0.05).
Results: Compared to the resin control, cobalt-chromium showed significantly greater signal intensity up to 40 mm in coronal T2-WI images and up to 70 mm in axial T1-WI images for the magnetic keeper. The signal intensities of gold-silver-palladium and casting gold alloy Type 3 were not significantly different from that of the control. The signal intensity of gold porcelain alloy was significantly different from that of the control at 0 mm and 5 mm in coronal T1,T2-WI and in sagittal T1-WI at 0 mm.
Conclusions: The artifacts generated by the magnetic keeper and the cobalt-chromium crown when they are used in a second molar can disturb the MR images of the temporomandibular joint.

Key words: artifacts, metallic alloys, MRI, magnetic keeper.

Introduction
Various kinds of alloy products are used in dental treatment, such as orthodontic wires, clips, inlays, crowns, denture frames, implants, and so on. In addition, magnetic attachments are used as retainers for conventional or implant-supported overdentures. Since the 1990s, magnetic attachments have become popular in Japan, but are not as well known in Europe and the USA. The major advantage of magnetic attachments is their ability to eliminate the lateral force to the abutment and the ease with which dentures can be manipulated, even by handicapped patients.

However, these alloys may generate artifacts when magnetic resonance imaging (MRI) is used as a diagnostic tool. Many studies have investigated the artifacts generated by metals in medicine and dentistry. New et al. investigated the deflection force of clips in stronger magnetic fields and the intensity of artifacts in the MRI of dental amalgam. Although dental amalgam and 14-carat gold did not produce artifacts, stainless steel in dentures produced intense artifacts. In the medical field, Sherlock and Kanal demonstrated that metal devices such as aneurysm clips composed of 90% silver and pure titanium could be a source of artifacts.

In dentistry, the loss of signal and image distortion can be observed in MRI of the head and neck due to the presence of dental alloys. Artifacts produced by different precious and non-precious alloys have been investigated. Shafiei et al. determined the compositions of dental casting alloys according to their elemental compositions. Savane et al. found minor artifacts without distortions with...
titanium and its alloys. Another study\(^9\) sought to identify the relationship between ferromagnetic and nonferromagnetic devices to compare their magnetic forces. Most of these previous studies used samples with shapes different from those used in dental practice. In the present study, crowns composed of different dental alloys and a pre-fabricated dental keeper were used to control the area of the magnetic field generated under MRI. The aim of this study was to evaluate the artifacts generated by metal crowns and keepers quantitatively by analyzing digital data within the region of interest (ROI).\(^7\)

### Materials and Methods

**1. Samples**

The samples used in this study were as follows: a magnetic keeper (Kp; Hitachi Metals Ltd., Tokyo, Japan), gold-silver-palladium (Pd; GC Corporation, Tokyo, Japan), gold casting alloy (Au; Sankin Industry Co., Ltd. Osaka, Japan), cobalt-chromium (CoCr; GC Corporation, Tokyo, Japan), gold porcelain alloy, porcelain bonding (MB) Penceram\(^{TM}\) 65 (Pentron, San Diego, CA, USA). An acrylic resin (Crown-S #5 GC, Tokyo, Japan) was used as the control (Rs). This resin is usually used clinically as a temporary crown and it does not generate artifacts in MRI. A shell crown molar (Mesio-distal: 8 mm; bucco-lingual: 7.5 mm) was used as a model for the entire dental crown. A total of 20 crown shapes and 5 magnetic keepers were investigated (Fig. 1, Table 1).

**2. Phantom and agar**

A cubic phantom (150 mm × 150 mm × 150 mm) (Fig. 2a) was used. To fix the sample in the phantom, a reversible hydrocolloid agar (Tai-Gel, GC Dental Corp., Tokyo, Japan) was used. The agar was first melted in a Colloid Bath ST-600 (Sankin Corp. Tokyo, Japan) at 80°C for 120 minutes. It was then poured up to the center of the phantom, about 70 mm from the base. After the agar had gelled, the sample was placed in the middle of the phantom. A second layer of agar was then poured to entirely fill the phantom (Fig. 2a).

**3. MR imaging**

The phantom was placed in a head and neck coil on the table of a 1.5-T MRI apparatus (Fig. 2b) (Magnetom Vision, Siemens, Erlangen, Germany). To investigate a sequence of artifact images in the axial, coronal, and sagittal planes, a T1-weighted spin-echo sequence (repetition time TR/echo time TE: 550 ms/14 ms) and T2-weighted turbo spin-echo sequence (TR/TE: 3400 ms/90 ms) were used with an acquisition time (TA) of 03:33. All images were taken with the following parameters: number of acquisitions (AC), 3; number of slices, 19;

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**Table 1**

<table>
<thead>
<tr>
<th>Dental casting</th>
<th>Abbreviation</th>
<th>Composition (%)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic keeper</td>
<td>Kp</td>
<td>Fe 58.8, Cr 19, Mo2</td>
<td>Hitachi, Japan</td>
</tr>
<tr>
<td>Sankin Ortop type 3</td>
<td>Au</td>
<td>Au 75, Pt 4, Ag 6, Cu 12, Others 3</td>
<td>Sankin, Japan</td>
</tr>
<tr>
<td>Cobalt-chromium</td>
<td>CoCr</td>
<td>Co 64, Cr30, Mo 6, MN, Si, C, N</td>
<td>Pentron, USA</td>
</tr>
<tr>
<td>Gold-silver-palladium</td>
<td>Pd</td>
<td>Au 12, Ag 46, Pd20, Cu 20</td>
<td>GC, Japan</td>
</tr>
<tr>
<td>Gold porcelain alloy</td>
<td>MB</td>
<td>Au 65, Pd25, In &lt; 9, Ir, Ga, Ag</td>
<td>Pentron, USA</td>
</tr>
<tr>
<td>Resin control</td>
<td>Rs</td>
<td>Resin acrylic</td>
<td>GC, Japan</td>
</tr>
</tbody>
</table>

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![Fig. 1](image1.png)  
**Fig. 1** Samples included in the study. a: Crown-shaped samples. b: Acrylic resin. c: Dental keeper.

![Fig. 2](image2.png)  
**Fig. 2** a: Cubic Phantom: (150 mm × 150 mm × 150 mm) Agar-agar (Tai-Gel, GC, Tokyo, Japan). b: MRI apparatus table (1.5 T, Magnetom Vision, Siemens, Erlangen, Germany). c: Axial, coronal, and sagittal planes, from buccal to lingual, of a crown-shaped sample.
thickness, 5 mm; pixel size, 0.9 mm × 0.9 mm; matrix size, 256 × 256; FOV, 230/mm; scan time, 6 min 10 s (Fig. 2).

4. Data and statistical analysis
The Digital Imaging and Communications in Medicine (DICOM) data obtained from MR images of each sample were analyzed using Image J software (Bethesda, MD, USA) and an ROI was drawn around square images for data acquisition. The ROI was drawn around the same image periphery. The center of each sample image was determined using DICOM 3D dimension viewer software (INTAGE Realia Professional). The mean and standard deviation (SD) of the signal intensity (SI) were obtained from the pixels within the ROI images, and the mean coefficient of variation (CV) for each sample was calculated. To analyze artifacts generated by the samples, different ranges were selected: for Au, MB, and Pd, 0–20 mm; for CoCr, 0–45 mm; and for Kp, 0–70 mm. To compare the SI between the control and the samples from 0 mm to 70 mm, Dunnett’s test was performed and p < 0.05 was considered significant (SPSS Ver. 11.5; SPSS Japan Inc., Tokyo, Japan).

Results
1. Artifacts in MR images
In the ROI (Fig. 3), artifacts from the center (0 mm) are shown in axial T1-WI images. With Au, MB, and Pd, artifacts appeared as a black gap in the middle of the phantom. With Kp and CoCr, an incurvation of the image at the center surrounded by a white area was observed. In the Rs image, the crown’s shape can be seen clearly without any deformation.

2. DICOM data
Using histograms, we identified different SI values throughout the ROI for each alloy (Fig. 4). Judging from the figures, SI is narrowly distributed from the ROI control and widely from Kp. The range of SI for Kp was between 2 and 4095 while for control it was between 6 and 2172. The SI was studied between 0 and 4095. Compared to Rs, SI showed wide variation throughout the ROI within a small number of pixels in samples that showed a high level of SI, like Kp and CoCr. The histograms for Au, MB, and Pd showed a narrow SI distribution.

Fig. 3 Axial T1WI MRI images from the center of the sample. Artifacts in the ROI. a: Gold casting alloy Type 3 (Au). b: Magnetic keeper (Kp). c: Cobalt-chromium (CoCr). d: Gold-silver-palladium (Pd). e: Gold porcelain alloy, porcelain bonding (MB). f: Control. g: Drawing of the phantom: ROI around the sample.

Compared with Rs at 0 mm, the mean CV of SI for CoCr showed a significant difference up to 25 mm for axial T1-WI, but for axial T2-WI, significant differences were only observed at 0 mm and 20 mm (Table 2). The SI was significantly different up to 40 mm in coronal T1-WI, but with a non-signal gap from 15 to 30 mm. CoCr showed artifacts up to 10 mm in coronal T2-WI. In sagittal T1-WI, the CV of SI was significantly different up to 10 mm, and T2-WI showed a much greater difference up to 15 mm.

The mean SI for Kp was significantly different in axial T1-WI up to 70 mm, i.e., up to the edge of the ROI. Artifacts were observed in axial T2-WI up to 45 mm (Table 3). The SI was statistically significant in coronal T1-WI up to 40 mm, with a signal void from 30 to 35 mm. In coronal T2-WI, SI was higher up to 60 mm. In sagittal T1-WI and T2-WI, a difference in SI was observed at less than 65 mm. However, a loss of signal was observed at 25-40 mm on sagittal T1-WI.

Based on the observed mean CV, the SI of MB was not significantly different from that of Rs (0 mm) on axial T1,T2-WI (Table 4). A significant difference in SI was observed up to 5 mm in coronal T1-WI and at 0 mm in T2-WI. A significant
difference was observed in T1-WI at 0 mm. Compared to Rs at 0 mm, Au and Pd did not show any significant differences in any of the coordinate planes.

**Discussion**

Depending on the magnetic field, three major types of alloys can be identified. (1) Ferromagnetic substances, which are strongly attracted by a magnetic field. Three sub-types of ferromagnetism are iron (Fe), cobalt (Co), and nickel (Ni). (2) Paramagnetic substances, which have unpaired orbital electrons and become demagnetized once the field is switched off. (3) Diamagnetic substances, which have few unpaired orbital electrons and therefore induce weak magnetic fields. In many cases, these can affect diagnostic interpretation, since ferromagnetic alloys produce much more artifacts than paramagnetic and diamagnetic materials. Artifacts can be classified into different types such as image-processing artifacts, patient-related artifacts, radio frequency (RF)-related artifacts, external magnetic field artifacts, gradient-related artifacts, errors in data, flow-related artifacts, and magnetic susceptibility artifacts. The latter reflect the ability of a substance to be magnetized, especially by a metal. Hence, within the oral cavity (head and neck section), dental alloys should be selected according to their composition.

1. **Crown shape**

Most clinicians use metal crowns due to their desirable properties such as longevity and resistance to high loading. Previous studies have examined the effect of dental alloys in MRI using shapes...
other than those used clinically. The major advantages of using crown-shaped samples in this study were that we could investigate the exact artifacts that could be observed clinically, since MRI is used as a diagnostic tool in radiology and to control the signal generated. Therefore, we compared the results with those obtained with the control at 0 mm to differentiate the samples according to the artifacts they generated.

2. Signal intensity
In a magnetic field, the signal generated by these alloys can have lower and higher values depending on the area and the coordinate plane of the image. In a signal void, the number of pixels has decreased to the point where there is no signal response. This could explain the absence of signal for CoCr in axial T2-WI from 5 to 15 mm and in coronal T1-WI from 15 to 30 mm in the statistical analysis. The same result was observed for Kp in coronal and sagittal T1-WI and T2-WI.

3. Artifacts
The artifact images of Au and Pd alloys did not show any disturbance in phantom MR images and the SI values were not significantly different from those for Rs (0 mm).

In this study, the control of the artifact area showed that the size of the artifact is not directly dependent on the size of the metal, as proposed by Iimuro et al., but mainly on the material, shape, position, and orientation. In particular, although Kp was smaller in both volume and weight, it created considerable artifacts. Artifacts can be projected far from the sample to create image distortion.

Au, MB, CoCr, Kp, and Pd are often used in prosthotronics due to their desirable properties, including higher life expectancy and ease of maintenance. However, in radiology, these materials can have some negative effects. CoCr generated artifacts but only up to 40 mm and only in coronal T1-WI. For Kp, artifacts were observed up to 70 mm. In addition, magnetic attachment has been shown to be a good solution to achieve better retention in aged patients who are often disabled and whose dentures are easily dislodged.

2. To avoid artifacts, the magnetic keeper can be removed from the oral cavity depending on the position. Since it is situated in the mouth, it should not cause a disturbance to readings in other parts of the body subjected to MRI. Keeper artifacts were observed up to a distance of 70 mm.

3. Variation in artifacts is dependent more on the type of metal than on the distance. In addition to the Fourier formula, the mean CV is useful for calculating the signal intensity generated by dental crown alloys and a dental keeper in MRI.

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References