REVIEW

Brain and spine MRI artifacts at 3 Tesla
Artéfacts en IRM 3 Tesla du cerveau et de la moelle

M.I. Vargas\(^a\), J. Delavelle\(^a\), R. Kohler\(^b\), C.D. Becker\(^b\), K. Lovblad\(^a\)

\(^a\) Division of Neuroradiology, Department of Radiology, Geneva University Hospital, 24, road Micheli-du-Crest, 1211 Geneva 14, Switzerland
\(^b\) Department of Radiology, Geneva University Hospital, Switzerland

Available online 5 October 2008

KEYWORDS
Artifacts; 3 Tesla; Brain; Spine; Magnetic resonance imaging

Summary
Introduction. — We illustrate here the most common MRI artifacts found on routine 3 T clinical neuroradiology that can simulate pathology and interfere with diagnosis.

Materials and methods. — Our group has worked with a 3-T Magnetom Trio (Siemens, Erlangen, Germany) system for two years, with 50% of our time devoted to clinical work and 50% dedicated to research; 65% of the clinical time is dedicated to neuroradiology (2705 patients) and the remaining time to whole-body MRI. We have detected these artifacts during our case readings and have selected the most representative of each type to illustrate here.

Results. — We have observed magnetic susceptibility artifacts (29%), pulsation artifacts (57%), homogeneity artifacts (3%), motion artifacts (6%), truncation artifacts (3%) and, finally, artifacts due to poor or inadequate technique in the examined region.

Conclusion. — High-field imaging offers the benefit of a higher signal-to-noise ratio, thus making possible the options of a higher imaging matrix, thinner slices, the use of spectroscopy and diffusion tensor imaging in the routine clinical neuroradiology with a reduction in time spent. It is vital to be able to recognize these artifacts in everyday practice as they can mimic pathological appearances, thus causing diagnostic errors that could lead to unnecessary treatment. Indeed, most of these artifacts could be avoided with an adequate technique.

© 2008 Elsevier Masson SAS. All rights reserved.

Résumé
Introduction. — Nous illustrons les artéfacts les plus fréquents en IRM à 3 T que nous avons rencontrés en pratique quotidienne et qui peuvent simuler une pathologie et donc interférer avec le diagnostic.

Matériel et méthodes. — Notre groupe travaille sur un système 3 T Siemens depuis deux ans, avec une activité clinique représentant 50 % du temps machine et 50 % du temps restant dédié à la recherche fondamentale ; 65 % du temps d’activité clinique est dédié à la neuroradiologie (2705 patients au total) et le reste dédié à une activité corps entier. Nous avons identifié ces artéfacts pendant nos lectures et montrons les plus représentatifs.

© 2008 Elsevier Masson SAS. Tous droits réservés.
Brain and spine MRI artifacts at 3 Tesla

Introduction

The use of a higher magnetic field provides a higher signal-to-noise ratio, which allows a higher imaging matrix and thinner slices, and improvements in the quality of spectroscopy, functional magnetic resonance imaging (fMRI), MR angiography [1] and diffusion tensor techniques [2], that can also now be acquired within a reasonable time frame; up to now, this technology has been reserved for research purposes only because of the long acquisition times. It is well-known that, although image quality is significantly improved on increasing magnetic field strength, there are also more artifacts generated at 3 T than at 1.5 T. Even though the physical basis of most of these 3 T artifacts is the same as at 1.5 T, there are nevertheless variations that are more misleading and appear more frequently at high field strengths. For these reasons, we believe it is important to be aware of the existence of such artifacts. In this report, we illustrate the most common ones encountered at 3 T during our routine clinical MRI investigations that can simulate a pathological finding and, thus, interfere with the correct diagnosis and treatment.

Materials and methods

We have been using a 3-T Magnetom Trio (Siemens, Erlangen, Germany) unit for two years: 50% of its activity is dedicated to clinical work and 50% to research; 65% of the clinical workload (2705 patients, 2094 brain and 611 spine) consists of neuroradiology, and the remaining time is dedicated to whole-body MRI investigations. Having looked for and detected artifacts during our everyday case readings, we have here selected the most typical examples of each type.

The present study was retrospective: the patients examined over the past two years in our practice were all looked at systematically by two neuroradiologists, each with 10 years of experience in neuro-MRI. These artifacts were classified according to their consensus.

Results

We noted many different types of artifacts, such as magnetic susceptibility artifacts (air—tissue interfaces, metallic dental and orthopedic implants), cerebrospinal fluid (CSF) pulsation artifacts, artifacts due to blood flow, homogeneity artifacts, motion artifacts, truncation artifacts and artifacts due to poor or inadequate technique in the examined region (Table 1).

Susceptibility artifacts are found in cases of dental implants, where there is a loss of signal in the facial and cervical regions mainly on spin-echo (SE) T1- and gradient-echo T2-weighted images (Fig. 1A). The brain can also show pseudoenhancement on T1-weighted images after contrast administration (Fig. 1B), as well as, major distortions on diffusion-weighted images (DWI; Fig. 1C). There may also be low signal intensities on three-dimensional (3D) Flair images extending over anatomical structures in the cortex (Fig. 2A), associated with pseudoenhancement in the brain parenchyma and ocular globe on T1-weighted images using contrast medium (Fig. 2B). The spontaneous retroocular hyperintense signals on unenhanced T1-weighted images with fat saturation are secondary to a lack of selective saturation of the retroocular fat due to inhomogeneity of the magnetic field due to dental implants (Fig. 3A).

We have also observed high signal intensities on Flair images in the temporal region caused by cerebral electrodes in patients with epilepsy (Fig. 3B).

On T1-weighted SE images, the artifacts induced by air—tissue interfaces, such as in the frontal region, may also cause pseudoenhancement (Fig. 4) as well as pseudoischemic lesions on DWI induced by the air—tissue interface in the sphenoidal region (Fig. 5).

CSF pulsation artifacts can create hyperintensities on Flair images at the level of the third and fourth ventricles, and hypointensities at the level of the suprasellar cistern on fast spin-echo (FSE) T2-weighted images (Fig. 6A, B). These phantom images can show up on either side of the third ventricle (Fig. 7).

CSF pulsation artifacts in the spine correspond to hypointensities on FSE T2 sequences and hyperintensities on Flair images located in front of the pons and cervical spinal cord (Fig. 8).

Other types of flow artifacts caused by the vessels are possible: transverse linear high signal intensities due to the encoding direction of the sequence provoked by the transverse sinus or the carotid arteries can be visible on SET1-weighted images after contrast injection as well as on
Table 1: Most frequent MRI artifacts encountered at 3 T and how to correct them.

<table>
<thead>
<tr>
<th>Artifacts</th>
<th>Technical solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air–tissue interface</td>
<td>Increase the receiver bandwidth</td>
</tr>
<tr>
<td></td>
<td>Apply parallel imaging techniques</td>
</tr>
<tr>
<td></td>
<td>Shorten the TE</td>
</tr>
<tr>
<td>Blood-flow artifacts</td>
<td>Change the orientation of the phase gradient</td>
</tr>
<tr>
<td></td>
<td>Use spatial presaturation pulses</td>
</tr>
<tr>
<td>Homogeneity artifacts</td>
<td>Obtain a highly homogeneous static magnetic field</td>
</tr>
<tr>
<td></td>
<td>Ensure B0 around the isocenter</td>
</tr>
<tr>
<td>Motion artifacts</td>
<td>Use saturation bands</td>
</tr>
<tr>
<td></td>
<td>Use respiratory or cardiac-gating methods</td>
</tr>
<tr>
<td></td>
<td>Reconfigure the k-space lines</td>
</tr>
<tr>
<td></td>
<td>Use of head and body restraints</td>
</tr>
<tr>
<td></td>
<td>Ensure the patient is informed removements</td>
</tr>
<tr>
<td>Metal artifacts</td>
<td>Use a fast SE sequence</td>
</tr>
<tr>
<td></td>
<td>Titanium implants cause fewer artifacts than ferromagnetic steel; more common with EGT2, DWI and fat-sat imaging</td>
</tr>
<tr>
<td>CSF pulsation artifacts</td>
<td>Change the phase and frequency-encoding direction</td>
</tr>
<tr>
<td></td>
<td>Increase the number of excitations</td>
</tr>
<tr>
<td>Inadequate or poor technique</td>
<td>Ensure proper technician training</td>
</tr>
<tr>
<td>Truncation or Gibbs artifacts</td>
<td>Increase the spatial resolution</td>
</tr>
<tr>
<td></td>
<td>Apply reconstruction filters (such as a Hanning filter)</td>
</tr>
</tbody>
</table>

Another type of blood-flow artifact is possible in the vessel itself and can mimic dissection of the vessel on 3D time-of-flight (TOF) images (Fig. 10). In addition, inhomogeneity artifacts are visible on DWI (Fig. 11).

There are also unexplained artifacts such as a high signal intensity in the pons that resembles an ischemic lesion only on axial FSE T2 images: its artifactual nature can be confirmed by the absence of anomalies in all other sequences as well as the absence of clinical signs attributable to ischemia (Fig. 12).

Artifacts are more frequently generated at the level of the spinal cord than in the brain. We have observed kinetic artifacts caused by discreet patient movement, and artifacts may also be caused at the cervical level by swallowing or by cardiac motion at the thoracic level, despite the use of saturation bands (Fig. 13). Truncation artifacts (Gibbs ringing) may also be seen (Fig. 8). In addition, artifacts caused by metallic orthopedic implants are more extensive at 3 T than at 1.5 T (Fig. 14).

We have also observed other types of artifacts due to poor technique such as the wrong choice of coils, which can cause hyperintense lines in the anterior part of the lumbar spine (Fig. 15). Choosing the wrong encoding direction can simulate a syrinx of the cervical cord that disappears as soon as the encoding direction is changed (Fig. 16).

Overall, the frequency of these artifacts is as follows:

- Flow artifacts, 57%;
- Magnetic susceptibility artifacts, 29%;
- Motion artifacts, 6%;
- Homogeneity and Gibbs artifacts, 3% each;
- All others, 2%.

Discussion

High-field MRI technology is becoming more widely clinically available, and radiologists are now being confronted by more images with higher contrast and better definition and, thus, more complex pathologies detectable through these technical improvements. What’s more? There is an increase in patients’ expectations. This is why, it is important to be able to recognize images that are, in fact, artifacts that can mimic pathology, thereby suggesting an incorrect diagnosis. Artifacts are defined as any image (signal or loss of constructive interference in steady state (CISS) 3D images (Fig. 9).

Another type of blood-flow artifact is possible in the vessel itself and can mimic dissection of the vessel on 3D time-of-flight (TOF) images (Fig. 10). In addition, inhomogeneity artifacts are visible on DWI (Fig. 11).

Figure 1: Susceptibility artifacts in a patient with a dental implant: there is loss of signal in the face (SET1, GET2) and cervical spine (arrows in 1A) associated with pseudoenhancement on enhanced T1-weighted images (arrows in 1B) as well as major distortions on diffusion-weighted images (1C).

Figure 2: de susceptibilité chez un patient avec un implant dentaire : il existe une chute de signal au niveau de la face (SET1, GET2) et de la colonne cervicale (flèches sur la Fig. 1A), associée avec une pseudoprise de contraste sur les images pondérées en T1 après injection de contraste (flèches sur Fig. 1A et 1B) ainsi que des phénomènes de distorsions majeures sur les images pondérées en diffusion (Fig. 1C).
Brain and spine MRI artifacts at 3 Tesla

Figure 2  This patient shows low signal intensities on 3D Flair images in the pre- and postcentral cortical regions (arrows in 2A); there is also pseudoenhancement in the brain parenchyma and ocular globe (arrows in 2B) caused by a dental implant.

Chez ce patient, il existe une hypo-intensité sur les images Flair 3D au niveau de la région corticale pré- et postcentrale (flèches — Fig. 2A) ; il existe également une pseudoprise de contraste au niveau du parenchyme cérébral et du globe oculaire (flèches — Fig. 2B) liée à un implant dentaire.

Figure 3  Retroocular high signal intensities on unenhanced T1-weighted images with fat saturation (arrows) due to inhomogeneity of the magnetic field induced by a dental implant (3A); high signal intensities are seen on Flair images in the temporal region (arrows) caused by cerebral electrodes (3B).

A : hyper-intensité rétro-oculaire sur les images pondérées en T1 avec saturation de graisse (flèches) secondaire à une inhomogénéité du champ magnétique induite par un implant dentaire. B : hyper-intensités sur les images Flair au niveau temporal (flèches) liées à des électrodes cérébrales.

Figure 4  The frontal region shows artifacts at the “air—tissue interface” with pseudoenhancement (arrows).

Artéfacts au niveau frontal induits par l’interface air—tissu avec une pseudoprise de contraste (flèches).

Figure 5  This pseudoischemic lesion in the pons (arrow), caused by sphenoidal air, was not visualized on Flair.

Pseudolésion du pons (flèche) liée à la présence d’air dans le sphénoïde non retrouvée sur l’image Flair.
signal) that has no anatomical basis, but is the result of distorted, additional or suppressed "information". Some artifacts are readily identifiable as such, while others may be more subtle, requiring a repeat examination or specific investigation for clinical signs. Many artifacts are due to a defective MRI unit or a poor choice of technical parameters, but most are inherent in the principles of physics [3]. We have found a larger number of artifacts at 3 T compared with 1.5 T. Even, when they are similar in nature to those found at 1.5 T, at 3 T, they tend to be increased in both size and number. A good knowledge of technique, as well as of anatomy and pathology, will improve the detection of these artifacts.

**Magnetic susceptibility artifacts**

These artifacts are caused by either the presence of ferromagnetic materials or an air–tissue interface, and are commonly found close to the skull base (Figs. 4 and 5). The susceptibility of a tissue reflects its ability to become magnetized when placed in a magnetic field. A wide variation of susceptibility causes a major local gradient that generates increased spin dephasing, resulting in signal loss and image distortions at the tissue interface [4].

These susceptibility artifacts increase at higher magnetic fields and are especially problematic in sequences such as DWI and gradient-echo. However, such distortions can be reduced by decreasing the echo spacing of the readout train.
Blood-flow artifacts: linear hyperintensities due to pulsations from the transverse sinus and carotid arteries follow a transverse direction due to the encoding direction of the sequence visible on SET1 and CISS images (arrows).

Artéfacts de flux : hyper-intensités linéaires dues aux pulsations du sinus transverse et des artères carotides qui suivent un trajet transversal dans la direction du codage de la séquence , visibles sur les images SET1 et CISS.

(increasing the receiver bandwidth) or by applying parallel imaging techniques to reduce the echo-train length [5]. Shmueli et al. have attempted to suppress this type of artifact by evaluating it on a phantom model, using materials to mimic soft tissue (wax) and bone (plastic skull). The authors concluded that the phantom model is a useful tool for evaluating and comparing different susceptibility artifact-reduction techniques [6].

The artifacts caused by “metal implants” (Figs. 1—3) result from the vast difference in magnetic properties between living human tissue and metal implants. The factors that influence the creation of these artifacts are the composition, size and orientation of the implant as well as its relationship to the external magnetic field, the type of pulse sequence applied and the sequence parameters [7]. The type of metal used in the implant also affects the artifact: implants in titanium (Fig. 14), which are non-ferromagnetic, generate fewer artifacts than those made of ferromagnetic steel [7—10].

This vascular-flow artifact simulates dissection in the left internal carotid artery (arrows).

Artéfacts de flux simulant une dissection de l’artère carotide interne gauche (flèches).

These homogeneity artifacts can be seen on diffusion-weighted imaging.

Artéfacts d’homogénéité sur les images pondérées en diffusion.

This unexplained artifact mimicking an ischemic lesion in the pontine region was only visible on axial FSE T2-weighted images (arrow).

Artéfact inexpliqué simulant une lésion ischémique pontique seulement visible sur les images axiales T2 FSE (flèches).
CSF pulsation artifacts

The body’s mean daily CSF production is 500 mL, and it has a pulsatile motion due to the expansion and contraction of the brain and intracranial vessels associated with the cardiac cycle. This pump effect causes the CSF flow in the cervical spaces to be 40% as fast as in the carotid arteries [11—13], resulting in multiple artifacts that may appear hypointense on T2-weighted, and hyperintense on Flair, images — and not only in front of or behind the spinal cord, where they can be very impressive, but also in the ventricles (Fig. 6A), and the suprasellar and prepontine cisterns (Figs. 6B and 8). Phantom images are frequently seen along the ventricles at 3 T, especially around the third ventricle (Fig. 7).

Blood-flow artifacts

Two types of these artifacts may occur. Artifacts may be due to the pulsation of the vessels themselves, causing hyperintense transverse or longitudinal lines (depending on the orientation of the phase gradient) and resulting in signal degradation in the parenchyma. With less-experienced readers, these images may be mistaken for false enhancement and may also hide an underlying pathology (Fig. 9). Flow artifacts may also be due to turbulent flow within the vessel itself and may simulate dissection (Fig. 10).
Truncation or Gibbs artifacts

These bright or dark lines are seen parallel to edges of abrupt intensity changes (Fig. 8), sometimes described as "ringing" artifacts following signal-intensity borders [3]. These occur when the number of phase-encoding steps at high spatial resolution is undersampled and, hence, is unable to faithfully reproduce the true anatomical details of the original image [14,15]. In addition, these may occur when the number of peripheral Fourier lines in the k-space is small or insufficient [14]. These artifacts are observed particularly in spinal imaging at 3 T, and frequently as a consequence of the improved signal-to-noise ratio in comparison to 1.5 T MRI. Their occurrence can be reduced by either increasing the spatial resolution or applying reconstruction filters, such as the Hanning filter, to smoothly reduce the signal at the edges of k-space [5].

Homogeneity artifacts

These artifacts may be caused by the MRI system itself and by the composition of the tissue sample being examined. An extremely homogeneous static magnetic field (B0) is required around the isocenter of the magnet because this will influence the distribution of the Larmor frequencies of protons as well as the linearity of the magnetic-field gradients required for spatial encoding [5]. These artifacts are especially important on DWI sequences, which are particularly sensitive to inhomogeneity of the local magnetic field (Fig. 11).

Motion artifacts

These artifacts are probably more commonly and extensively seen at the level of the spinal cord than in the brain. We have observed kinetic artifacts caused by discreet patient movement; they may also be caused at the cervical level by swallowing and at thoracic level by cardiac motion, despite the use of saturation bands (Fig. 13).

Inadequate technique

The artifacts due to poor or inadequate technical choices are unlimited, and their resolution depend considerably upon the realization that a wrong choice was made.

Unexplained artifacts

Finally, we have observed unexplained artifacts where their truly artifactual nature was only confirmed by the absence of anomalies on all other sequences (Fig. 12), the absence of clinical signs or by a repeat evaluation by MRI.

Conclusion

It is vital in everyday neurological practice to learn to recognize all of these artifacts as they can mimic pathology, thus leading to diagnostic errors that could result in the unnecessary treatment of patients.

References