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MRI LIMITATIONS: THE MAIN ASPECTS AND RESOLVING TECHNIQUES

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ABSTRACT Since its development in the 1970s and 1980s, MRI has confirmed to be a versatile imaging technique. It used in diagnostic medicine and biomedical research. MRI scans are capable of producing a variety of chemical and physical data, in addition to detailed spatial images. But this wide range of applications was restricted by many drawbacks make a limitation in its application. Because of its usefulness and its important roles in the process of diagnosing diseases, scientists worked hard to overcome these drawbacks. And as a result of continuous research, recent developments have addressed these drawbacks. This review aims to highlight the main aspect of limitations, and the methods and advanced techniques that have enabled the MRI to overcome its limitations.

KEYWORDS : MRI Limitations, long scan time ,acoustic noise, Drawbacks.

INTRODUCTION

Magnetic Resonance Imaging (MRI) is a powerful imaging modality for noninvasive examination of the body .it does not require the utilization of ionizing radiation and gives predominant soft-tissue characterization with adaptable image-contrast parameters. These properties permit great visualization of anatomical structure, physiological work, bloodstream, and metabolic data, making MRI compelling in an assortment of clinical applications.

But despite the superiority of magnetic resonance over other imaging modalities, some drawbacks accompanied MRI imaging since its beginning, which limited its practical use, such as 1) the complexity and high cost, 2) the long scan time, 3) the noise during the scan, 4) the exclusion of some patients due to pacemakers and metallic artifacts [1] and 5) limit applications of MRI in the chest region. Currently, the rapid development of advanced technologies and the continuous efforts of scientists to overcome limitations have paid off. This review aims to highlight the methods and novels developments that have enabled magnetic resonance to get rid of its limitations. This review concentrating in four limitations:1) long scan time,2) the acoustic noise, 3) lung scan limitations , and 4) limitation in metal implant object.

LONG SCAN TIME:

One of the main drawbacks of MRI is the long scan time needed to localize the MR signal in K-space to reconstruct an MRI image. This long acquisition time makes the image susceptible to motion artifacts, which decreases the quality of the image.[2] Many techniques had been developed to accelerate MRI acquisition includes:

Parallel imaging (PI)

This technique is based on the fact that acquisition time has a direct relation to the number of phase-encoding lines in k-space. So if it was possible to reduce the number of phase-encoding lines, it would reduce the scan time of MRI this is called under-sampling. But this also decreases the field of view (FOV), resulting in aliasing or wraparound artifact. For that in parallel imaging, the phased-array coil elements are used to remove or prevent the aliasing. [3]The simple form of undersampling even by collecting a smaller number of k-space lines near the center of k-space, or to skip phase-encoding lines at regular intervals. The amount of undersampling is expressed by the acceleration factor R, which is defined as the ratio of the number of k-space points in the fully-sampled data to the undersampled data. [4]

The parallel imaging is subdivided in to two categories, according to where the images are reconstructed and artifacts are corrected. The sensitivity encoding (SENSE), is an image domain in which, the data are firstly Fourier transformed, resulting in aliased images and then "unwrapped" [5] .the second category is generalized autocalibrating partially parallel acquisition (GRAPPA), which works in the k-space domain.[6] One of the most important advantages of parallel imaging is its wide applicability: it can be applied to any pulse sequence; However, PI acceleration factors 2 are not reliably achievable in the clinic, without unacceptable image degradation.[7]

Multiple contrast images

Instead of decreasing the amount of k-space data collected for improvements in acquisition time, several methods that acquire multiple contrast images in a single scan have been proposed. Fast spin-echo (FSE) sequence employing k-space data sharing between images of different contrasts is proposed for dual-contrast or triple-contrast FSE sequence. [8, 9] An example of this method multi-contrast imaging to collect whole brain images in a matter of minutes had been introduced recently. It called strategically acquired gradient echo (STAGE) imaging. This was designed to establish a standardized, rapid brain imaging method for evaluating neurological diseases. STAGE imaging offers the potential to create a standardized brain imaging protocol providing four pieces of quantitative tissue property information and multiple types of qualitative information in just 5 min [10]

Compressed sensing:

Compressed sensing (CS) is also depending on the concept of reconstructing an image from an incompletely filled k-space. [11, 12] however, in CS, no integral information is collected. The innovation for CS came from attempts to solve a somewhat related imaging problem: storage and transmission of increasingly large imaging data sets. This problem was solved by image compression, a process that reduces file size by permanently discarding certain data elements. Using a variety of algorithms, medical images can be successfully compressed while maintaining diagnostic efficacy, even at compression ratios from 9: 1 to 25: 1. [13]

ACOUSTIC NOISE IN MRI

During the operation of the MRI scanner acoustic noise is produced. The main source of this noise is the gradient coil, which arises due to the rapid alterations of currents within the coils. These currents, in combination with the magnetic field of the MR system, produce significant (Lorentz) forces that act upon the gradient coils. [14] In MRI systems, noise levels until 112 dB were reported depending on the type of pulse sequence and the strength of the external magnetic field. [15] This noise may cause simple annoyance, difficulties in verbal communication, anxiety, temporary hearing loss, and potentially permanent hearing impairment for both the patient and operator. [16-19] to reduce this acoustic noise and improve patient comfort many techniques had been introduced in clinical practice Such as the use of earplugs or headphones. This helps in the reduction of noise levels from 10 to 30 dB. But it has its limitations.1) Earplugs are a big size to be well accommodated in the ear canal of adolescences and infants. 2) Usage of earplugs interfaces the communication between the patient and operator. Another reduction technique was introduced by enveloping the whole gradient coil in a vacuum chamber or the use of buffer materials avoids the vibration transmission and reduced the noise. But this technique increased the manufacturing cost of the MRI scanner. [20] All these techniques used a hardware solution to reduce the acoustic noise which leads to an increase in the cost of the MRI scanner.

Recently a reduction technique based on MR pulse sequence optimization has appeared. In this technique, acoustic noise is reduced by optimizing the gradient activity and/or avoiding acoustic resonance frequencies. An optimization of gradient activity was employed by carefully modifying the gradient shapes too, for example, sinusoidal shapes to minimize high acoustic frequencies and by reducing the applied gradient strength. Sequence-based approaches generally do not require any hardware changes. [21]

Newly GE Healthcare and Siemens Healthcare launched silent "low noise" sequences known as SilentScan and QuietX respectively. Most of the sequences have similar structures to conventional ones, but use "milder" gradient waveforms with more progressive gradient rise and fall times. These methods reduce the noise of an MRI sequence to less than 10 dB of ambient noise but result in a signal/noise penalty of about 10% due to shorter windows available for data sampling. [22]

LUNG MRI LIMITATIONS

MRI plays an important role in the diagnosis of cardiovascular disease, mediastinal lesions, and pathologies of the brachial plexus and chest wall. However, clinical indications are limited to specific conditions due to low proton density in the lung which result in low signal to noise ratio and the fast signal decay due to susceptibility artifacts at air-tissue, as well as cardiac and respiratory motion artifacts reduce the image quality. [23]

The recent technological advances and the use of new imaging technologies have helped MRI lung imaging to challenge its well-known limitations.

Airways lung ventilation can overcome a low SNR problem: Since air has no signal on MRI, ventilation can only be visualized directly with inhalational contrast agent hyperpolarized noble gases.[24,25] So a high signal from the lungs and clear image can be obtained to study lung ventilation properties. One of the approaches consists of the inhalation of a paramagnetic contrast agent such as gadolinium chelates aerosol or molecular oxygen gas to increase the relativity of protons and thus the recovery rate of the NMR signal. Another approach is based on non-proton-MRI of inhaled nuclei such as perfluorinated gas or hyperpolarized gases such as helium ^{3}He or xenon ^{129}Xe. [26]

The current trends in lung MRI to reduced motion artifacts: The majority of the applied lung protocols which are pursued to compensate the limitations from breathing are based on two basic strategies: The fast single-shot imaging with very short acquisition time like steady state (SSFP) or Half Fourier single shot sequences (e.g. HASTE) have been successfully implemented. SSFP sequences allow for fast acquisition of ten slices with breath-hold times below 10 s. And the second strategy is the respiratory gating/triggering acquisition. This may Increases imaging time but provides better spatial resolution and soft-tissue contrast. [27,28]

METAL IMPLANT MRI:

The use of MR imaging in patients with metallic implants is limited by the presence of artifacts, which can obscure pathologic findings and lower the reader's confidence. Metallic objects artifacts occur due to their magnetic susceptibility, it exerts its own magnetic field, thereby distorting the external magnetic field (B 0). This distortion results in a field inhomogeneity near the metal, which in turn alters the phase and frequency of the local spins. [29,30]

These artifacts can be reduced through the use of metal artifact reduction (MAR) techniques which divided into two categories:

Standard Metal Artifact Reduction Techniques [31]

1.1 Scanning on a low-field-strength system
1.2 Orientating the long axis of the hardware parallel to the external magnetic field
1.3 Orienting the frequency-encoding gradient parallel to the external magnetic field
1.4 Increasing the receiver bandwidth
1.5 Using fast spin echo sequences with short echo spacing
1.6 Using short tau inversion recovery for fat suppression
1.7 Using smaller voxel size, high-resolution matrix, small FOV, and thin slice images

Advanced Metal Artifact Reduction Techniques

2.1 View angle tilting (VAT): Although first described by Cho and colleagues in 1988, VAT corrects the in-plane distortion by applying a gradient along the z-direction with the same amplitude as the slice select gradient during readout. This helps to correct the linear malposition of spins along the readout direction. [32]

2.2 Off Resonance Suppression (ORS): It uses different strengths for RF excitation and refocusing pulses to exclude some misregistration. ORS can be combined with VAT to further improve in-plane distortion. [33]

2.3 Slice encoding for metal artifact correction (SEMAC): is a newer MAR technique that corrects through-plane distortions caused by metal. This method uses a 2D excitation pulse combined with a 3-dimensional (3D). [31] It uses FSE imaging technique to reduce the intravoxel dephasing and the VAT technique to correct the in-plane distortion. It resolves the true location of all excited signal by acquiring signal not only from the excited slice but also from the slices above and below the excited slice with an additional phase-encoding gradient applied along the z-axis. Post processing techniques are then used to combine the signal from all of the individual slices from the volume to generate a corrected 2D image for each particular slice. [31]

2.4 Multi-acquisition variable-resonance image combination (MAVRIC): It is a new imaging technique that reduces both through-plane and in-plane susceptibility artifact by combining the signal from a volume of data excited with RF pulses over a range of frequencies centered around the resonance frequency. [31] With MAVRIC, the protons can be excited through the use of multiple narrow bandwidth RF pulses with a range of frequencies at, above, and below the resonance frequency. A 3D FSE technique is used to acquire volumetric data for each frequency range, and the final image is then generated by combining the data for all of these volumes. [31]

2.5 SEMAC-MAVRIC hybrid technique MAVRIC-SL (MAVRIC selective): It combines the application of a slice-encoding gradient during acquisition with the MAVRIC technique. This hybrid approach takes advantage of both techniques to provide the spectral selectivity of MAVRIC and the slice selectivity of SEMAC to obtain images with good SNR and minimal aliasing. [34]

2.7 ORS for MSI: ORS can be combined with MAVRIC and SEMAC sequences, allowing a tunable trade-off between scan time and proximity to the implant, and reducing through-plane aliasing. (11) Downsides include signal voids and loss of homogeneity due to far off-resonance suppression. A recent study has demonstrated that these techniques are feasible with reasonable scanning times; more evidence is needed to assess their clinical applicability. [33]

CONCLUSIONS

So due to advanced technology, most of the MRI limitations were addressed. The new generation of the MRI scanner is faster, quieter and allows a wide range of clinical applications even in a patient with a metallic implant and the only drawback that still not solve the complexity and the high cost of the MRI scanner. Even this one may be changed in the near future.

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