Principles and applications of echo planar imaging in magnetic resonance

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ABSTRACT

Echo planar imaging was initially introduced as a technique to reduce the magnetic resonance imaging exam to a single shot (snap-shot) acquisition, much like a conventional radiograph. This vision, of course, created a good deal of speculation about the clinical impact of an echo planar imaging-equipped magnetic resonance imaging device. From completing the entire magnetic resonance exam in a matter of seconds to expanding the applications field of magnetic resonance imaging into territories traditionally claimed by other modalities, the perceived potential of echo planar imaging was indeed great. It was not until this decade, however, that the technical challenges involved with developing echo planar imaging into a clinical tool have been overcome.

Keywords: Echo planar, magnetic resonance, imaging, physical principles, application.

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The best way to begin the definition of echo planar imaging (EPI) is by comparing it with conventional spin echo acquisition. Figure 1[1] illustrates (a) the basic spin echo pulse sequence, (b) the raw image data or the "K-space" that is collected during the pulse sequence and (c) the typical image quality that results from the completion of the scan. In order to keep the analysis simple, we can say that within each repetition time (TR) period, the pulse sequence is executed and one line of image data (one phase encode) is collected. The pulse sequence is then repeated for a number of TR periods until all of the phase encodes are collected. The scan time for this technique can therefore, be represented by this equation: Scan time = TR period x Total phase encodes.

So for a TR periods of 2-3 seconds and 128-256 phase encodes, the scan time will be easily approaching 6 to 12 minutes. In Figure 2[1], the same simple analysis is applied to EPI. Figure 2a is an illustration of the pulse sequence, (b) illustrates the data collected during a single TR period and (c) demonstrates the resulting image quality.

By comparing the resulting two images, we find that the EPI image is very similar to the spin echo image. The first half of the pulse sequence is essentially identical to a standard spin echo pulse sequence, in that there is 90-180 excitation. The second half of the pulse sequence is where it differs significantly from a standard spin echo acquisition. The readout or "Frequency" gradient oscillates rapidly from positive to negative amplitude to form a train of gradient echoes. Each echo in this (echo train) is phase encoded differently by the phase encode that occur on the phase axis. The first, and most important difference between spin echo acquisition and EPI acquisition is that EPI pulse sequence acquires multiple lines of image data during one TR interval. Comparison to fast spin echo imaging for those who are familiar with fast spin echo (FSE) technique[2], they will find that EPI does indeed have many similarities to it. Both

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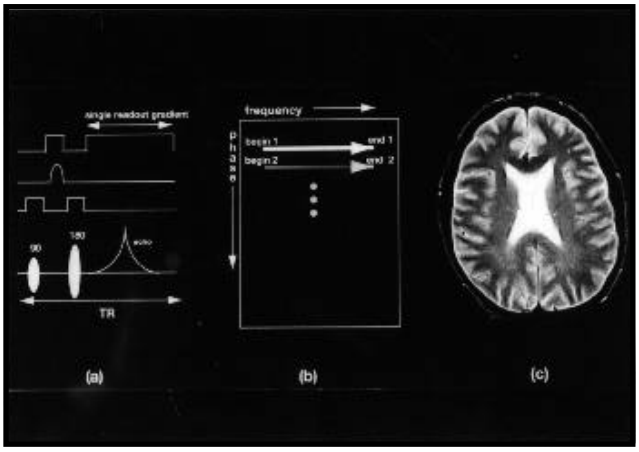

Figure 1 - (a) The basic spin echo pulse sequence (b) The raw image data or the "K-space" (c) The typical image quality that results from the completion of the scan.

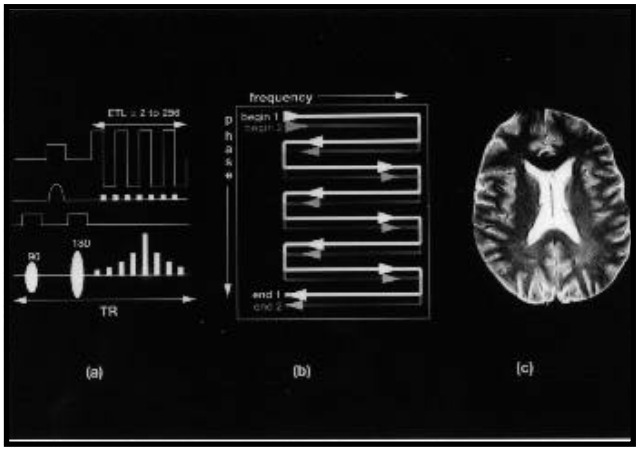

Figure 2 - (a) Illustration of the pulse sequence (b) Illustration of the data collected during a single TR period (c) The resulting image quality.

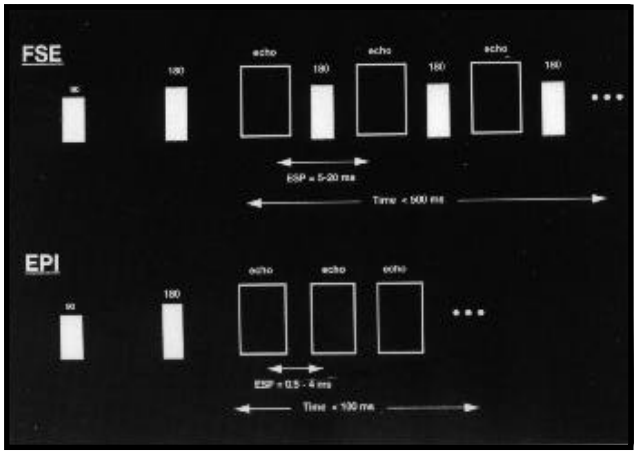

Figure 3 - Illustration of the difference between FSE echo train and the EPI echo train.

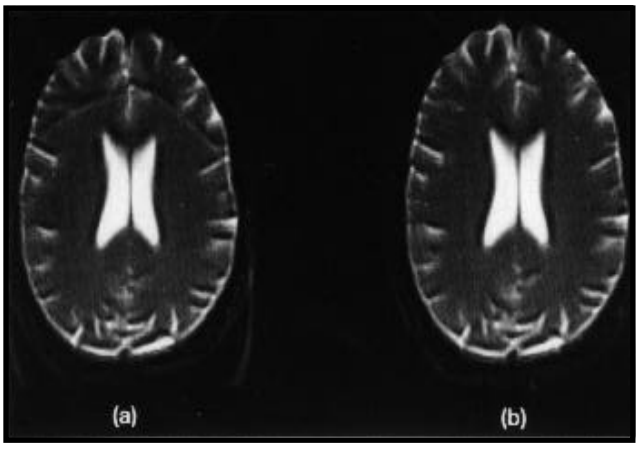

Figure 4 - An image with chemical shift artifact (b) The same image after fat suppression technique.

Figure 5 - Illustration of the larger number of slices when using EPI rather than FSE in the same TR period.

techniques collect multiple lines of image data during each TR interval, both techniques have an associated echo train length (ETL) and this ETL is an approximate measure of the extent to which the acquisition will be faster than a conventional spin echo technique; then what is the difference between them? The difference is illustrated in Figure 3.[1] We see that during the FSE echo train, there is a 180 degree radiofrequency refocusing pulse associated with each echo, which means that each line of image data that is collected is preceded with its own radiofrequency refocusing pulse. The EPI echo train, on the other hand does not contain any rf refocusing pulses. Each line of image data is collected by simply reversing the readout gradient to form another gradient echo. In fact a simple way to describe EPI is to say that its nothing more than FSE with the radiofrequency refocusing pulses removed.

Single-shot or multi-shot EPI ? In EPI instead of using ETL and the number of ETL to describe the FSE protocol, we use the number of "shots". The number of shots is just another term for the number of TR periods that we will use to complete the acquisition. Echo planar imaging protocols that use more than one shot to complete the image acquisition are referred to as multi-shot EPI and those that use only one shot to acquire the image are referred to as single-shot or snap-shot EPI protocol

Unique features (characters) of EPI. The lack of radiofrequency refocusing pulses in EPI is responsible for the unique features of it:

A high sensitivity to off-resonance effects. This is the only down-side or disadvantage of excluding rf refocusing pulses from the EPI echo train. An off-Resonance artifact, as a result of phase error accumulation due to lack of rf refocusing pulses to correct that, will appear in the image.

An example of a common off-resonance artifact is the chemical shift of fat. In order to eliminate this artifact, fat suppression techniques must be used for all types of echo planner imaging (Figure 4).[1]

Capability for T2 or T2*-weighted contrast. This is a positive feature or character of EPI were we can obtain, unlike FSE, both T2 or T2* (Gradient Echo) weighted image contrast.

Increased slice efficiency (more slices/Tr). Another benefit of excluding the rf refocusing pulses from the EPI echo train is that EPI becomes more slice-efficient than FSE. By excluding the rf refocusing pulses, EPI echo train times are generally 3 to 5 times shorter than FSE echo train times. This allows EPI to excite a larger number of slices in the same TR period (Figure 5).[1]

Echo planar imaging appliccations/indications. Rapid T2-weighted brain screening for unco-operative and claustrophobic patients: Here we have two choices, either using a multi-shot EPI sequence and reduce the brain examination time to 1 minute or using single shot (snap-shot) EPI for those cases where even one minute examination time can result in a distorted image due to motion. In these circumstances a snap-shot imaging can virtually "freeze" the bulk motion of the patient.

Breath-hold T2-weighted abdominal imaging. Echo planar imaging, as previously stated, has the advantage of increased slice efficiency. Echo planar imaging protocols using 8 shots can achieve 12 to 16 slice coverage in a single 18 second breath-hold of an abdominal examination. Still we have another faster choice, which is the single or snap shot protocol where the entire liver can be covered in about 5 seconds.[6] This protocol can be performed during a short breath-hold or the scan could proceed during respiration.

Functional imaging.[3-5,7-9] The capacity of EPI to produce T2*-weighted image contrast plays an important role in the application of functional neuroimaging (FMRI). During the performance of simple motor, sensory and visual tasks it has been shown that the venous blood oxygen level increases in the cortical regions associated with respective task. Changes in blood oxygen causes changes in the magnetic susceptibility of the blood. When the magnetic susceptibility of the blood changes, the homogeneity of the magnetic field in the region of the blood vessel changes and this, in turn, changes the local T2*. Increases in the blood oxygen level increase the T2* level and decreases in the blood oxygen level decrease the T2*. When acquiring T2* weighted EPI during the performance of a motor task, the blood oxygen level in the motor cortex will increase causing the T2* to increase. This T2 lengthening will result in a brighter signal intensity in the EPI image.

In conclusion, I have discussed the basic principles and application of EPI. The primary aim of this discussion is to strip away the misconceptions and myths of EPI, placing it in its proper place among the family of MR acquisition techniques. By doing this, people would understand the advantages of EPI as well as its limitaion.

References

1. Schrack T. Echo Planar Imaging, Advanced MR Applications, GE Medical Systems, Milwaukee, Signa Application Guide, Milwaukee 1996; 1-39.
2. Henning J, Nauerth A, Friedburg H. Rare Imaging: A Fast Imaging Method for Clinical MR. Magnetic Resonance in Medicine 1986; 3: 823-833.
3. Ogawa S, Lee T, Nayak A, Glynn P. Oxygenation-Sensitive Contrast in MRI of Rodent Brain at High Magnetic Fields. Magnetic Resonance in Medicine 1990; 14: 68.
4. Ogawa S, Lee T. MRI of Blood Vessels at High Fields: In Vivo and in Vitro Measurements and Imaging Stimulation. Magnetic Resonance in Medicine 1990; 16: 9-18.
5. Turner R, Bihan D, Maonen C, Despres D, Frank J. Echo-planer Time Course MRI of CAT Brain Oxygentation Changes. Magnetic Resonance in Medicine 1991; 22: 159-166.

6. Butts K, Riederer SJ, Ehman RL. The effect of Respiration on the Contrast and Sharpness of Liver Lesions in MRI. Magnetic Resonance in Medicine 1995; 33: 1-7.
7. Rosen BR, Belliveau JW, Vevea JM, Brady TJ. Perfusion Imaging with NMR Contrast Agents. Magnetic Resonance in Medicine 1990; 14: 249.
8. Rosen BR, Bellivean JW, Buchbinder BR, McKinstry RC, Porkka, Kennedy DN et al. Contrast Agents and Cerebral Hemodynamics. Magnetic Resonance in Medicine 1991; 19: 285-292.
9. Turner R, LeBihan D, Majer J, Vavrek R, Hedges LK, Pekar J. Echo-Planar Imaging of Introvoxel Incoherent Motion. Radiology 1990; 177: 407- 414.