the full dynamic range (0-100%) relies on using phase data and accurate fieldmap estimation. However, (i) phase distortions are often present in clinical practice, and/or (ii) phase information may either not be reliable, or, in many cases, simply not available. By comparison, magnitude data is always available and almost always reliable.

Bydder et al., (15) present different signal models with increasing levels of complexity that use only the magnitude data to estimate fat fraction. These models are subject to the known magnitude-related water-fat ambiguity.

Current species separation methods based on the magnitude of multi-echo signals require either (a) using at least two signal models during the fitting; (b) substantially in-phase echo times, or (c) prior knowledge about the subject being imaged (to avoid confusion between true converged values and aliased estimates).

Summary of the invention

According to example embodiments of a first aspect of the invention there is provided a method of analysing the magnitude of Magnetic Resonance Imaging (MRI) data for images acquired at arbitrary echo times for a subject, to determine the relative signal contributions of at least two species to each voxel of the images, the method comprising the steps of: using the magnitude only of the multi-echo MRI data of images from the subject, where the images are acquired at asymmetric echo times; fitting the magnitude of said multi-echo MRI data acquired at asymmetric echo times, to a single signal model to produce a plurality of potential solutions for the relative signal contributions for each of the at least two species from the model, by using a plurality of different starting conditions to generate a particular residual value for each of the plurality of starting conditions, where said residual values are independent of a field map term for the MRI data; and analysing said residual values to calculate the relative signal separation contribution for each species at each voxel of the images.

Preferably, said analysis of said cost function values comprises the step of: comparing the generated cost function values to determine which is the correct solution for said signal separation.

In an example of the invention, the method is applied on acquired MRI data of a phantom model.

In an example of the invention, the method is applied on acquired MRI data of human tissue including tissue from at least one of liver, pancreas, kidney, spleen, heart, muscle or adipose tissue.

In an example of the invention, cost function values in a certain voxel are used to update a likelihood map of the presence of at least one species in the voxel

In accordance with another aspect of the invention there is also provided an image processing system arranged to analyse the magnitude of Magnetic Resonance Imaging (MRI) data for images acquired at arbitrary echo times for a subject, to determine the relative signal contributions of at least two species to each voxel of the images, the image processing system comprising at least one processing device arranged to: use the magnitude only of the multi-echo MRI data of images from the subject, where the images are acquired at asymmetric echo times; fit the magnitude of said multi-echo MRI data acquired at asymmetric echo times, to a single signal model to produce a plurality of potential solutions for the relative signal contributions for each of the at least two species from the model, by using a plurality of different starting conditions to generate a particular residual value for each of the plurality of starting conditions, where said residual values are independent of a field map term for the MRI data; and analyse said residual values to calculate the relative signal separation contribution for each species at each voxel of the images.

In accordance with an aspect of the invention, a non-transitory computer program product is provided. The non-transitory computer program product has executable program code stored therein, the program code operable for analysing the magnitude of MRI data in accordance with any of the methods described above.

The non-transitory computer program product comprises at least one from a group including: a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a Read Only Memory, ROM, a Programmable Read Only Memory, PROM, an Erasable Programmable

Claims

1. A method of analysing the magnitude of Magnetic Resonance Imaging (MRI) data for images acquired at arbitrary echo times for a subject, to determine the relative signal contributions of at least two species to each voxel of the images, the method comprising the steps of:

using the magnitude only of the multi-echo MRI data of images from the subject, where the images are acquired at asymmetric echo times;

fitting the magnitude of said multi-echo MRI data acquired at asymmetric echo times, to a single signal model to produce a plurality of potential solutions for the relative signal contributions for each of the at least two species from the model, by using a plurality of different starting conditions to generate a particular residual value for each of the plurality of starting conditions, where said residual values are independent of a field map term for the MRI data; and

analysing said residual values to calculate the relative signal separation contribution for each species at each voxel of the images.

2. A method according to claim 1 wherein said analysis of said residual values comprises the step of:

comparing the generated residual values to determine which is the correct solution for said signal separation.

3. A method according to claim 2 wherein the lowest residual value of said species is determined to be the correct solution for said signal.

4. A method according to any preceding claim wherein said magnitude of said multi-echo MRI data is fitted to said single signal model using least squares estimation.

5. A method according to claim 4 wherein said least squares estimation is a regularised least squares estimation.

6. A method according to any preceding claim in which the single signal model includes a spectral model of one of the at least two species with more than one spectral component.

7. A method according to any preceding claim wherein said single signal model includes at least one of the relaxation time constants (T_1, T_2, T_2*) to correct for signal decay.

8. A method according to claim 7 wherein the starting condition values of the relaxation time constants are in the physically observable range.

9. A method according to claim 8 wherein the starting condition values of the relaxation time constants are between 1 to 100ms.

10. A method according to claim 9 wherein the starting condition values of the relaxation time constants are between 20 to 30ms.

11. A method according to any preceding claim further comprising the step of using said species signal contribution to generate separate images showing the results for each species.

12. A method according to claim 11 in which one or more of the resulting images are post-processed.

13. The method according to any preceding claim wherein the separated species contributions are used to estimate a field heterogeneity ('fieldmap') term.

14. The method according of any of claims 7 to 9 wherein the estimated relaxation constants are used to estimate a field heterogeneity ('fieldmap') term.

15. The method according to any preceding claim wherein the at least two species include at least two of water, fat, hyperpolarized contrast elements or metabolites of such elements, markers for the presence of cancerous cells.

16. The method of any preceding claim in which fitted values in a certain voxel are used to update a likelihood map of the presence of at least one species in the voxel.

17. An image processing system arranged to analyse the magnitude of Magnetic Resonance Imaging (MRI) data for images acquired at arbitrary echo times for a subject, to determine the relative signal contributions of at least two species to each voxel of the images, the image processing system comprising at least one processing device arranged to:

use the magnitude only of the multi-echo MRI data of images from the subject, where the images are acquired at asymmetric echo times;

fit the magnitude of said multi-echo MRI data acquired at asymmetric echo times, to a single signal model to produce a plurality of potential solutions for the relative signal contributions for each of the at least two species from the model, by using a plurality of different starting conditions to generate a particular residual value for each of the plurality of starting conditions, where said residual values are independent of a field map term for the MRI data; and

analyse said residual values to calculate the relative signal separation contribution for each species at each voxel of the images.

18. A non-transitory computer program product having executable program code stored therein, the program code operable for analysing the magnitude of magnetic resonance imaging (MRI) data in accordance with the method of any of claims 1-16.

19. The non-transitory computer program product of Claim 19, wherein the non-transitory computer program product comprises at least one from a group including: a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a Read Only Memory, ROM, a Programmable Read Only Memory, PROM, an Erasable Programmable Read Only Memory, EPROM, an Electrically Erasable Programmable Read Only Memory, EEPROM, and a Flash memory.