Original article

Impact of orthodontic appliances on the quality of craniofacial anatomical magnetic resonance imaging and real-time speech imaging

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Summary

Aims: The aim of this work was to investigate the effects of commonly used orthodontic appliances on the magnetic resonance (MR) image quality of the craniofacial region, with special interest in the soft palate and velopharyngeal wall using real-time speech imaging sequences and anatomical imaging of the temporomandibular joints (TMJ) and pituitaries.

Methods: Common orthodontic appliances were studied on 1.5 T scanner using standard spin and gradient echo sequences (based on the American Society for Testing and Materials standard test method) and sequences previously applied for high-resolution anatomical and dynamic real-time imaging during speech. Images were evaluated for the presence and size of artefacts.

Results: Metallic orthodontic appliances had different effects on image quality. The most extensive individual effects were associated with the presence of stainless steel archwire, particularly if combined with stainless steel brackets and stainless steel molar bands. With those appliances, diagnostic quality of magnetic resonance imaging speech and palate images will be most likely severely degraded, or speech imaging and imaging of pituitaries and TMJ will be not possible. All non-metallic, non-metallic with Ni/Cr reinforcement or Ni/Ti alloys appliances were of little concern.

Limitations: The results in the study are only valid at 1.5 T and for the sequences and devices used and cannot necessarily be extrapolated to all sequences and devices. Furthermore, both geometry and size of some appliances are subject dependent, and consequently, the effects on the image quality can vary between subjects. Therefore, the results presented in this article should be treated as a guide when assessing the risks of image quality degradation rather than an absolute evaluation of possible artefacts.

Conclusions: Appliances manufactured from stainless steel cause extensive artefacts, which may render image non-diagnostic. The presence and type of orthodontic appliances should always be included in the patient’s screening, so that the risks of artefacts can be assessed prior to imaging. Although the risks to patients with fixed orthodontic appliances at 1.5 T MR scanners are low, their secure attachment should be confirmed prior to the examination.
Introduction

Over the last two decades, magnetic resonance imaging (MRI) has become an important and valuable imaging tool for clinical assessments and investigations of a wide range of pathologies and structures. With its excellent soft tissue contrast, it is also recognized to be ideal for anatomical imaging of the brain and craniofacial region. High-resolution anatomical MRI also plays an important role in the clinical anatomical imaging of pituitary gland (1, 2), while dynamic contrast enhancement techniques aid diagnosis of pituitary and sellar lesions (3). MRI is now the primary modality for the evaluation of the temporomandibular joints (TMJ) (4, 5). There is a growing interest in using MRI to image the vocal tract. Several imaging techniques including ultrasound, computed tomography (CT), nasendoscopy, and X-ray fluoroscopy have been used for visualization of the vocal tract.

However, only X-ray multiview videofluoroscopy (6) and nasendoscopy (7) are currently used in routine clinical assessments. In ultrasound, while the palate and velum may be observed in some lingual positions, air interfaces, and bone are highly reflective and structures beyond these interfaces are not visualized, somewhat limiting the technique. CT is able to obtain high spatial resolution (<1 × 1 × 1 mm3) volumetric images with delineation of soft tissue and bone, which may be reformatted in any plane. However, radiation doses are typically greater than those from planar X-ray studies. On the other hand, X-ray videofluoroscopy and nasendoscopy provide information about structure, movement, and extent of closure and timing but have no ability to directly visualize underlying musculature. X-ray videofluoroscopy is also associated with a radiation dose, which increases risk in paediatric subjects. Nasendoscopy is invasive, and subjects may experience discomfort from nasal insertion of the scope and only limited views of the velopharyngeal port can be obtained. In contrast, MRI is non-invasive, free from ionizing radiation, and can flexibly image in different planes at different resolutions. It is, therefore, well suited to the clinical assessment of cleft palate anatomy (8, 9) including paediatric population. With recently developed real-time techniques, MRI has also become a very promising tool for the evaluation of velopharyngeal function during speech (10–13). A number of possible diagnostic applications have been described (14–17) suggesting that MRI may be able to provide a comprehensive diagnostic exam in cleft palate patients and become the imaging modality of choice in this cohort. For a detailed overview of this active field of research, please refer to the recent review of speech MRI (18).

However, due to prolonged periods of orthodontic treatment, it is likely that many subjects may require craniofacial or speech MRI examinations during this period. There are issues associated with performing MR imaging in subjects who have metallic orthodontic appliances. These include both safety concerns and the effects that the metallic devices can have on the diagnostic quality of the images.

In subjects with metallic appliances, the main MRI safety concerns are with the possible displacement or movement of the objects and potential excessive heating via induced currents in conductive materials. Magnetic field interactions of orthodontic components and deflection forces during MRI have been previously measured and are well described in the literature (19–24). Although some components display measurable ferromagnetism, movement during scanning with MR systems operating at the field strength up to 3T is unlikely, providing they are securely fixed to the teeth. Studies considering the heating effects (25, 26) have demonstrated that the temperature rise during a conventional MR procedure involving a subject with a passive metallic, small orthodontic appliance does not represent a substantial hazard, and there are no reported cases of injuries related to heating by orthodontic appliances. Consequently, securely attached orthodontic appliances should not pose a safety hazard in MR scanners operating at the field strength of up to 3T and only their effect on image quality is of concern.

Mapping of MR signal for image formation and image quality rely on homogeneity of magnetic field. Presence of a metallic appliance that has much higher magnetic susceptibility than that of a tissue causes large variations in Larmor frequency in tissue around the implant. This leads not only to dephasing of transverse magnetization that subsequently causes signal reduction or signal void but also affects frequency-position encoding leading to image distortions, the severity of which depends on the imaging sequence used.

An image artefact can be defined as a distortion, change of signal intensity, or signal void that does not originate from the anatomy in the plane being imaged.

Image artefacts can destroy clinical information and lead to diagnostic misinterpretation.

There are a number of previous studies investigating effects of dental objects on MRI. Artefacts caused by orthodontic objects have been reported in reported in head (27), brain (28), facial and TMJ MRI images (29, 30). However, there is no previous work that has focused on the effect of orthodontics appliances on the diagnostic quality of velum/velopharyngeal wall region in MR images. In particular, no study was so far concerned with artefacts assessment for novel real-time sequences used for dynamic speech imaging and swallowing studies.

The aim of this investigation was to evaluate the effects of most commonly used orthodontic appliances on quality of MR scans, in a simulation of a clinical situation using test objects.

Due to the sequence dependence, in addition to standard in clinical practice (spin echo and gradient echo) MR imaging techniques, we considered anatomical high-resolution and dynamic real-time imaging sequences suggested for speech imaging (12). This work aims to help clinicians with the management of patients that might require MRI scans while undergoing orthodontic treatment.

Materials and methods

Test objects

All appliances were tested using a dedicated test object that consisted of a polystyrene mouth guard attached to a plastic container filled with a copper sulphate (CuSO4) solution. CuSO4 was used to reduce T1 relaxation time of the solution to avoid saturation of the background signal in fast, real-time acquisitions. Orthodontic appliances to be tested were mounted on the guard (Figure 1) individually and in sets mimicking the realistic positions on the teeth in vivo and subsequently immersed in the CuSO4 solution. Samples of orthodontic appliances commonly used in clinical settings were examined including both titanium alloys and stainless steel orthodontic aligning archwires, orthodontic expansion push coils, molar bands, and orthodontic brackets: ceramic (SiO2), ceramic with metallic (Ni/Cr) reinforcement and stainless steel brackets. Details of the various orthodontic and codes used in the remainder of the article are given in Table 1.

Before scanning, the components were checked using a hand-held magnet, and all stainless steel archwires, brackets, and bands were shown to be magnetic, while components made from all other materials were non-magnetic.
Table 1. Reference codes and description of appliances used in the study.

<table>
<thead>
<tr>
<th>Appliance code</th>
<th>Appliance description</th>
<th>Appliance size</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW1</td>
<td>Nickel/titanium archwire—circular</td>
<td>0.35 mm inner diameter (Ø)</td>
<td>Ormco, USA</td>
</tr>
<tr>
<td>AW2</td>
<td>Stainless steel archwire—rectangular</td>
<td>0.45 × 0.625 mm²</td>
<td>A-Company, USA</td>
</tr>
<tr>
<td>PC1</td>
<td>Nickel/titanium push coil</td>
<td>0.3 mm inner diameter (Ø); 0.75 mm lumen; 32 mm length</td>
<td>Ormco, USA</td>
</tr>
<tr>
<td>PC2</td>
<td>Stainless steel push coil</td>
<td>0.3 mm inner diameter (Ø); 0.75 mm lumen; 38 mm length</td>
<td>Ormco, USA</td>
</tr>
<tr>
<td>MB</td>
<td>Upper molar stainless steel band</td>
<td>0.55 × 0.70 mm²</td>
<td>3M Unitek, USA</td>
</tr>
<tr>
<td>B1</td>
<td>Clarity advanced APC III ceramic brackets</td>
<td>0.45 mm slot size</td>
<td>3M Unitek, USA</td>
</tr>
<tr>
<td>B2</td>
<td>Clarity (metal reinforced) APC II ceramic bracket</td>
<td>0.45 mm slot size</td>
<td>3M Unitek, USA</td>
</tr>
<tr>
<td>B3</td>
<td>Stainless steel brackets (centric roth braces)</td>
<td>0.45 mm slot size</td>
<td>3M Unitek, USA</td>
</tr>
</tbody>
</table>

Figure 1. Example of in vivo images of magnetic resonance imaging (MRI) in midsagittal (A) and coronal views (B); regions of interest (ROI) including the soft palate and velopharyngeal area shown in green (A1 and B1, respectively); ROI including pituitary gland (A2 and B2, respectively) and a right temporomandibular joint (A3 and B3, respectively). Images of the test object (without any appliances attached) shown for comparison: photograph (C) and MRI in axial (D) and midsagittal (E) views. Examples of orthodontic appliances investigated in this work (F): b1—ceramic brackets; b2—ceramic brackets with metallic reinforcement; b3—stainless steel brackets; mb—stainless steel molar bands; pc1—Ti alloys push coil; pc2—stainless steel push coil; aw1—Ti alloys archwire; pc2—stainless steel archwire.

MR experiments

MR studies were performed on 1.5T Philips Achieva (Best, The Netherlands) clinical scanner in conjunction with a 16-channel head and neck radio frequency (RF) coil. The test object was placed with the mouth guard perpendicular to the static magnetic field, simulating dental position. MR examinations were similar to those described in the document issued by the American Society for Testing and Materials (ASTM Standard Test Method F2119) (31). Apart from standard spin-echo and gradient echo, sequences previously optimized for real-time speech imaging (12) and anatomical imaging of vocal tract musculature were tested. These included standard balanced steady-state free precession (bSSFP) (32) and 3D turbo spin echo (TSE) based on rapid acquisition with repeated echoes sequence (33). Imaging parameters for these sequences are given in Table 2.

Image analysis

Images were evaluated for the presence and size of artefacts including image distortions and signal intensity changes. The artefact size, following the definition given in the ASTM document (31), was measured as the maximum distance from the device boundary to the fringe of the artefact. In the cases where the boundary of the component was not clearly visible, the image of the test object without any appliances was used as a reference.

In order to estimate potential effects on speech and craniofacial MRI, regions of interest (ROI) enclosing anatomy of interest were considered and defined as average ROIs based on in vivo images from 32 adult volunteers (acquired previously as a part of larger study) (12). All volunteers who took part in the MR study were recruited with informed consent according to Ethics Committee approval (reference number: 08/H0701/30).

The ROI for speech MRI was defined as the 30 × 40 × 50 mm³ volume, along midline of the ‘bite plane’ (represents theoretical plane – mean of curvature of the surface touching the incisal edges of incisors and the tips of the posterior teeth), 60 mm from the front teeth as shown in Figure 1A1 (the horizontal line represents the ‘bite plane’) and Figure 1B1. The same ROI was positioned on the phantom images in a similar way along the mouth guard’s midline and using the front of the guard instead of the front teeth. In a similar way, ROIs corresponding to the pituitary gland and TMJ regions were also used. Figure 1A2 and 1B2 illustrates ROI for pituitary gland: 20 mm × 20 mm × 20, 90 mm along the midline, posterior from the front teeth and 50 mm up from the ‘bite plane’. The ROI for TMJ was 30 mm × 30 mm × 30 mm, 80 mm posterior along the midline, 40 mm from the ‘bite plane’, and 50 mm off the midline—in this case to the right (Figure 1A3 and 1B3).
The extent of the artefacts reaching the ROIs was examined by comparing artefact size with the distance between the ROI and the ‘bite plane’. In addition, the effect on the field homogeneity within the ROI was evaluated by measuring the line width of the water signal.

Results

Orthodontic appliances

Measurements of the artefact sizes for different components investigated are provided in Table 3. Artefacts sizes varied between different appliances and sequences used; the smallest were for spin echo-based sequences, they were larger for gradient echo, and the most extensive were for the bSSFP sequence.

Examples illustrating the extent of the artefacts caused by different components are shown in Figure 2A–2G for spin echo-based (left) and bSSFP (middle and right) sequences.

Components made from Ni/Ti alloys (B1, AW1, and PC1) had minimal effect with the signal void being less than 1 mm around the point where they were mounted to the guard and not reaching any of the ROIs except of the small area in the bite plane and these will affect tongue (Figure 2A and 2F). No distortion of field homogeneity within ROIs was observed and the measured line width of water signal within ROI was very close to that obtained in the phantom without any appliances present, ranging from 6 to 10 Hz.

The effect on the image quality was larger for ceramic brackets with metal (Ni/Cr) reinforcement (B2) (Figure 2B), but still localized to the region around the mounting points and not exceeding a diameter of 1.5 mm. Sizes of artefacts from individual stainless steel B3 brackets were larger approximately 3 mm. Again this would affect images of a tongue but still will not reach the all other ROIs when mounted on the anterior teeth (Figure 2C).

Individual stainless steel molar bands (MB) created large artefacts extending to all ROIs and all sequences, the worse being for bSSFP (Figure 2D) images. In addition, images from lateral and frontal lobes can be distorted if a band is placed on the upper molar as estimated distance from the bite plane is approximately 70 mm. Artefacts from the push coils were again small for PC1—Ni/Ti alloys (Figure 2F) but more extensive for the stainless steel push coils PC2 (Figure 2E) especially for gradient echo and bSSFP sequences.

Stainless steel archwire (AW2) was found to produce extensive effect for all sequences, likely to affect all ROIs, also line width measured within ROI was exceeding 200 Hz (Figure 2G).

Effects caused by the combined components are illustrated in Figure 3.

Artefacts created by sets of ceramic brackets with Ni/Cr metal reinforcement were local and unlikely to reach ROIs around the palate, pituitary gland, or TMJ (Figure 3A); however, they will affect imaging of the tongue.

Although the artefacts from individual B3 brackets were not very extensive approximately 3 mm, they become problematic when brackets were placed on all—maxillary and mandibular teeth (as in Figure 3B). Also a combination of stainless archwire (AW2) with stainless steel brackets (B3) resulted in an extensive artefact that affected all ROIs with frontal and temporal lobes of brain in the spin echo-based, gradient echo, and bSSFP sequences (Figure 3C).

As expected, combination of components made from Ni/Ti alloys or with ceramic brackets still produced small artefacts—for example AW1 with PC1 (Figure 3D). For AW1 wire combined with any other stainless steel component, image distortion was not significantly different from that created by the individual stainless steel component.

Examples of in vivo images

For comparison with phantom experiments, in vivo images from subjects wearing orthodontic appliances are shown in Figure 4.

Figure 4A and 4B illustrates images acquired with bSSFP sequence as used for real-time speech imaging, from the subject wearing braces

Table 2. Acquisition parameters of the magnetic resonance imaging sequences. bSSFP balanced steady-state free precession.

<table>
<thead>
<tr>
<th>Imaging parameters</th>
<th>Spin echo</th>
<th>Gradient echo</th>
<th>bSSFP</th>
<th>3D TSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetition time (ms)</td>
<td>450</td>
<td>30</td>
<td>2.9</td>
<td>1000</td>
</tr>
<tr>
<td>Echo time (ms)</td>
<td>15</td>
<td>3.2</td>
<td>1.5</td>
<td>116 (effective)</td>
</tr>
<tr>
<td>Pixel size (mm²)</td>
<td>0.88 × 0.88</td>
<td>1.48 × 1.98</td>
<td>1.90 × 1.90</td>
<td>0.90 × 0.90</td>
</tr>
<tr>
<td>Slice thickness (mm)</td>
<td>2</td>
<td>10</td>
<td>5</td>
<td>0.90</td>
</tr>
<tr>
<td>Bandwidth (Hz/px)</td>
<td>259</td>
<td>284</td>
<td>1720</td>
<td>770</td>
</tr>
<tr>
<td>Orientation</td>
<td>Axial/sagittal</td>
<td>Axial/sagittal</td>
<td>Sagittal/oblique—nasendoscopy</td>
<td>Axial</td>
</tr>
</tbody>
</table>

Table 3. Artefact sizes in (mm) for the different appliances and sequences. Spin echo (SE), axial imaging plane (axial), sagittal imaging plane (sag), gradient echo (GE), oblique imaging plane (oblique), balanced steady-state free precession (bSSFP), 3D turbo spin echo (3D TSE), region of interest (ROI), water peak line width (line width).

<table>
<thead>
<tr>
<th>Component</th>
<th>SE axial</th>
<th>SE sag</th>
<th>GE axial</th>
<th>GE sag</th>
<th>bSSFP sag</th>
<th>bSSFP oblique</th>
<th>3D TSE</th>
<th>ROI (palate)</th>
<th>line width (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>7</td>
</tr>
<tr>
<td>AW2</td>
<td>8.28</td>
<td>8.79</td>
<td>12.36</td>
<td>11.06</td>
<td>13.30</td>
<td>11.71</td>
<td>8.95</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>PC1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>6</td>
</tr>
<tr>
<td>PC2</td>
<td>4.31</td>
<td>4.22</td>
<td>7.42</td>
<td>6.93</td>
<td>9.86</td>
<td>8.65</td>
<td>5.03</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>MB</td>
<td>6.29</td>
<td>6.18</td>
<td>7.61</td>
<td>6.86</td>
<td>7.64</td>
<td>8.31</td>
<td>6.29</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>6</td>
</tr>
<tr>
<td>B2 (individual)</td>
<td>1.05</td>
<td>1.15</td>
<td>1.19</td>
<td>1.46</td>
<td>1.32</td>
<td>1.02</td>
<td>&lt;1</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>B3 (individual)</td>
<td>1.05</td>
<td>1.11</td>
<td>1.51</td>
<td>2.26</td>
<td>2.71</td>
<td>2.97</td>
<td>1.12</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Set of 16 B3</td>
<td>10.80</td>
<td>11.22</td>
<td>12.00</td>
<td>11.02</td>
<td>11.16</td>
<td>12.70</td>
<td>11.74</td>
<td>&gt;200</td>
<td></td>
</tr>
<tr>
<td>Set of 16 B3 with AW2</td>
<td>11.20</td>
<td>11.81</td>
<td>12.26</td>
<td>11.44</td>
<td>12.76</td>
<td>13.00</td>
<td>12.40</td>
<td>&gt;200</td>
<td></td>
</tr>
</tbody>
</table>
containing Ni/Ti archwire Ni/Ti push coils and ceramic brackets.
The region including the soft palate, TMJ and pituitary gland was
clearly visible and image quality adequate. However, for subjects wearing braces containing stainless steel
archwire, stainless steel brackets, the artefacts, and signal voids were
extensive for both spin and gradient echo sequences and affected
the craniofacial regions around the soft palate, pituitary gland, and
TMJ making it impossible to carry out a full clinical scan as shown
in Figure 4C and 4D. In the subject, both frontal and temporal
brain lobes were also non-diagnostic (Figure 4E and 4F). The extent
of the artefact seen in vivo was similar to the images from the test
object containing stainless steel brackets and archwire as shown in
Figure 3C.

Discussion

There are concerns associated with performing MR imaging in
subjects who have metallic orthodontic appliances. These include
safety concerns and the effects that the metallic devices can have
on the diagnostic quality of the images. Safety concerns are related
to possible movement of metallic orthodontic components and
excessive heating in conductive materials caused by magnetic
interaction. Previous studies, however, have demonstrated that
movement of orthodontic appliances during scanning at the field
up to 3 T is unlikely if the components are securely attached to
the teeth (19–24). Also heating effects due to the temperature rise
do not represent a substantial hazard during conventional MRI
(25, 26).

This work focused on the effects that most commonly used
orthodontic appliances can have on quality of MR images acquired
from craniofacial regions with focus on a soft palate dynamic MR
images acquired during speech.

The results in this clinical simulation investigation showed that the severity of the artefact caused by orthodontic appliances
depended on many factors, the most important of them being mate-
rial of appliances, their geometry and location, and the imaging
sequence used. The anatomical areas closest to the appliances are
most likely to be affected. Spin echo-based sequences use RF refocus-
ing pulses to recover transverse magnetization decay due to effects
from magnetic field inhomogenities, thus mitigating signal loss. This
is not the case for gradient echo-based sequences; hence, these are
more prone to metal artefacts.

Appliances made from materials that do not interact with mag-
netic field, including titanium/nickel or titanium/chromium alloys,
ceramic or plastic were of little concern. However, stainless archwire
causd the most extensive for an individual device, and for all types
of sequences, artefacts. As a result, the presence of a stainless steel
archwire in combination with any other appliances would most cer-
tainly lead to extensive artefacts affecting all studied regions. The
presence of a stainless steel molar band is also likely to cause exten-
sive artefact on a palate, pituitary TMJ, and brain temporal lobe
MRI especially for gradient echo-based sequences. An individual
stainless steel push coil created large artefacts; however, as push coils
are usually employed anteriorly in the arch, they are much less likely,
at least in spin echo-based sequences, to cause image interference to
the regions of soft palate, pituitary glands, TMJ, or brain. Similarly,
the extent of the artefact created by individual metallic brackets is
limited particularly if attached to the frontal teeth; however, a full
set of stainless steel brackets created a large signal void reaching the
palate ROI, and also images of pituitary gland and TMJ are likely to
be affected. The most significant adverse effect was observed using
a combination of stainless steel archwire with a full set of stainless
steel brackets.

Our results complement and support the previously published
data. In general, there is an agreement that the presence of the steel
archwires causes greater artefacts on images than the bands and
brackets alone (29, 30). Also stainless steel brackets were found to
consistently cause more severe image distortion on in vivo images
compared to other bracket material (ceramic, titanium, and plastic)
In addition, metallic orthodontic appliances were found to be the most likely origin of large areas of artefact compared to those caused by dental implants, crowns, and filings (30). So in terms of reducing artefacts in MR images, the most favourable would be combination of appliances such as archwire, push coils, and bands, made of Ti alloys with ceramic brackets. Also use of ceramic brackets with reinforcement made from non-magnetic metal should be acceptable i.e. without large artefacts. Use of a stainless steel archwire in a set, particularly if combined with stainless steel brackets, most likely result in extensive artefact reaching all investigated regions. This compromises the integrity of a scan which then has to be repeated increasing delays and costs. In order to avoid non-diagnostic scans and wasted appointments, it is very crucial that the presence and type of orthodontic appliances are always included in the patient’s screening, so the risks of artefacts can be assessed prior to imaging.

We recommend that removable, ferromagnetic components should be removed beforehand as they could render MRI of craniofacial regions useless, especially palate and speech imaging as real-time imaging is based on gradient echo acquisitions.

Another approach to reduce artefacts caused by metallic implants would be to optimize imaging technique. There are several ways that could aid metal artefact reduction in particular if acquisition speed is not crucial. For example, use of spin echo sequences with short echo time or turbo spin echo with short echo spacing will allow to mitigate signal loss. Eliminating parallel imaging could help as image reconstruction rely on coil sensitivity information that can be erroneous close to metal devices. Also increasing receiver bandwidth will cause larger range of resonant frequencies within a pixel, so in-plane distortions will be contained inside a smaller area. Further, number of new techniques have been recently reported, for example, SEMAC: slice encoding for metal artefact correction (34), designed to reduce metal artefacts. SEMAC technique corrects metal artefact via robust encoding of each excited slice against metal-induced field inhomogeneities. Development of similar methodology (35) would help to perform MRI in some special situations, for example when the implants cannot be removed.

There are some limitations of this study that need to be highlighted. Not every existing type of appliances was assessed, only those most commonly used in clinical practice. Furthermore, both the geometry and the size of some appliances are subject dependent and this will have an effect on the artefact produced. Consequently, the shape and size of artefacts can vary substantially between different subjects, as previously reported (26). Additionally, imaging was solely performed at 1.5 T. However, susceptibility effects are field strength dependent, and consequently, the effect of metallic
appliances on image quality will also be related to the field strength. Therefore, results at 1.5 T cannot necessarily be an accurate predictor of artefacts at other field strengths.

Finally, artefacts are dependent on the imaging sequences used; consequently, the results presented in this study are only valid for the sequences used and cannot necessarily be extended to other sequences.

Therefore, the results presented in this article should be treated as a guide when assessing the risks associated with image quality degradation due to the presence of orthodontic appliances, rather than an absolute evaluation or an accurate prediction of the artefact geometry and size.

Conclusions

Although the risks to patients with orthodontic appliances at 1.5 T MR scanners are low, their secure attachment should be confirmed prior to the examination. Many orthodontic appliances cause severe artefacts, in anatomical imaging of craniofacial regions including pituitary glands, TMJ, and soft palate area as well as in dynamic speech. Devices manufactured from stainless steel may degrade image quality beyond clinical acceptability and should be removed prior to imaging, in particular archwire. In contrast, non-metallic, non-metallic with Ni/Cr reinforcement or Ni/Ti alloys.

The presence and type of orthodontic appliances is always included in the patient’s notes and MRI screening forms; therefore, the risk of artefacts can and should be assessed prior to imaging.

Orthodontists should be aware of the possible artefacts caused by appliances and the type of fixed orthodontic appliances fitted should be considered in patients that may require cranial and facial MRI.

Further development and application of novel imaging sequences designed to reduce metal-induced artefacts can be helpful to some extent especially for anatomical imaging.

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