Magnetic resonance imaging artefacts and fixed orthodontic attachments

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Summary

Background/Objectives: Orthodontic appliances are often removed before magnetic resonance imaging (MRI) scans because they are known to produce artefacts. The purpose of this study was to find the exact indications for removal of various fixed attachments when imaging four specific areas of the head and neck.

Materials/Methods: Sixty patients requiring an MRI scan of the head for medical reasons volunteered for this investigation. One of four different types of fixed attachments (stainless steel brackets, titanium brackets, ceramic brackets with metal slots, and stainless steel retainers) were assigned to a patient. Each patient had two scans at 1.5 T: with an ‘empty wax jig’ and with a wax jig including the attachment. Archwires were not investigated as they are easily removed before a scan. Two radiologists evaluated the scans of each patient and each of the four areas under investigation: maxillary sinus, oral cavity, temporomandibular joints, and posterior cerebral fossa.

Results: Stainless steel brackets always caused non-interpretability of all anatomic areas (100 per cent). Titanium brackets, ceramic brackets with metal slots, and stainless steel retainers caused artefact in the oral cavity only (for 20, 16.65, and 86.65 per cent of the subjects).

Conclusions/Implications: Our results show that ceramic brackets with metal slots and titanium brackets do not always have to be removed before MRI scans of the head and neck, depending on the area under investigation. Metal fixed retainers should only be removed if the oral cavity itself is under investigation. Stainless steel brackets should always be removed before MRI scans of the head and neck.

Introduction

Magnetic resonance imaging (MRI) has been used in medicine for over 20 years; it is a non-invasive diagnostic tool that does not use ionizing radiations. MRI is based on the signal of nuclear magnetic resonance emitted by the interaction of atomic nuclei that possess spin with incident radiofrequency within a static magnetic field (1).

However, the presence of metallic objects during MRI scans can produce artefacts. An MRI artefact is defined by pixels that do not faithfully represent the tissue components studied (2). The dimensions of artefacts depend on the magnetic properties of the metal that are divided according to their magnetic susceptibility in three groups: paramagnetic, diamagnetic, and ferromagnetic and also their shape, size, spatial orientation, and homogeneity (3–5).

Orthodontists are frequently asked to remove fixed orthodontic appliances for MRI scanning, particularly when looking for pathology in the head and neck region. But debonding procedures, apart from potentially damaging enamel, are time consuming, uncomfortable for the patient, and costly (6). Furthermore, orthodontic appliances can be made in many different alloys, including some that have never been tested and their compositions and designs keep evolving. Finally, artefacts do not always interfere with the diagnosis since they can affect areas that are not of interest.
The main purpose of our study was to determine which orthodontic fixture should be removed by the orthodontist before an MRI scan to prevent artefacts that could interfere with MRI images to such a degree that diagnosis may be compromised. Artefacts created by fixed appliances potentially affecting four defined anatomic areas of the head and neck were assessed to give radiologists guidelines when to recommend removal of fixed appliances before MRI scans of the head and neck area are taken.

Materials and methods

The subjects selected for the present study were volunteer adult patients referred for head and neck MRI examinations at the private hospital Jean Mermoz, Lyon. Thirty-five men and 25 women—a total of 60 subjects in ages ranging from 24 to 87 years (mean age, 55 years)—participated. All patients were given an informed consent form explaining the purpose of the study. For each patient, one out of four types of orthodontic fixtures were inserted into a wax jig (Table 1); the type of appliance included was randomly assigned. The wax jig, about 0.4 inches in thickness, had an arch shape and contained either a metal wire extended from canine to canine (representing a mandibular fixed retainer) or 24 stainless steel, ceramic, or titanium brackets (arranged in two rows representing upper and lower fixed appliances from first molar to first molar). Each patient underwent two successive MRI scans: the first was for diagnostic purposes and served as control (no appliance); during the second one, the patient was asked to bite on the selected wax sample. Neither the patient nor the examiner knew the content of the particular sample.

All MRI scans were undertaken on a 1.5 T system (Siemens Avanto: Siemens AG, Erlangen, Germany) with the following parameters: T2 Blade SPAIR (spectral selection attenuated inversion recovery). Transverse, slice thickness of 3.5 mm, matrix size of 256×256, field of view 240×240, TR 4200 ms, TE 131 ms. For each scan, 20 slices were obtained, archived, and analysed later.

All images were evaluated independently by two experienced radiologists (Denis Bossard, Jean-François Dugor). For each patient, both scans were compared, and the examiners had to determine whether the second image was interpretable specifically assessing four specific anatomic areas of the head: maxillary sinus, oral cavity, temporomandibular joints, and posterior cerebral fossa. The image of an area was considered non-interpretable if at least a part of the area was distorted or subject to a black artefact. If any artefact existed on the first scan due to pre-existing dental restorations, the examiners had to determine if this artefact was exacerbated on the second scan. The scans of 20 patients were re-evaluated 2 weeks later by the two radiologists to assess intra- and inter-examiner reliability.

Results

The percentages of images with artefacts by type of appliance and anatomic area are shown in Table 2. Stainless steel brackets caused non-interpretability of all four anatomic areas in all 15 patients (100 per cent). Titanium brackets caused no artefact for 12 patients out of 15 (80 per cent), and artefacts located in the oral cavity only for 3 patients. Ceramic brackets with metal slots caused no artefact for 12 patients (for the first examiner)/13 patients (for the second examiner) out of 15 (83.35 per cent mean) and artefacts located in the oral cavity for 3 (for the first examiner)/2 (for the second examiner) patients. Stainless steel retainers caused no artefact for 2 patients out of 15 (13.35 per cent) and artefacts located in the oral cavity only for 13 patients (86.65 per cent).

The artefacts caused by stainless steel brackets consisted in a large area of deformation, circled by a ring of low signal (Figure 1). The absence of artefact made the wax jig clearly visible (Figure 2). The artefacts caused by titanium and ceramic brackets consisted in small areas of low signal, located in the anterior part of the oral cavity (Figure 3). The artefacts caused by stainless steel retainers were larger and contained both deformation and low signal areas (Figure 4).

Cohen’s kappa and Siegel’s kappa were measured. Kappa (Cohen) = 0.986003, Z = 44.1331, P = 0; Kappa (Siegel) = 0.971604, Z = 13.3476, P = 0. Both kappa coefficients were larger than 0.80, which reveals almost perfect agreement between examiners.

Diagnostic re-evaluation of 20 patients showed identical results.

Table 1. The four types of appliances used for the study.

1. Omniarch® (GAC) stainless steel brackets

<table>
<thead>
<tr>
<th>Alloy</th>
<th>UNS No.</th>
<th>Carbon</th>
<th>Silicorne</th>
<th>Manganese</th>
<th>Phosphorus</th>
<th>Sulphur</th>
<th>Nickel</th>
<th>Chrome</th>
<th>Copper</th>
<th>Niobium</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel support (contains nickel)</td>
<td></td>
<td>&lt;0.07%</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>&lt;0.4%</td>
<td>&lt;0.03%</td>
<td>3–5%</td>
<td>15–17.5%</td>
<td>3–5%</td>
<td>0.15–0.45%</td>
<td>Other</td>
</tr>
</tbody>
</table>

2. TitaniumOrthos® (Ormocent) titanium brackets

<table>
<thead>
<tr>
<th>Alloy</th>
<th>UNS No.</th>
<th>Cr</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel support</td>
<td></td>
<td>&lt;0.1%</td>
<td>&gt;99.0%</td>
</tr>
<tr>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Clarity® (3M) ceramic brackets with metal slot

<table>
<thead>
<tr>
<th>Transparent polycrystalline alumina</th>
<th>Alumina grains</th>
<th>Stainless steel support (contains nickel)</th>
<th>Marking ink soluble in water</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;90%</td>
<td>&lt;5%</td>
<td>&lt;5%</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>

4. Bond-a-braid® (American Ortho) stainless steel retainers

<table>
<thead>
<tr>
<th>Cobalt</th>
<th>Silicone</th>
<th>Manganese</th>
<th>Aluminium</th>
<th>Molybdenum</th>
<th>Nickel</th>
<th>Chrome</th>
<th>Copper</th>
<th>Tungsten</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5%</td>
<td>0–5%</td>
<td>0–2%</td>
<td>0–2%</td>
<td>0–4%</td>
<td>8–12%</td>
<td>15–20%</td>
<td>0–4%</td>
<td>0–4%</td>
<td>65–75</td>
</tr>
</tbody>
</table>
Discussion

Few studies showed the effect of metal fixtures used in orthodontics on MRI scans and the results obtained from studies using prosthodontic materials (7–11) cannot be transferred to orthodontics because of the different shapes and metal composition of the appliances.

Table 2. Percentages of images with artefacts by type of appliance and anatomic area.

<table>
<thead>
<tr>
<th></th>
<th>Stainless steel brackets</th>
<th>Titanium brackets</th>
<th>Ceramic brackets with metal slots</th>
<th>Stainless steel retainers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral cavity</td>
<td>100%</td>
<td>20%</td>
<td>16.65%</td>
<td>86.65%</td>
</tr>
<tr>
<td>Maxillary sinus</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Temporomandibular joints</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Posterior cerebral fossa</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Figure 1. Example of artefacts caused by stainless steel brackets. All areas under investigation were affected.

Figure 2. No artefact shown. The dark area in the oral cavity corresponds to the wax sample. Being magnetically neutral, it sends no information to the device and thus has the same contrast as air.

Figure 3. An example of artefacts caused by either titanium or ceramic brackets (with metal slot).

Figure 4. Example of artefacts caused by a stainless steel retainer, affecting the oral cavity only.

Existing studies evaluating orthodontic appliances (12–14) are neither particularly comprehensive nor comparable in terms of materials and situations investigated. Moreover, several studies are in vitro and the effects of the different materials investigated are not consistent.

Our study did not investigate temperature changes and displacement forces induced by magnetic fields on orthodontic appliances,
which have already been shown respectively negligible (15) and should not be problematic for as long as the bonding and attachment of the different elements are checked before the MRI scan (16, 17).

Our study focused on bonded appliances for which removal procedures could potentially damage enamel, are time consuming, uncomfortable for the patient, and costly. We did not include archwires or removable appliances in our study; these can be easily removed before an MRI examination without causing any of the above-mentioned unwanted effects (13, 18).

Apart from the stainless steel brackets, we chose contemporary orthodontic materials that have either not been tested extensively (titanium) or had, to our knowledge, not been investigated before (fixed retainers, ceramic brackets with metal slots). For each type of appliance, a single brand was chosen: even if slight variations between manufacturers exist, components and shapes are fairly similar and the evaluation methods used in our study would not have been able to differentiate between those. We hence considered our sample as reasonably representative for each type of appliance. We chose Clarity brackets to represent ceramic brackets containing a metal slot. We chose not to use self-ligating ceramic brackets because shape and composition are quite similar to ceramic brackets with a metal slot, so we would expect similar results in terms of artefacts.

All samples were embedded in single use wax sticks because wax is magnetically neutral, economical, easy to prepare, adaptable to the arch shape and size of each patient, and allows an easy fitting and removal.

An in vivo design was chosen to resemble a clinical scenario best in terms of materials used and anatomical areas investigated.

The study was undertaken using a 1.5 T MRI scanner (Siemens Avanto: Siemens AG, Erlangen, Germany) because a magnetic field of this strength is commonly used in radiology. The sequence we used was representative for the pathologies usually investigated in the head and neck area. Most MRI examinations use axial slices in T2-weighted sequence, which is most likely to produce artefacts and it was used for that reason.

We decided to include 60 patients as artefacts are known to vary between patients (12). Sixty may seem to be a small sample compared to other epidemiological studies but for this study, it was deemed satisfactory because of the good intra- and inter-examiner reproducibility.

MRI is a non-ionizing imaging technique and is not known to cause short-term side effects. However, there are important safety concerns to consider before performing an MRI scan: pacemakers malfunction, artificial limbs heating up, and skin irritation due to skin tattoos have all been encountered (19, 20). No contrast media was used for this study. All volunteers who presented with medical indications for a head and neck MRI scans were consented accordingly.

The first scan was used as a reference in our study. Evaluation was based on clinical criteria (interpretable or non-interpretable image) unlike other studies that measured size of the artefact (9, 21, 22) or pixel density (1). To standardize results, we defined the term non-interpretable as an artefact covering ‘part of the area under investigation’; i.e. one of the four anatomical areas. Artefacts, caused by dental restorations, were detected by the first diagnostic scan and these were taken into account when interpreting the scan that included the appliances.

The results of our investigation confirmed that stainless steel causes artefacts, a finding that previous authors already described (9, 22–26).

Stainless steel brackets rendered the MRI scans diagnostically unusable in all cases. The amount of ferromagnetic metal plays an
important factor in degradation of image quality: although stainless steel retainers caused artefacts in 86.6 per cent of scans, this affected the oral cavity only; indeed in the residual 13.3 per cent of scans, no artefact was present at all. Ceramic brackets with stainless steel inserts also caused only localized artefacts in 13.3 per cent of scans. Our results are consistent with other authors who noted that the size of the artefact partly depends on volume and shape of the metal object in the scan (1).

A number of authors showed that titanium does not generally cause artefacts (26–28). This can be explained by the small quantities used (1). However, in 20 per cent of scans, very localized artefacts appear in the oral cavity. This confirms that titanium is able to produce artefacts, and this has been reported before (1, 9, 22, 29–31). Titanium itself has ferromagnetic properties but the presence of traces of other metals could also explain the ability to degrade MRI images. The titanium brackets used in our study contained less than 0.1 per cent of chromium, which is ferromagnetic. Some of the authors above found the artefacts on MRI scans caused by titanium significant, while we did not. This can be explained by the different quantities of titanium used in other studies: Lissac (9) used a titanium block of 9 × 9 × 1 mm in size and found a spherical deformation doubling the size of the sample; many other authors use titanium screws or implants (22, 29–31) and the results of those investigations are not transferable to orthodontics due to the amount and concentration of titanium in one anatomical area.

The image distortion caused by stainless steel brackets rendered all of our MRI scans non-diagnostic for all anatomical areas investigated. We therefore recommend that stainless steel brackets are always removed before MRI scan of the head and neck region is undertaken. Only 10 per cent of our patients required an MRI scan of the oral cavity for diagnostic purposes. Removal of fixed appliances containing titanium brackets, ceramic brackets with metal slots, or metal fixed retainers is only indicated for this small cohort of patients.

Conclusions
1. Ceramic brackets with a metal slot and titanium brackets caused either very limited or no artefacts on MRI images. These orthodontic fixtures will only have to be removed if the area under investigation is close to the fixed appliances, i.e. in the oral cavity.
2. Fixed retainers containing steel cause poor image quality in the area of the oral cavity only and only need to be removed ahead of an MRI scan if the area under investigation is within the oral cavity.
3. Stainless steel brackets caused extensive artefacts, rendering the images for all areas investigated here uninterpretable in all cases and should therefore always be removed before MRI images of the head and neck area are taken (Figure 5).

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References


