Artifacts Quantification of Metal Implants in MRI

I N Vrachnis¹, G F Vlachopoulos¹, T G Maris², L I Costaridou¹

¹ Department of Medical Physics, School of Medicine, University of Patras, Patras, Greece
² Department of Medical Physics, Faculty of Medicine, University of Crete, Iraklion, Crete, Greece

Corresponding Author: Georgios Vlachopoulos, gvlachop@gmail.com

Abstract. The presence of materials with different magnetic properties, such as metal implants, causes distortion of the magnetic field locally, resulting in signal voids and pile ups, i.e. susceptibility artifacts in MRI. Quantitative and unbiased measurement of the artifact is prerequisite for optimization of acquisition parameters. In this study an image gradient based segmentation method is proposed for susceptibility artifact quantification. The method captures abrupt signal alterations by calculation of the image gradient. Then the artifact is quantified in terms of its extent by an automated cross entropy thresholding method as image area percentage. The proposed method for artifact quantification was tested in phantoms containing two orthopedic implants with significantly different magnetic permeabilities. The method was compared against a method proposed in the literature, considered as a reference, demonstrating moderate to good correlation (Spearman's rho = 0.62 and 0.802 in case of titanium and stainless steel implants). The automated character of the proposed quantification method seems promising towards MRI acquisition parameter optimization.

1. Introduction

The evolution of orthopedic techniques has increased the number of patients carrying metallic implants. The presence of such devices however is not uncomplicated, and imaging of the surrounding bone and tissue is necessary when problems occur. Magnetic Resonance Imaging (MRI), is a three dimensional imaging method with superior soft tissue contrast when compared to other methods. However, orthopedic hardware creates susceptibility artifacts that may hinder diagnosis. Artifacts are features appearing in the image without being present in the imaged object. The introduction of any object in the magnetic field induces changes in the magnetic flux density. When placed in homogenous magnetic field the object produces inhomogeneities in the local magnetic field that interfere with the frequency encoding gradient, altering the phase and the frequency of local hydrogen nucleus spin. These alterations in the nucleus spin result in an erroneous proton nucleus location in image matrix (k-space), due to image distortion in slice selection (through plane distortion) [1] and frequency encoding failure (in plane distortion) [2], [3]. Many techniques and pulses sequences have been proposed in order to reduce metal artifacts effect. The most simple of them propose adjustments of the orientation of the implants, the receiver bandwidth, echo train length, selection of spin echo sequences, or voxel size to name some of them [2]. More sophisticated techniques require dedicated systems, with special pulse sequences not commonly available. Optimization of all these techniques depends greatly on our ability to quantify the generated artifact. Several methods of varying complexity have been proposed for susceptibility artifact assessment and quantification, considering acquisition parameters, such as field strength, pulses sequences, implant orientation and encoding gradient bandwidth, with most of them relying on observer dependent assessment. Regarding quantification methods proposed Matsuura et al. [4] suggested...
comparison of profile line length, perpendicular to the longitudinal axis of three metallic and a ceramic implant of the same cylindrical shape. Kolind et al.[5] estimated the susceptibility artifact as image energy difference between the implant image and the image of an identical wax replica (no susceptibility artifact). Tacheuchi et al. [6] used two image thresholds to segment regions of high and low intensity artifact. Koff et al. [7] placed the orthopedic hardware in the center of a three-dimensional grid. A corner detecting software was used to identify the grid corners, with the number of missing corners associated with the susceptibility artifact.

In the current study an image gradient based segmentation method is proposed for susceptibility artifact quantification, identifying in one step high and low intensity artifacts. It was validated utilizing acquisitions at low and high bandwidth, representing high and low artifact states. The method performance was compared to a variation of the method proposed by Kolind et al [5]

2. Materials and methods

All measurements were carried out in physical phantom models. The phantom consisted of a plastic tank filled with tap water. The total water volume was 5lt. In the container 5ml of MAGNEVIST ( gadoparomic acid) of concentration 469mg/ml was added, obtaining a concentration of 469mg/l, to simulate the magnetic properties of the soft tissues. At the bottom of the tank a frame capable of holding the imaged object was fixated in the middle of the tank.

Two MRI compatible metallic prostheses of different composition were tested. The first is a stainless steel Stryker cephalomedullary nail of proximal femur. The second is a titanium locking compression plate by Synthes, used in femoral fracture fixation. MRI images were obtained using a 1.5 T MR scanner (Siemens Magnetom Sonata - maestro class with slew rate 200mT/min and G_r 45mT/m). All images were acquired using the head coil. The phantom was placed at the isocenter of the MR scanner. The temperature during the measurements was 25°C. Image processing was carried out in FIJI (https://imagej.net/Fiji). Correlation was analyzed in IBM SPSS statistics 21.

The presence of implants creates distortion in the magnetic flux. This distortion is translated in abrupt signal alterations in the acquired image. The distortion may be caused either from signal pill ups (high intensity) or from signal voids (low intensity). Image gradient magnitude is capable of identifying both types of artifact simultaneously. Image gradient magnitude is obtained from the first derivative of an image. The resulting image obtained by the Gradient Magnitude operation provides the largest gradient magnitude, when every possible direction is taken into account, given by:

\[ G(x,y) = \sqrt{\left(\frac{\partial f(x,y)}{\partial x}\right)^2 + \left(\frac{\partial f(x,y)}{\partial y}\right)^2} \]  

(1)

When the gradient magnitude operator has been applied, the higher values at the resulting image will correspond to the more abrupt alterations of the signal regardless if it comes from signal void or signal pill ups. So if we set a threshold in the resulting image regions of both of high and low intensity artifact can be identified. This is very convenient since we transform the complicated task of segmentation, to a thresholding problem. The selection of a threshold affects the accuracy and the efficiency of the image segmentation. The basic assumption behind setting a threshold in an image is that the object and the background can be distinguished by comparing their gray value levels with suitably selected threshold value [8]. Global thresholding techniques (measuring global criteria of the image histogram as criteria for the selection) were considered more suitable for our task since, as they are less prone to image noise (repeatable). In our study, Otsu’s thresholding method [9], was considered, resulting in binary mask corresponding to the artifact region. Two binary masks are obtained, one corresponding to an image with lower artifact (acquired with higher bandwidth 780Hz/pixel, misregistration error \(\Delta X \sim B_o \Delta \chi/G_r \) (2),
$B_0$ = magnetic field strength, $\Delta \chi$ = susceptibility difference, $G_R$ = gradient) and another one corresponding to image with higher artifact [10] (acquired with lower bandwidth 50 Hz/pixel). The two resulting binary masks corresponding to low and high bandwidth acquisitions, were subtracted, resulting in a final binary mask. The number of pixels of the segmented artifact region over the total number of image pixels, expressed as a percentage, provides an estimate of the extent of the artifact.

The proposed method performance was compared to a variation of the method proposed by Kolind et al [5], considered as a reference. The reference method is differentiated from [4] in that it does not use an image reference with no artifact, but a low artifact image. Furthermore, artifact quantification in the proposed method takes into account the mean image intensity over the segmented artifact region, as opposed to mean image energy in [4]. Due to different evaluation procedures of the two methods, only a qualitative comparison between the two methods is feasible.

3. Results

A T2w –TSE sequence was utilized for imaging both implants, as it is the most commonly used for musculoskeletal imaging. Axial T2w –TSE slices were selected, as the transverse plane provides much more slices than the coronal one, due to the longitudinal shape of the implants tested.

![Figure 1](image1.png)

**Figure 1.** (A) Axial slice of stainless steel implant acquired with BW= 780 Hz/pixel (low artifact state), (B) The same slice acquired with BW=50Hz/pixel (high artifact state) at the same pulse sequence (TSE) and magnetic field strength B=1.5T (C) The result of subtraction of low artifact state (1.A) from high artifact state (1.B).

Correlation analysis was performed between the artifact extent estimator results obtained by the proposed method and the method based on the subtraction of images. In case of stainless steel implant high correlation coefficient (Spearman's rho=0.802) was obtained between the two methods tested, while in case of the titanium implant correlation was moderate (Spearman's $\rho$ = 0.623).

4. Discussion

The proposed method detects artifacts based on its primary characteristic, the abrupt alteration of the image gradients, which represents the distortion caused from the implants in a magnetic field. The main advantage of the proposed image quantification method is its automated character, avoiding observer repeatability errors-interference making the method both easily reproducible and objective, using tools that are commonly available. This is of great importance when a method is used for parameter optimization. However, the method obtained moderate to good correlation with a reference method, inspired from the literature [5]. There are many reasons for that. First of all, each method quantifies artifact in a different way. The proposed method tends to detect signal pill ups more, and loses large areas of signal voids,
where the signal does not change. Moreover, the reference method was not used at its original form and some assumptions concerning the noise have been neglected. The proposed method is expected to be more effective in case of quantification of artifacts of the same pulse sequence, rather than between sequences, as the sequence itself affects image, as well as artifact signals. Finally, combination of the thresholding method segmentation output with powerful image segmentation methods, such as active contours, may offer additional advantages in precise spatial localization of the artifact.

5. Conclusions

The proposed method was aimed at susceptibility artifact quantification in phantom images of MRI compatible metallic prostheses. Being of automated character it is repeatable and thus suitable for MRI acquisition parameters optimization. It provides relative estimation of the artifact rather than absolute quantification.

References

[1] Hargreaves B A, Worters P W, Pauly K B, Pauly J M, Koch K M, Gold G E (2011) American Journal of Roentgenology 197(3) 547-555.
[2] Lee M J, Kim S, Lee S A, Song H T, Huh Y M, Kim D H, Han S H, Suh J S (2007) Radiographics 27(3) 791-803.
[3] Lu W, Pauly K B, Gold G E, Pauly J M, Hargreaves B A (2009) Magnetic resonance in medicine 62(1) 66-76.
[4] Matsuura H, Inoue T, Ogasawara K, Sasaki M, Konno H, Kuzu Y, Nishimoto H, Ogawa A (2005) Neurologia medico-chirurgica 45(8) 395-399.
[5] Kolind S H, MacKay A L, Munk P L, Xiang Q S (2004) Journal of Magnetic Resonance Imaging 20(3) 487-495.
[6] Takeuchi N, Hiromichi M, Tomonori N (2011) Fukuoka Igaku Zasshi, 102(5) 185-94.
[7] Koff M F, Shah P, Koch K M, Potter H G (2013) Journal of Magnetic Resonance Imaging 38(3) 610-618.
[8] Li C H, Lee C K (1993) Pattern recognition 26(4) 617-625.
[9] Otsu N (1979) IEEE transactions on systems, man, and cybernetics 9(1) 62-66.
[10] Schenck J F (1996) Medical Physics 23(6) 815-850.