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ARTICOLO ORIGINALE

UN ALGORITMO PER LA CORREZIONE ORTOGONALE DEGLI ARTEFATTI DA CODIFICA DI FASE IN RISONANZA MAGNETICA

AN ALGORITHM FOR ORTHOGONAL CORRECTION OF PHASE-ENCODING DERIVED ARTIFACTS IN MAGNETIC RESONANCE

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Riassunto

Introduzione: In Risonanza Magnetica (MR) gli artefatti da codifica di fase sono molto comuni e spesso disturbano l'interpretazione dell'immagine.

Il Tecnico Sanitario di Radiologia Medica, per tentare di ridurre questo genere di artefatti, usa tutti i sistemi che l'attuale tecnologia offre anche se, talvolta, possono presentare vari aspetti negativi.

Obiettivo e finalità: L'algoritmo proposto si prefigge lo scopo di ottenere, tramite un'opportuna post-elaborazione, un'immagine priva di artefatti da codifica di fase.

Materiali e metodi: Il metodo si basa su un confronto ortogonale fra due immagini acquisite con gli stessi identici parametri (sezione anatomica, pesatura) ma con codifica di fase diversa. Gli artefatti si dispongono in modo casuale lungo la direzione della codifica di fase, quindi sono l'unica diversità fra le due immagini. L'algoritmo riconosce questa diversità e ricostruisce una terza immagine in cui riporta le porzioni non coperte da artefatto, prendendole in seguito ad un'apposita procedura dall'una o dall'altra immagine acquisita.

Per non aumentare il tempo totale di esame rispetto alle attuali procedure, si sfrutta il numero di eccitazioni (o simili) acquisendo la sequenza desiderata un numero pari di volte in modo che le immagini siano metà in una direzione di codifica di fase e metà nell'altra.

Al termine del procedimento si esegue una media delle immagini risultanti al fine di migliorare il rapporto segnale-rumore.

L'algoritmo è stato testato su 547 coppie di immagini con artefatti ottenute dallo studio di differenti parti anatomiche, sequenze e macchine (da 0.22T a 3 T).

In tutte le acquisizioni erano stati impostati gli accorgimenti specifici per ridurre gli artefatti secondo le raccomandazioni dalle case produttrici.

Risultati: La completa eliminazione degli artefatti è stata ottenuta in 91.4% (500/547) dei casi esaminati con una riduzione incompleta in 8.6% (47/547).

Conclusioni: L'elaborazione delle immagini con l'algoritmo proposto ha ridotto significativamente l'incertezza diagnostica derivante dalla presenza di artefatti da codifica di fase, senza aumentare il tempo di esame. Il metodo risulta potenzialmente applicabile per vari tipi di sequenze e sulle macchine attualmente disponibili in commercio.

Parole chiave: Risonanza Magnetica, Codifica di Fase, artefatti, algoritmo, aliasing

Abstract

An algorithm for orthogonal correction of phase-encoding derived artifacts in Magnetic Resonance

Introduction: Phase encoding artifacts are very common in Magnetic Resonance Imaging (MRI), often disturbing interpretation of the image. Radiology technicians, aiming at reducing this kind of artifacts, use all the systems provided by the current technology despite potential negative features.

Object: The proposed algorithm aims at eliminating phase encoding derived artifacts from MRI image through a suitable post-processing.

Materials and methods: The proposed orthogonal algorithm compares two images of the same anatomical region acquired with identical parameter but different (vertical vs. horizontal) phase encoding directions. The key concept is that artifacts are randomly distributed, whereas the spatial distribution of body anatomy is not. The algorithm finds out this diversity and fully reconstructs a third image showing the portions not covered by artifacts, as a result of a special procedure from one of the two scanned images. In order to avoid prolongation of exam time, the Number of Signal Averages (NSA), (or similar parameters) can be exploited by making an even number of acquisition, with half of them being distributed along one phase encoding direction and the remainder half being distributed along the opposite one. Then the procedure performs an average of the resulting images in order to improve the signal-noise ratio.

The algorithm was applied to n=547 pairs of artifact-positive images obtained from different body anatomical sites, and different sequences with different machines (0.22 to 3 T).

Specific measures were applied to all acquisitions in order to reduce artifacts as recommended by manufacturers.

Results: A complete elimination of the artifacts was obtained in 91.4% (500/547) of the cases, with incomplete reduction in 8.6 % (47/547).

Conclusion: The introduction of the algorithm led to a significant reduction in the diagnostic uncertainty, resulting from phase encoding artifacts, without prolonging the examination time. The method was found to be potentially applicable to various kinds of sequences, and commercially available machines.

Key words: magnetic resonance imaging, phase encoded directions, artifacts, algorithm, aliasing

Introduction

In Magnetic Resonance (MR) artifacts are false signal intensities that overlap with the real patient anatomy and are generally categorized according to their causes, i.e., hardware issues, physiological (motion, flow), and to overturning (aliasing or wrap around)[1]. The latter two factors are usually the most difficult to remove[7,8], and are due to the phase encoding[2].

The removal of artifacts is very important in MR for a variety of reasons including: 1) image quality, 2) a consequent reduction of diagnostic uncertainty, and 3) reduced need for further investigations with contrast medium or other methodologies.

Despite several algorithms have been proposed over the years[4,9,10], to date no reliable methods exist in order to fully eliminate PEDAs. It is well known that they could be partly reduced by modifying several variables, including acquisition parameters and/or use of additional diagnostic procedures[6,3]. Both options, however, are usually based on the technician's empirical knowledge and require a prolongation of the exam time. In addition, it should be considered that changes in the acquisition parameters are usually counterbalanced by a relative loss in diagnostic accuracy.

Abbreviations

MR: Magnetic Resonance
PEDAs: Phase-Encoding Derived Artifacts
MRI: Magnetic Resonance Imaging

Object

Here, we propose a newly conceived algorithm aimed at reducing or eliminating PEDAs from MR images.

Materials and methods

Algorithm

We based our algorithm on the key concept that signal intensity alterations are always randomly distributed, whereas the spatial distribution of body anatomy is always non-random according to the well-known orthogonal correlation principle[5,11]. In more detail, when acquiring twice the same MRI sequence on a given anatomical region by using identical parameters, possible artifacts will be located along the vertical direction of the image when the phase encoding is directed on columns, and along a horizontal directions of the image when the phase encoding is directed on rows.

In the algorithm process, image **A** is acquired with phase encoding for columns and image **B** is acquired with phase encoding for rows, in the post process stage the software compares the different intensity values of the same image portions (pixels).

Pixels with small/imperceptible different intensities are considered to be equal. The small gap in the numeric intensity of colour was calculated during the algorithm development.

For each pair of images, the software calculates a number of different pixels (K).

In the first step, the algorithm considers image A as the true image, and then compares A with B.

Each column with a number of different pixels < *K* is directly copied from A in the new image B'. Each column having the value of different pixels bigger than *K* is copied from B (scheme 1).

A simplified example may be of help to better understanding the basic principle behind the algorithm (scheme 2.)

Compare two images of the same anatomical section.

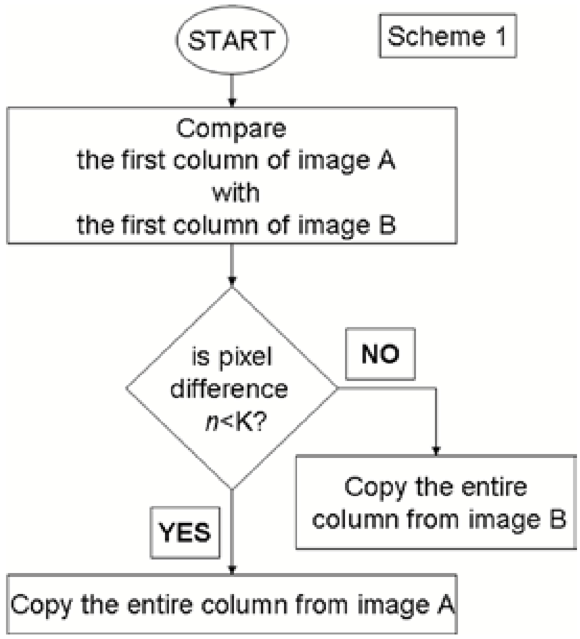
At the end of this operation the algorithm considers B as the true image, and compares B with A for rows.

The mechanism is similar to previous (scheme 3).

Thus, we get two images A' and B' which in this example are identical, and are formed only from pixels in common (scheme 4).

The dot striped remains because, lying in the intersection between row and column and then in the same position in two images, is a part of the body and not an artifact (i.e., aorta).

Matching of these two images currently translates into doubling of the exam time. In order to avoid the prolongation of exam time, Number of Signal Averages (NSA), sometimes defined as Number of Excitations (NEX), can be exploited by making an even NSA with half of them being distributed along one phase encoding direction and the remainder



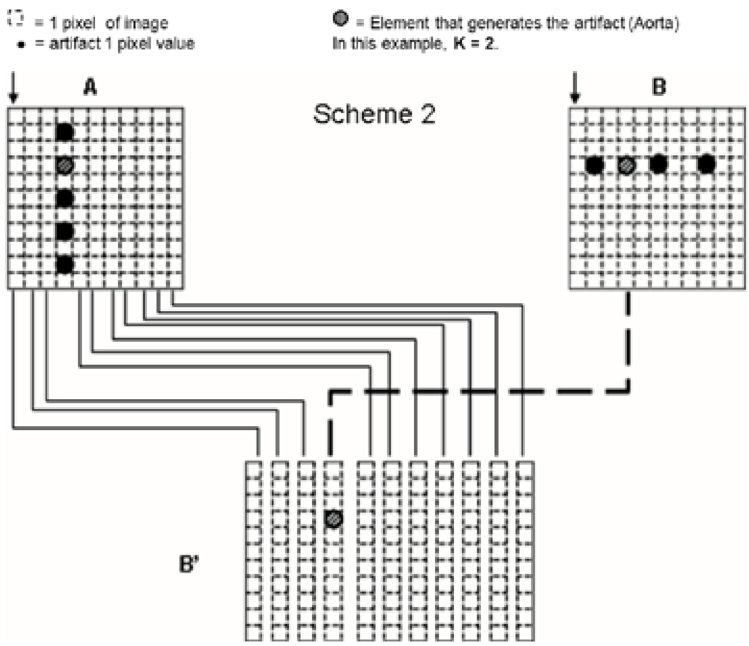
Scheme 1 *- Key concept of the algorithm*

half being distributed along the opposite one.

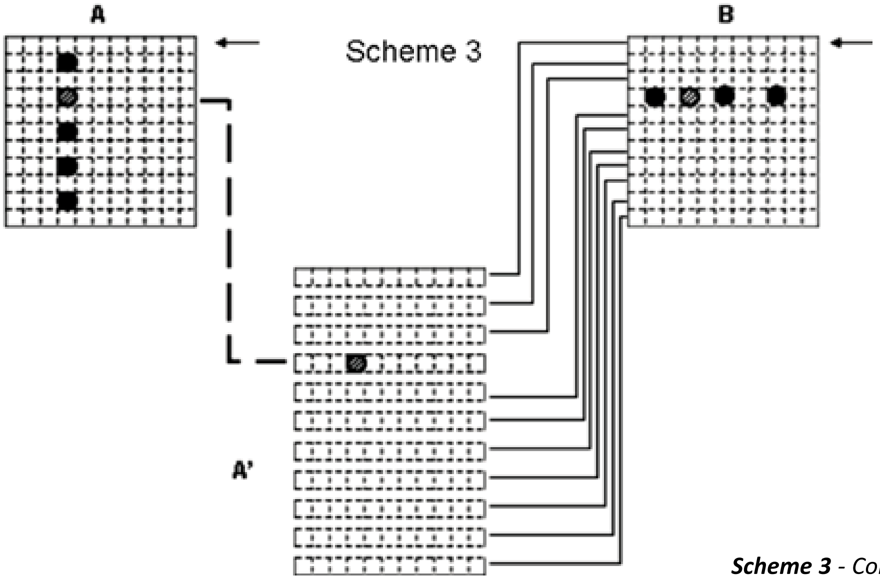
In the case of some modern scans, acquired with NEX = 1, you can record half of K space.

For example this sequence is scanned four times (4 NSA), (scheme 5).

Compare A with B and C with D, but it is also possible to compare A with D and C with B. Therefore, images can be compared for all the possible combinations.

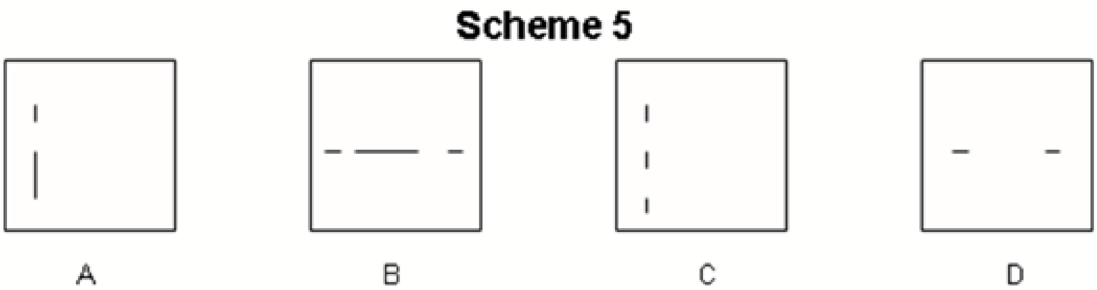


Scheme 2 *- Comparison for columns*



Scheme 3 *- Comparison for rows*

Scheme 4 *- Result of procedure*



Scheme 5 *- Take advantage of the NEX to acquire with opposite phase encode direction*

The algorithm previous the average from the result of every couple of image to decrease noise. The whole procedure is feasible in the order of 1 sec or less, using a standard PC.

This procedure can be applied to all the images in the sequence.

Testing procedure

The algorithm was applied at the post-processing stage to n=547 couple of artifact-positive images obtained with different machines, at different magnetic field intensities: (3.0 T, n=40; 1.5 T, n=118; 0.35 T, n=17; 0.22 T, n=372.), and including different body anatomical sites (brain, n=100; cervical spine, n=90; shoulder, n=64; wrist n=68; lumbar spine, n=70; knee, n=104; leg, n=51) with different sequences: (T1, n=192; T2, n=191; IR, n=95; Flair, n=40; Gfe T2, n=29).

Research has obtained the approval of the Ethics Committee of the structures in which the images were acquired in accordance with the Declaration of Helsinki of 1975 and subsequent revisions.

Results

Data analysis

The presence of artifacts in the images was independently evaluated by two medical radiologists with more than 10 years' specific experience in MRI interpretation and who were unaware of the use of the algorithm. Inter-rater agreement between observers was measured by weighted Kappa statistics. The fraction of artifact-free images (i.e., no artifacts) or with markedly reduced artifacts (i.e., mild artifacts not affecting image interpretation) after application of the algorithm was the main outcome measure of the study. Differences in the occurrence of artifacts before-after algorithm application were tested by chi-square statistics, and a two-sided *p* value of <0.05 was considered to be statistically significant. The MedCalc ver. 12.0 statistical software package (MedCalc. Software, Mariakerke, Belgium) was used.

Inter-rater agreement between observers (weighted Kappa) was 0.949 (standard error: 0.036, 95% Confidence interval: 0.880-1).

After applying the algorithm to 547 pairs of images, a complete elimination of the artifacts was obtained in 500/547 (91.41%) of the cases (white area in scheme 6) (See example: Fig 1 A, Fig 1 B, Fig 1 C; Fig 2 A, Fig 2 B, Fig 2 C; Fig 3 A, Fig 3 B, Fig 3 C; Fig 4 A, Fig 4 B, Fig 4 C).

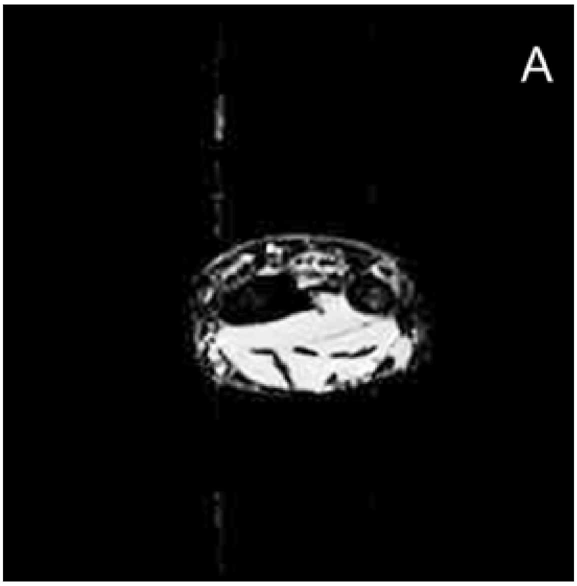


Fig. 1A *- Axial, IR, of wrist acquired with phase encode for columns*

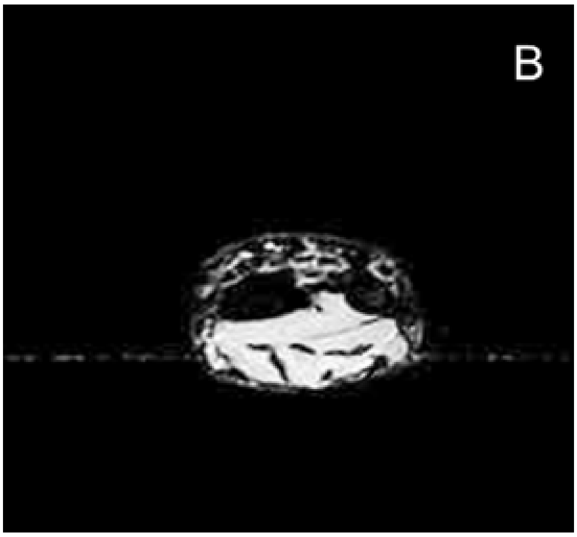


Fig. 1B *- Axial, IR, of wrist acquired with phase encode. for rows*

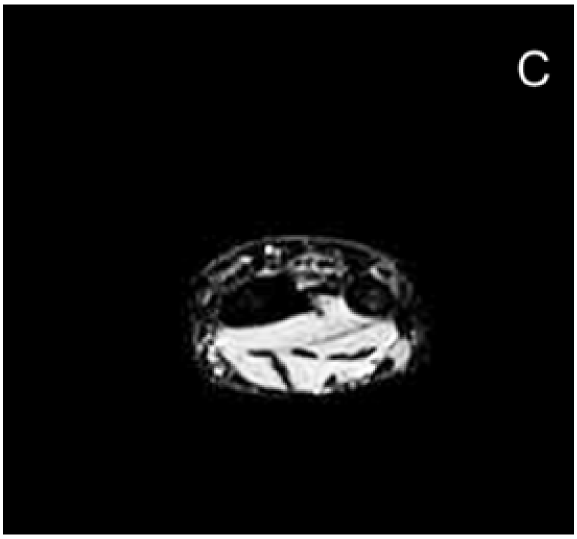


Fig. 1C *- Axial, IR, of wrist obtained by algorithm*

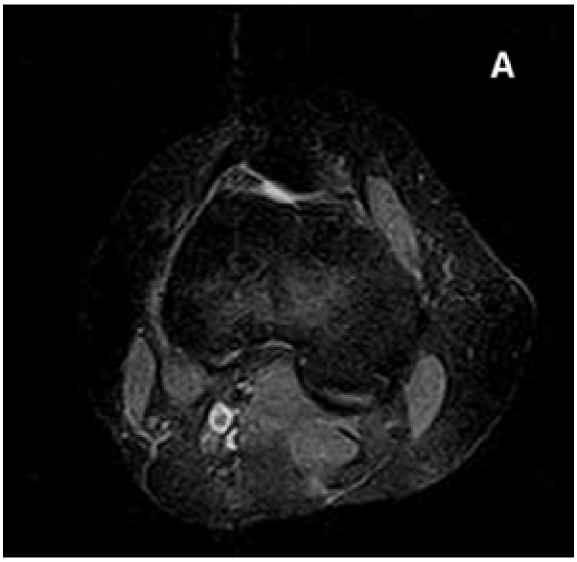


Fig. 2A *- Axial, IR, of knee acquired with phase encode for columns*

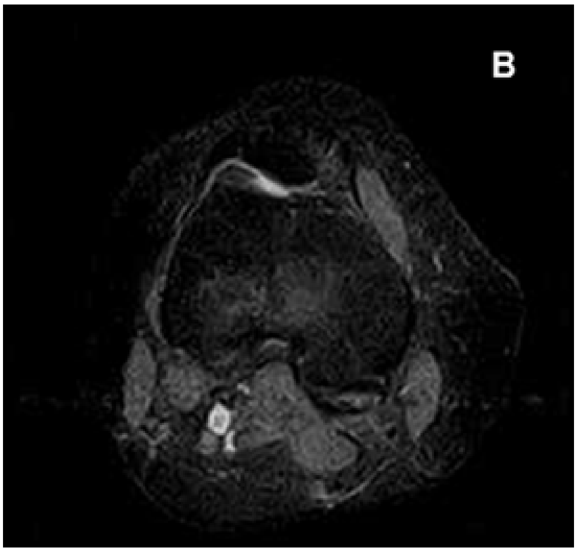


Fig. 2B *- Axial, IR, of Knee acquired with phase encode for rows*

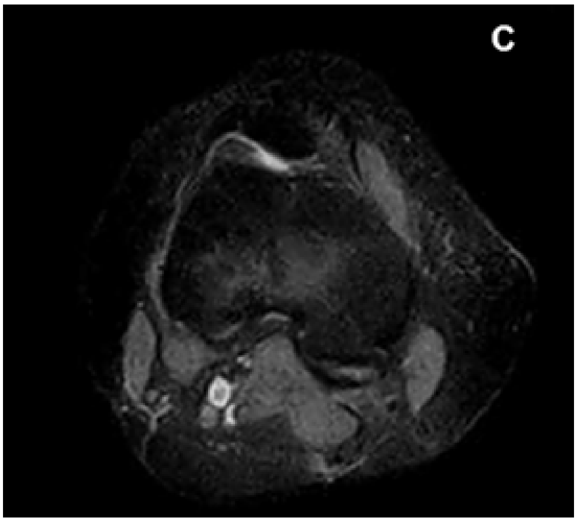


Fig. 2C *- Axial, IR, of Knee obtained by algorithm*

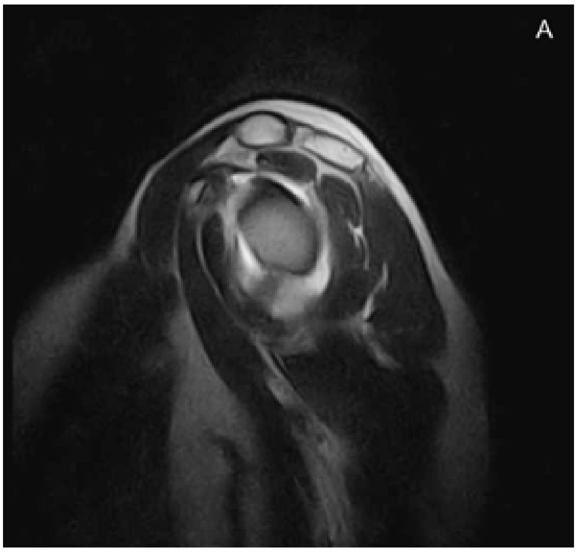


Fig. 3A *- Sagittal, T2, of shoulder acquired with phase encode for columns*

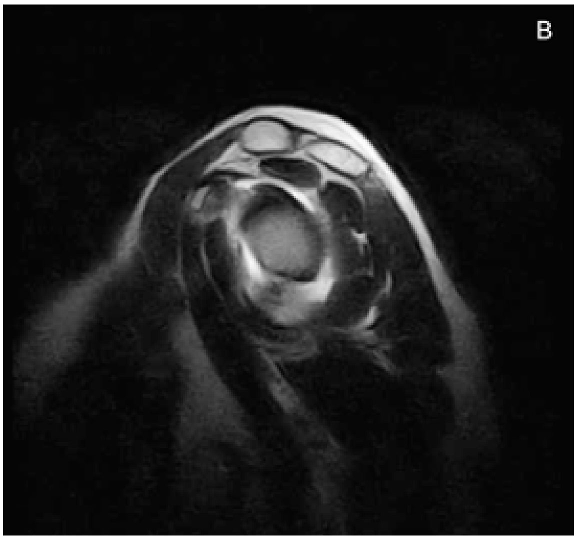


Fig. 3B *- Sagittal, T2, of shoulder acquired with phase encode for rows*

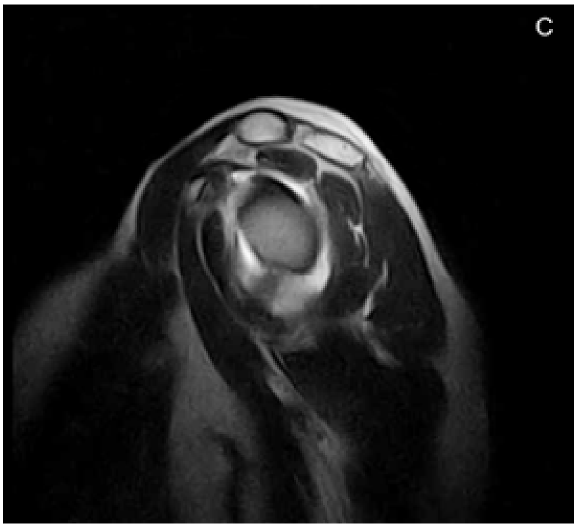


Fig. 3C *- Sagittal, T2, of shoulder obtained by algorithm*

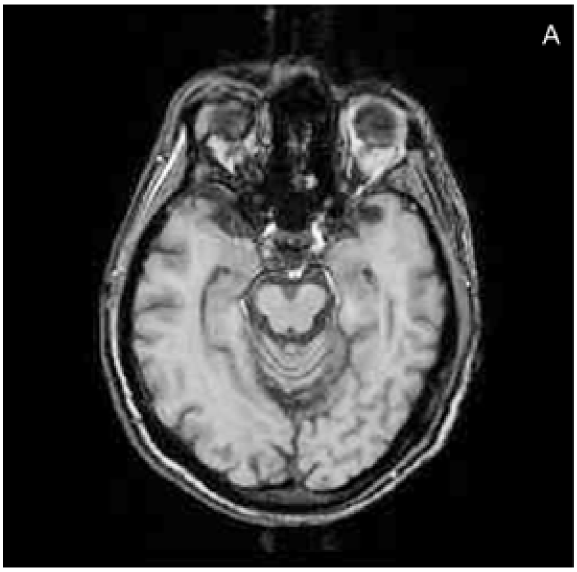


Fig. 4A *- Axial of brain acquired with phase encode for columns*

Fig. 4B *- Axial of brain acquired with phase encode for rows*

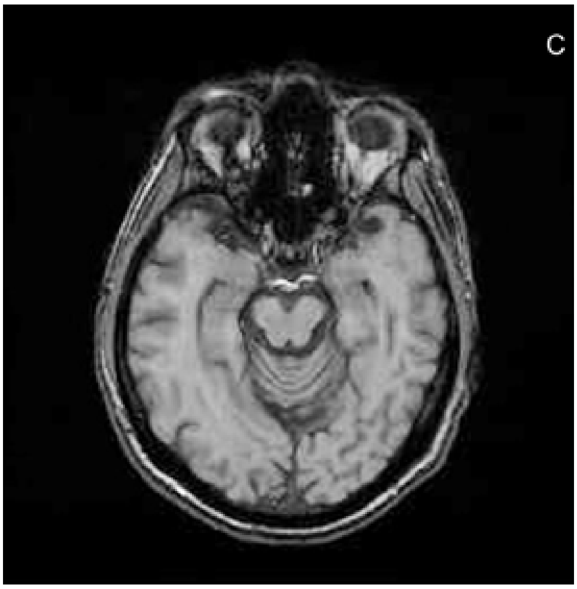
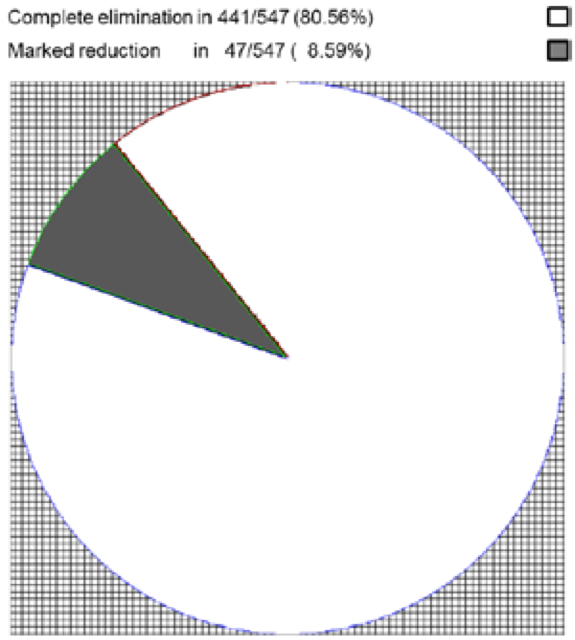


Fig. 4C *- Axial of brain obtained by algorithm*

Exclusively limited at coronal orientation of the shoulder, in all kinds of sequences and weighings, we obtained a partial correction of the image (8.59% of cases, 47/547, grey area in the scheme 6). Given that, in this case, the artifact is present in the same position in both images, the algorithm sum the false signal intensity instead of removing it, because in that point any image haven't the correct data (See: Fig 5 A, Fig 5 B, C Fig 5, the circles show the artifacts).

Overall, the introduction of the algorithm led to a significant reduction in the diagnostic uncertainty in approximately 90% of the treated images (chi-square 880.977, df=2, p<0.0001).



Scheme 6 *- Pie chart representation of the obtained results*

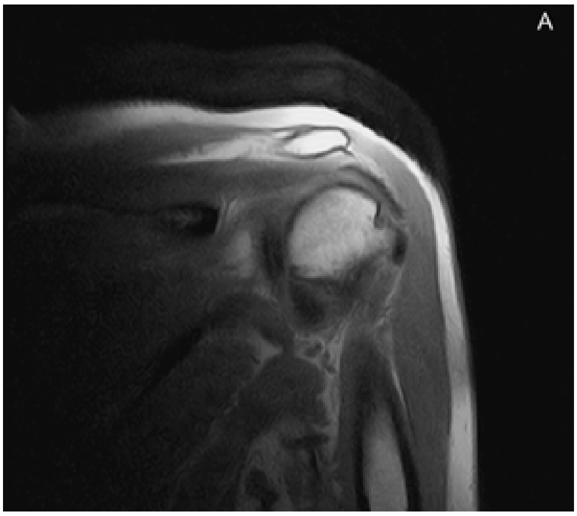


Fig. 5A *- Coronal, T1, of shoulder acquired with phase encode for columns*

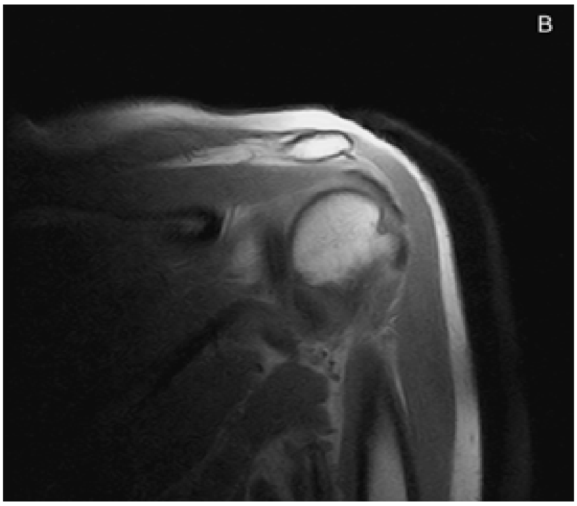


Fig. 5B *- Coronal, T1, of shoulder acquired with phase encode for rows*

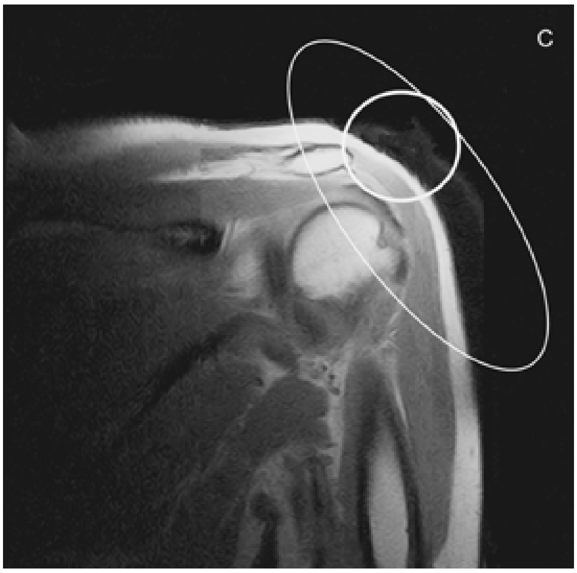


Fig. 5C *- Coronal, T1, of shoulder obtained by algorithm, solid lines surround artifacts*

Discussion

Over the years, several techniques for reducing PEDAs have been proposed, but have so far encountered very little success. Some authors have developed the ability to use rephasing gradients [3], while other authors have proposed the comparison between the different directions of phase encoding. [4,5,11].

In particular, over the last two decades, two algorithms have been developed with the specific aim of reducing or eliminating PEDAs [5,11], although they have not met commercial standards of use. Despite some obvious similarities, a comparison between the previous ones and the present algorithm indicates the existence of key differences (Table 1). All the methods share the concept that artifacts are randomly distributed, and therefore it is necessary to increase acquisition number to correct them. However, there are four distinctive features: 1) lack of action on the K-space, with the possibility to act on the final image in the post-processing phase; 2) no need for major changes of acquisition and recording signal; 3) possibility of eliminating the phase encode direction parameter; and finally 4) no need for increasing exam time.

The need for maintaining a perfect patient immobility is certainly a problem for this method, as for every MRI setting. Motion artifacts by patient's mispositioning still represent a major problem which is currently impossible to counteract by means of a software. The preferential regions of application of the method are expected to be the abdomen, chest, and neck since PEDAs in these particular anatomical regions are well-known to generate several diagnostic doubts deriving by physiological processes (such as: swallowing, peristalsis, breathing movements, cardiac dynamics, and aorta blood flow).

When the anatomic region of interest is subjected to physiological movements the acquisition of the sequence can be carried out in the "gate mode", i.e., by synchronizing the acquisition with an electrocardiogram or with a sensing device expansion of the chest / abdomen. In this way, the anatomical parts occupy the same position in the images.

Initially, the inhomogeneity of the magnetic field could be regarded as a cause of incomplete reduction of artifacts. In fact, a small distortion of the image is generated by moving out from the centre of the field, depending on the phase code direction. This phenomenon leads to non-perfectly overlapping pairs of images in the extreme borders of the image.

Table 1 *- Comparison between different reports on correction of artifacts*

Reports	Concept of "Random Artifact"	Increase acquisition number	Change Phase Encode Direction	Work on final or resulting images	Work on K-space	Major difficulties in acquisition and/or recording signal	Manual control parameter of "Phase Encode Direction"	Total sequence Exam Time
Ref (11)	+	+	-	-	+	+	+	↑
Ref (5)	+	+	+	-	+	+	+	↑
Present Study	+	+	+	+	-	-	-	↔

This problem has been overcome by adding a function to the software in order to tolerate minimum distortions due to minor muscle contractions or chemical shift or minor recording differences leading to not perfectly overlapping images.

It is currently under study the opportunity to apply the proposed algorithm also to reduction or elimination of aliasing or wrap-around artifacts, as they always arise along the direction of phase encoding. By use of this method, we could have the possibility of zooming in on the image with a very high space resolution in a relatively inexpensive way without prolonging the overall exam time (saturation bands or other proposed algorithms).

Conclusion

The results show how the success of the use of the algorithm depends by the type of orientation according to the anatomic region under exam, rather than from the weighing of the sequence or from used machine.

Given the basic characteristics of the proposed post-processing algorithm, requiring a small implementation to the reconstruction software, the proposed system is potentially applicable to the existing MRI machines, independently from Tesla power and other technical characteristics.

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Conflict of Interest Statement

The Authors declare that they did not receive any funds for the present study and deny any financial involvement in the treated topic and/or the results obtained by the study. The core idea behind this original article is an Italian Patent number n° 0001403363.

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