A Review on Brain Magnetic Resonance Imaging Artifacts: Description, Causes and their Elimination

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Abstract- Magnetic Resonance Imaging (MRI) is a powerful medical imaging technique used in radiology to investigate the anatomy and physiology of the human brain in both health and disease. A wide variety of artifacts are commonly being encountered during MR image acquisition. An artifact is any undesirable feature that appears in an image which is not present in the original imaged object. Artifacts are caused by a variety of factors that may be MRI scanner hardware/software related or patient related. Some artifacts affect the diagnostic quality of MRI, while others cause confusion with pathology, resulting in false negatives or false positives. To detect any abnormality in the brain like tumor or lesion, the artifact must be removed or minimized. The radiologist/clinician requires constant effort and up-to-date knowledge to recognize the artifacts and their elimination. Some of the artifacts can be removed by adjusting the acquisition or scan parameters of the MRI scanner. Those artifacts which are beyond the immediate control of radiologist have to be removed in technical ways. This review article gives an overview of the most important and commonly observed artifacts during MRI scan of brain along with their cause, appearance, diagnostic effect and measures taken by the radiologists/technicians to eliminate or minimize them.

Keywords: Magnetic Resonance Imaging (MRI), Imaging artifacts, Brain MR Image, Artifact, Zipper, Herringbone, Chemical shift, Aliasing, Gibbs truncation, Magnetic susceptibility, Intensity inhomogeneity.

I. INTRODUCTION

Magnetic Resonance Imaging (MRI) is widely used in medical diagnosis for its various advantages such as high resolution, noninvasive technique, uses non-ionizing radiation, ability to produce an arbitrary anatomic cross-sectional image and capable of providing excellent soft tissue contrast with imaging in any arbitrary plane (axial, coronal, saggital). The MRI uses strong and uniform magnetic field and radio frequency waves to form detailed images of the human brain and the surrounding tissues. Primarily there are three types of MR brain images namely T1 weighted, T2 weighted and Proton density which focus on different contrast characteristics of the brain tissues [1]. However the technology of MRI is associated with many potential sources of image artifacts which can degrade or distort the image quality and cause inaccurate diagnosis. The artifacts may be caused by the MRI scanner hardware itself or by the interaction of the patient with the hardware. The presence of artifacts in the image may be confused with pathology or just reduce the quality of examinations [2]. Hence it is important for the radiologists to recognize the artifacts and have basic understanding of their origin, causes and to learn how to eliminate them [3]. Some of the artifacts and their negative influence on MR images can be minimized or removed by the radiologists by adjusting the MRI scanner parameters such as sampling rate, field of view (FOV), receiver bandwidth, sequence type, slice thickness, TE/TR times, number of slices, matrix size, magnetic field, receiver coils, acceleration factor, flip angle and frequency/phase encode directions [4].

MRI is more susceptible to artifacts than other imaging techniques due to the fact that MR signal depends on a variety of tissue parameters such as proton density, diffusion, relaxation times, presence of different molecules containing Hydrogen (e.g. water and fat), temperature and scanner parameters such as field strength, field homogeneity, sequence type and sequence parameters [5]. This multiparametric dependency is the reason for the high and variable soft tissue contrast.

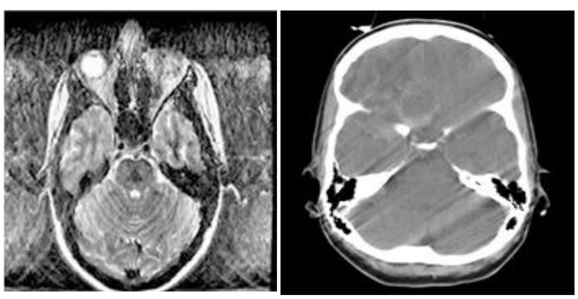
Now a days MRI uses the Fourier concept for spatial encoding. Gradient fields are used for spatial encoding of the MR signal and an inverse Fourier transform for image reconstruction. This in turn results in a complex relationship between the artifact patterns and their origin. Therefore the MR technicians, radiologists, and physicians need good knowledge about MR physics and MR artifacts which may help to choose proper techniques and methods to avoid or minimize the artifacts [5].

Some artifacts which obscure pathology and are out of radiologist immediate control are removed or minimized in technical ways using image processing techniques [12-19].

II. MRI ARTIFACTS: CAUSES AND ELIMINATION

A. Motion Artifact

Motion is the most prevalent source of MR imaging artifacts, causing blurring and ghosting of images in the phase encoding direction of the image, regardless of the direction in which the motion actually occurred (Fig.1). The reason for mainly affecting data sampling in the phase encoding direction is the significant difference in the time of acquisition in the frequency and phase encoding direction. Frequency encoding sampling in all rows of the matrix takes place during a single echo (milliseconds). Phase encoded sampling takes several seconds or even minutes, owing to the collection of all the k-space lines to enable Fourier analysis of image data. Major physiological moments are of milliseconds to seconds durations and thus too slow to affect the frequency encoded sampling, but they have a pronounced effect in the phase encoding direction [3]



(a) (b)

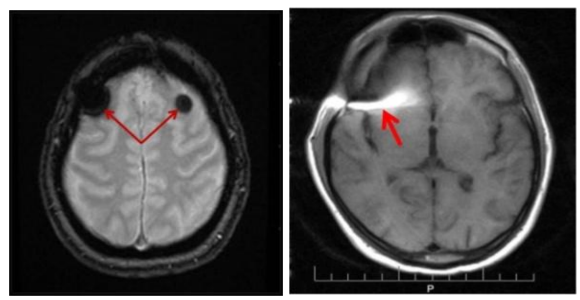
Fig.1 Motion Artifacts (a) Ghosting (b) Blurring

The appearance of motion artifact is dependent on whether the motion is mainly periodic or random [4]. The periodic movements such as cardiac motion, respiratory motion, CSF pulsation cause ghost images, while non periodic or random movements such as swallowing, coughing, eye movement and body movement causes blurring of the image.

Several methods can be used to reduce motion artifacts which includes patient immobilization, cardiac and respiratory gating, signal suppression of the tissue causing the artifact, choosing the shorter dimension of the matrix as phase encoding direction and swapping phase and frequency encoding directions to move the artifact out of the field of interest[3]. Also one can administer sedatives, repeat imaging and use autocorrelation [7]. These artifacts can also be minimized by signal averaging in the same way that multiple averages increase the signal-to-noise ratio [5].

B. Magnetic Susceptibility Artifact

Magnetic susceptibility artifacts occur as the results of microscopic gradients or variations in the magnetic field strength that occur near the interfaces of substance of different magnetic susceptibility. Susceptibility describes the property of matter of becoming magnetized when exposed to a magnetic field. There are two main effects of magnetic susceptibility. First, ferromagnetic materials can lead to a strong distortion of the B_0 field and the linearity of the frequency encoding gradient close to the object. This frequency shift results in geometric distortion of the image [4, 6]. Second, susceptibility gradient results in different precession frequencies of adjacent protons, resulting in stronger dephasing of spins. The net results are bright and dark areas with spatial distortion of surrounding anatomy (Fig.2). These artifacts are worst with long echo times and with gradient echo sequences.



(a) (b)

Fig.2 Magnetic Susceptibility artifacts (a) Dark area (b) White area (shown in arrows)

Susceptibility artifact can be reduced by performing imaging at low magnetic field strength, decreasing slice thickness, decreasing echo time TE, increasing frequency matrix, increasing receiver bandwidth, using fast spin echo sequences and avoiding gradient echo and echo planar sequences.

C. Chemical Shift Artifact

A chemical shift artifact is caused by the difference in resonance frequencies of proton in fat and water. It occurs in the frequency encoding direction but can also occur along the slice selection direction of the image. The artifact manifests itself as misregistration between fat and water pixels in an image. The effect is being that fat and water spins in the same voxel are encoded as being located in different voxels. The magnitude of the effect is proportional to the magnitude of B_0 field and inversely proportional to the sampling rate in the frequency encoding direction. The amount of chemical shift is often expressed in arbitrary units known as ppm of the main magnetic field strength. Its value is always independent of the main field strength and equals 3.5ppm for fat and water. At 1.5T the fat precesses at 220 Hz less than water [5, 6, 11]. The chemical shift appears as a bright band on one side and dark band on the other side of a fat soft tissue interface (Fig.3). Chemical shift increases with magnetic field strength and decreases with increasing bandwidth.

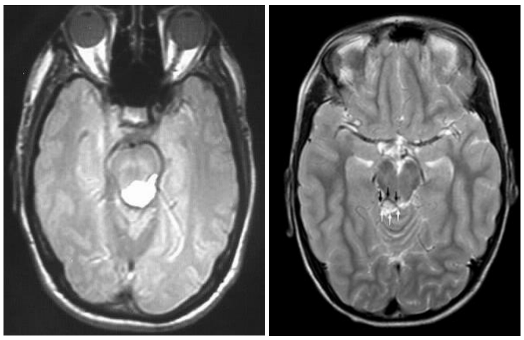


Fig.3 Chemical Shift Artifacts (shown in arrows)

Chemical shift is not a severe problem in brain imaging [11]. It can be reduced by performing imaging at low magnetic field strength, by increasing bandwidth or by decreasing voxel size. Fat suppression methods often eliminate visible artifacts and gradient reorientation can redirect chemical shift artifact to another portion of the image. The artifacts tend to be more prominent on T2 weighted than T1 weighted images.

D. Aliasing Artifact

Aliasing also known as wrap around artifact occurs when the field of view (FOV) is smaller than the size of the body part being imaged. The part of the body that lies beyond the edge of the FOV is projected on to the other side of the image [1, 2, 3, 6, 7]. Volume elements outside the FOV experience a field offset leading to a high frequency shift. If the sampling rate is lower than the expected maximum frequency range, this results in an inadequate sampling and reveals artificially low measured frequencies. This in turn results in a spatial mismapping of the voxels outside the FOV to the opposite side of the image (Fig.4).

There are several ways to over come this problem [5]. The first is to increase the FOV to the size of the imaged object.

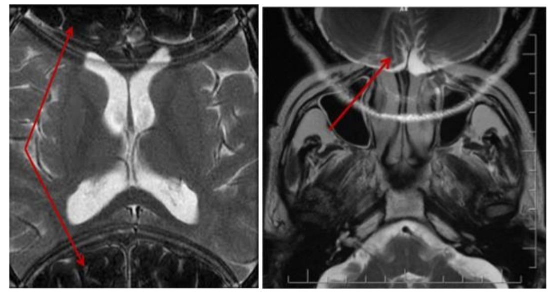


Fig.4 Aliasing Artifacts (shown in arrows)

Second is to increase the sampling rate that is twice as high as the expected maximum frequency range. Another way to avoid aliasing is

- To use surface coil to reduce the signal outside the FOV
- Use a pre-saturation pulse to saturate the spins outside the FOV
- Swap the phase and frequency encoding directions
- Use anti aliasing filter/software

E. Zipper Artifact

These artifacts appear as discrete lines of noise or alternating bright and dark pixels in a line across the image either in phase or frequency encoding direction. There are many causes for this type of artifact, most of them are related to the hardware or software problems beyond the radiologist immediate control [4, 5, 6]. The zipper artifacts that can be controlled easily are those due to RF entering the scanning room when door is open during acquisition of images (e.g. RF noise from mobile devices or aircraft). RF from some radio/TV transmitter will cause zipper artifact that are oriented perpendicular to the frequency axis of the image. Broadband noise degrades the entire image whereas narrow frequency noise produces linear bands that transverse the phase encoding direction of the image (Fig.5). Frequently this artifact can cause more than one artifact line on an image corresponding to different radio frequencies. Width and position of the artifact depends on frequency and bandwidth of the extrinsic RF signal. The remedies for zipper artifact are

- Close the door of the MR room during scanning
- Search for and eliminate extrinsic RF sources
- Use only MR compatible monitor equipment
- Eliminate sources of static electricity or avoid too low humidity

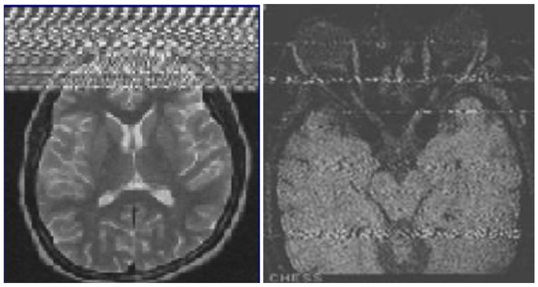


Fig.5 Zipper Artifacts (lines at top of images)

F. Gibbs Ringing Artifact

Gibbs ringing or truncation artifacts are bright or dark lines that are seen parallel and adjacent to edges of abrupt intensity change [1, 3, 4]. The ringing is caused by incomplete digitization of the echo. This artifact is seen in images when a small acquisition matrix is used.

The MR image is reconstructed from k-space which is finite sampling of signal subjected to inverse Fourier Transform in order to obtain the final image. At high contrast boundaries the Fourier Transform corresponds to an infinite number of frequencies and since sampling is finite, the discrepancy appears in the image in the form of a series of lines. These lines can appear in both phase and frequency encode directions (Fig.6).

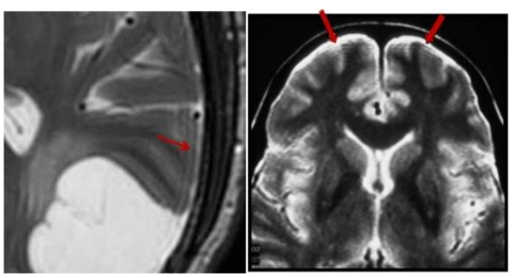


Fig.6 Gibbs Ringing Artifacts (shown in arrows)

Methods employed to correct Gibbs artifact include filtering the k-space data prior to Fourier transform and reduce pixel size by increasing the matrix size for a given FOV. If the acquisition matrix is lower in the phase encoding direction, the artifacts can be reduced by choosing the phase encoding direction perpendicular to the prominent edges of anatomic structures [4]. Technical methods to reduce Gibbs ringing artifact can be found in [12, 13, 14].

G. Intensity Inhomogeneity Artifact

This artifact is caused by the variation in intensity for the pixels of the same tissue over the image domain (Fig.7). It may be due to failure of the RF coil, non uniform magnetic field, and non uniform sensitivity of the receiver coil or presence of ferromagnetic material in the imaged object [3]. Intensity inhomogeneity in MR images can adversely affect quantitative image analysis such as segmentation and registration that are highly sensitive to the spurious variations of image intensities. The presence of intensity inhomogeneity can significantly reduce the accuracy of segmentation and registration [15, 16]. The removal of this artifact from MR images is difficult because inhomogeneities could change with different MRI acquisition parameters from patient to patient and from slice to slice. Hence a number of methods for intensity inhomogeneity correction of MR Images are proposed in [15, 16, 17, 18].

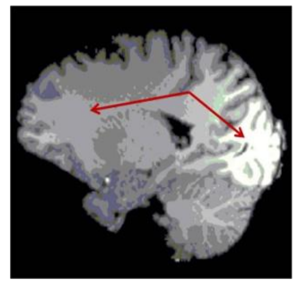


Fig.7 Intensity Inhomogeneity Artifact

H. Central Point Artifact

Central point artifact is a focal dot of increased or decreased signal in the exact center of an image, often with a surrounding ringing artifact (Fig.8). This effect is the result of the Fourier Transform of a constant offset in the raw data, which is caused by an offset of the receiver signal as a result of an error in receiver electronics [4]. Today with the quality of MR scanner hardware, this artifact is occasionally seen.

The technique to avoid this artifact is based on phase alternation of two RF excitation pulses, cancelling out the signal offset at the cost of doubling the required number of pulses (i.e. doubling the acquisition time). A software self calibrating technique can be applied to estimate DC offset voltage in the receiver and adjust the data in k-space to minimize this artifact. Also repeating the imaging sequence may get rid of the artifact.

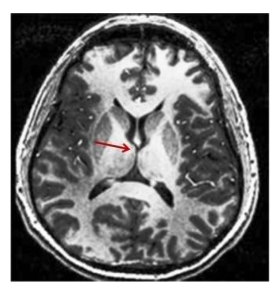


Fig.8 Central Point Artifact (shown in arrow)

I. Herringbone Artifact

Herringbone artifact is also called as crisscross artifact which appears as a fabric of herring bone. This artifact is scattered all over the image in a single slice or multiple slices (Fig.9). It is caused by electromagnetic spikes by gradient coils, fluctuating power supply and RF pulse discrepancies. The solution to this artifact can be done by the service engineer.

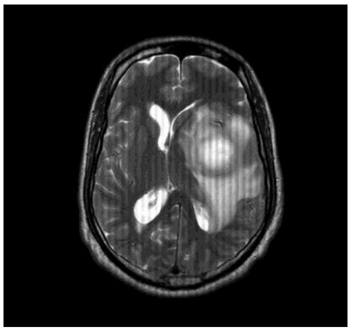


Fig.9 Herringbone Artifact (vertical stripes)

III. CONCLUSION

In this paper, the different types of artifacts frequently encountered in brain MR imaging, causes and methods to eliminate or minimize them are presented. The radiologists require constant effort and up-to-date knowledge to recognize the artifacts and decide a method to remove or minimize them by adjusting acquisition parameters of the MRI scanner. However, there are technical ways to reduce the artifacts using image pre-processing techniques which go beyond the scope of this paper but can be found in the cited literature [12-21].

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