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(54) **SYSTEM AND SOFTWARE MODULE OF IMPROVED MULTIPLE-PHASE DYNAMIC CONTRAST-ENHANCED MAGNETIC RESONANCE IMAGING**

SYSTEM UND SOFTWARE MODUL ZUR VERBESSERTEN MULTIPHASEN-MAGNETRESONANZBILDGEBUNG MIT DYNAMISCHER KONTRASTVERSTÄRKUNG

SYSTÈME ET LOGICIEL D’AMÉLIORATION D’IMAGERIE PAR RÉSONANCE MAGNÉTIQUE À CONTRASTE DYNAMIQUE À PHASES MULTIPLES

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Description

FIELD OF THE INVENTION

[0001] The invention pertains to a method of operating a magnetic resonance imaging system with regard to acquiring multiple-phase dynamic contrast-enhanced magnetic resonance images, and a magnetic resonance imaging system being operated by employing such a method.

BACKGROUND OF THE INVENTION

[0002] In the art of magnetic resonance imaging it is known to employ dynamic contrast-enhanced (DCE) imaging for obtaining physiological information like organ functions and perfusion, for instance by administering a contrast agent to a subject of interest, usually a patient, for tumor assessment. Several types of contrast agents and ways of administering are known in the art. Standard clinical practice is to acquire one magnetic resonance image or more images before administering the contrast agent (pre-contrast), and to acquire images at a specified number of phases after administering the contrast agent (post contrast), for instance at the arterial phase, portal venous phase, delayed venous phase and at equilibrium.

SUMMARY OF THE INVENTION

[0003] Motion artifacts due to respiratory motion of the subject of interest can degrade image quality. Therefore, data are preferably acquired during a series of breath-holds. An acquisition during multiple breath-holds of the subject of interest might result in spatial displacement of the images, because the previous state of motion is not exactly achieved, and also because the patient might be in stress after the contrast agent has been administered.

[0004] Another issue that may arise during the acquisition of the magnetic resonance images is insufficient breath-hold capability of the subject of interest. This especially occurs during the arterial phase, which is crucial, for instance, for a differentiation of lesions.

[0005] Motion of the subject of interest occurring between consecutively acquired magnetic resonance images and a limited reproducibility of a required breath-hold position may thus result in degraded support for a diagnostic assessment. A MRI system including using the the distribution of fat for retrospective motion correction during reconstruction is known from EP2626718 A1.

[0006] It is therefore desirable to reduce the above-mentioned artifacts, to obtain consistent magnetic resonance image data, to improve time resolution of the acquired magnetic resonance images, in particular for post-contrast phases.

[0007] It is therefore an object of the invention to provide a method of operating a magnetic resonance imaging system with regard to acquiring multiple-phase dynamic contrast-enhanced magnetic resonance images with at least one of improved time resolution, improved independency of the ability of the subject of interest to hold breath and reduced effort and/or improved accuracy for magnetic resonance image reconstruction.

[0008] In one aspect of the present invention, the object is achieved by configured for acquiring magnetic resonance images of at least a portion of a subject of interest (20), comprising:

- an examination space (16) provided to position at least the portion of the subject of interest (20) within;
- a main magnet (14) configured for generating a static magnetic field Bo in the examination space (16);
- a magnetic gradient coil system (22) configured for generating gradient magnetic fields superimposed to the static magnetic field Bo;
- at least one radio frequency antenna device (36) that is configured for applying a radio frequency excitation field B_1 to nuclei of or within the portion of the subject of interest (20) for magnetic resonance excitation;
- at least one radio frequency antenna device (38) that is configured for receiving magnetic resonance signals from the nuclei of or within the portion of the subject of interest (20) that have been excited by applying the radio frequency excitation field B_1;
- a control unit (26) configured for controlling functions of the magnetic resonance imaging system (10);
- an image processing unit (32) configured for processing magnetic resonance signals to determine magnetic resonance images of at least the portion of the subject of interest (20) from the received magnetic resonance signals;

wherein the control unit (26) is configured to carry a method of
acquiring multiple-phase dynamic contrast-enhanced magnetic resonance images, wherein one magnetic resonance image or more images are acquired before administering the contrast agent, and wherein to multiple images are acquired at a specified number of phases after administering the contrast agent ,the method comprising steps of

- acquiring (48) at least a first set of magnetic resonance image data (x_{pre}) prior to administering a contrast agent to the subject of interest (20),
- by employing a water/fat magnetic resonance signal separation technique, determining (52) a first image of a spatial distribution of fat (I_{pre}) of at least the portion of the subject of interest (20) from the first set of magnetic resonance image data (x_{pre}),
- acquiring (50) a plurality of sets of magnetic resonance image data (xi) of at least the portion of the subject of interest (20) after administering the contrast agent to the subject of interest (20),
- by employing a water/fat magnetic resonance signal separation technique, determining (54) at least a second image of the spatial distribution of fat (I_2^{ph}) of at least the portion of the subject of interest (20) from the second set of magnetic resonance image data (x_2),
- applying (56) an image registration method to at least the second image of the spatial distribution of fat (I_2^{ph}) with reference to the first image of the spatial distribution of fat (I_{pre}) for correcting a potential motion of the subject of interest (20) having occurred in the time between acquiring the first set of magnetic resonance image data (x_{pre}) and acquiring at least the second set of magnetic resonance image data (x_2)
- using (60) the determined first image of the spatial distribution of fat (I_{pre}) as prior knowledge for image reconstruction of each set of magnetic resonance image data of each set of magnetic resonance image data of the plurality of sets of magnetic resonance image data (xi) acquired after administering the contrast agent.

[0009] The term "dynamic magnetic resonance imaging", as used in this application, shall be understood particularly as acquiring a magnetic resonance signal with two or three spatial coordinates and time as an additional dimension. In an appropriate transform domain, dynamic magnetic resonance images may have a sparse representation.

[0010] The phrase "water/fat magnetic resonance signal separation technique", as used in this application, shall be understood particularly to encompass methods known in the art of clinical magnetic resonance imaging for discriminating and separating the fat signal portion and the water signal portion in acquired magnetic resonance images.

[0011] The phrase "image registration", as used in this application, shall be understood particularly as a technique of transforming two different sets of image data into one coordinate system. Image registration techniques are commonly known in medical imaging and are commercially available (e.g. MATLAB® module by MathWorks®). The registration transformation is usually determined by optimizing a similarity measure calculated from the different sets of image data. In particular, the phrase "image registration method" shall encompass intensity-based and/or feature-based methods, rigid and/or non-rigid image registration as well as local correlation methods and/or registration techniques based on mutual information. Other image registration techniques that appear suitable to the person skilled in the art may as well be applied.

[0012] The invention is based on the concept that the spatial distribution of fat as determined from the first set of magnetic resonance image data and the spatial distribution of fat as determined from at least the second set of magnetic resonance image data are congruent and can be brought to alignment with high precision by applying an image registration method, as the magnetic resonance signal corresponding to the fat in the portion of the subject of interest is unaffected by the administering of the contrast agent.

[0013] An advantage of the invention lies in that any motion of the subject of interest occurring between a point in time of acquiring the first set of magnetic resonance image data and a point in time of acquiring at least the second set of magnetic resonance image data can be precisely corrected for despite the fact that the magnetic resonance image has changed because of the administering of the contrast agent.

[0014] Preferably, the sets of magnetic resonance image data are acquired during breath-hold periods in the respiration of the subject of interest. In principle, however, they may also be acquired while the subject of interest is breathing in a regular breathing pattern.

[0015] The method further comprises a step of using the determined first image of the unaltered spatial distribution of fat as prior knowledge for image reconstruction of each set of magnetic resonance image data acquired after administering the contrast agent.

[0016] By making use of the a priori-knowledge that the magnetic resonance signals received from the fat is common to the magnetic resonance data acquired in the different phases, and is not very much affected by the administering of the contrast agent to the subject of interest, a portion of the effort for image reconstruction can be saved by using the data from the determined first image of the spatial distribution of fat as prior knowledge.

[0017] The method comprises steps of

- acquiring a plurality of sets of magnetic resonance image data after administering the contrast agent, and
- using the determined first image of the spatial distribution of fat as prior knowledge for image reconstruction of each set of magnetic resonance image data of the plurality of sets of magnetic resonance image data acquired after administering the contrast agent.

[0018] In this way, a substantial amount of effort for image reconstruction can be saved and the image reconstruction can be expedited.

[0019] In yet another embodiment of the method, the water/fat magnetic resonance signal separation technique is based on the difference in the Larmor frequencies of excited nuclei due to chemical shift. In this particular case, the chemical shift is the difference of the resonance frequencies of 3.5 ppm of protons bound in water versus protons bound in fat. Preferably, the water/fat magnetic resonance signal separation technique is based on the Dixon method, which is known in the art and is first described in the article by Dixon, W. T., "Simple Proton Spectroscopic Imaging", Radiology 153:189 (1984). Some embodiments of the Dixon method require acquiring more than one set of magnetic resonance image data, for instance an "in-phase" image set and an "opposed-phased" image set (the terms "in-phase" and "oppose-phased" describing the relation between the spin phases of protons bound in water and protons bound in fat), from which separate fat and water images can be calculated. It shall be understood that the image data required for one water/fat magnetic resonance signal separation approach are considered as acquiring one set of magnetic resonance image data. In this way, images of the spatial distribution of fat of at least the portion of the subject of interest can readily be obtained.

[0020] In another preferred embodiment, the method further comprises steps of

- obtaining, from determining the first image of the spatial distribution of fat of at least the portion of the subject of interest from the first set of magnetic resonance image data, a spatial distribution of a local static magnetic field strength Bo,
- reconstructing magnetic resonance images from any of the sets of magnetic resonance image data acquired after administrating the contrast agent to the subject of interest by using the obtained spatial distribution of the local static magnetic field strength.

[0021] The determined spatial distribution of the local static magnetic field strength can be utilized for correlating spin phase disturbances induced by variations of the static magnetic field strength that comply with the acquired magnetic resonance data. These correlations can advantageously be used for improving and/or expediting the image reconstruction process.

[0022] In yet another embodiment of the method, at least one of the second set of magnetic resonance image data or at least one set of magnetic resonance image data of the plurality of sets of magnetic resonance image data acquired after administering the contrast agent is obtained by employing a compressed sensing method.

[0023] In the art of magnetic resonance imaging, compressed sensing is known as a method of image reconstruction that provides a potentially significant reduction of acquisition time. Examples of compressed sensing magnetic resonance imaging are, for instance, given in the article by M. Lustig et al., "Sparse MRI: The Application of Compressed Sensing for Rapid MR Imaging", Magnetic Resonance in Medicine 58:1182-1195 (2007).

[0024] In this way, an improved temporal resolution for imaging a process of inflowing/out-flowing contrast agent by magnetic resonance methods can be accomplished.

[0025] In another preferred embodiment, the method comprises a step of applying a filter to a set of magnetic resonance image data acquired prior to administering the contrast agent to the subject of interest, wherein the filter is equivalent to a high pass filter in k-space. As the main effect of the contrast agent can be expected at low frequencies in k-space, image reconstruction results for data acquired after administering the contrast agent can be improved with the help of the filtered signal acquired prior to administering the contrast agent.

[0026] The magnetic resonance imaging system is provided that is configured for acquiring magnetic resonance images of at least a portion of a subject of interest.

[0027] Further, the magnetic resonance imaging system comprises

- an examination space provided to position at least the portion of the subject of interest within,
- a main magnet configured for generating a static magnetic field Bo in the examination space,
- a magnetic gradient coil system configured for generating gradient magnetic fields superimposed to the static magnetic field Bo,
- at least one radio frequency antenna device that is provided for applying a radio frequency excitation field B_1 to nuclei of or within the portion of the subject of interest for magnetic resonance excitation,
- at least one radio frequency antenna device that is configured for receiving magnetic resonance signals from the nuclei of or within the portion of the subject of interest that have been excited by applying the radio frequency excitation field B_1,
- a control unit for controlling functions of the magnetic resonance imaging system,
- an image processing unit configured for processing magnetic resonance signals to determine magnetic resonance images of at least the portion of the subject of interest from the received magnetic resonance signals.

[0028] The control unit is configured to carry out steps of an embodiment of the methods disclosed herein or a combination thereof.

[0029] In yet another aspect of the present invention, a software module is provided for carrying out an embodiment of any of the methods disclosed above or a combination thereof, of operating a magnetic resonance imaging system with regard to acquiring multiple-phase dynamic contrast-enhanced magnetic resonance images. The method steps to be conducted are converted into a program code of the software module, wherein the program code is implementable in a memory unit of the magnetic resonance imaging system and is executable by a processor unit of the magnetic resonance imaging system. The processor unit may be the processor unit of the control unit that is customary for controlling functions of a magnetic resonance imaging system. The processor unit may, alternatively or supplementary, be another processor unit that is especially assigned to execute at least some of the method steps.

[0030] The software module can enable a robust and reliable execution of the method and can allow for a fast modification of method steps.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter. Such embodiment does not necessarily represent the full scope of the invention, however, and reference is made therefore to the claims and herein for interpreting the scope of the invention.

[0032] In the drawings:

Fig. 1 is a schematic illustration of a part of an embodiment of a magnetic resonance imaging system in accordance with the invention, and

Fig. 2 shows a flowchart of a method in accordance with the invention of operating the magnetic resonance imaging system pursuant to Fig. 1.

DETAILED DESCRIPTION OF EMBODIMENTS

[0033] Fig. 1 shows a schematic illustration of a part of an embodiment of a magnetic resonance imaging system 10 configured for acquiring magnetic resonance images of at least a portion of a subject of interest 20, usually a patient. The magnetic resonance imaging system 10 comprises a scanning unit 12 having a main magnet 14. The main magnet 14 has a central bore that provides an examination space 16 around a center axis 18 for the subject of interest 20 to be positioned within, and is further provided for generating a static magnetic field Bo at least in the examination space 16. For clarity reasons, a customary table for supporting the subject of interest 20 has been omitted in Fig. 1. The static magnetic field Bo defines an axial direction of the examination space 16, aligned in parallel to the center axis 18. It is appreciated that the invention is also applicable to any other type of magnetic resonance imaging systems providing an examination region within a static magnetic field.

[0034] Further, the magnetic resonance imaging system 10 comprises a magnetic gradient coil system 22 provided for generating gradient magnetic fields superimposed to the static magnetic field Bo. The magnetic gradient coil system 22 is concentrically arranged within the bore of the main magnet 14.

[0035] The magnetic resonance imaging system 10 comprises a control unit 26 configured to control functions of the magnetic resonance imaging system 10. The control unit 26 includes a human interface device 24 including a monitor unit having a touch-sensitive screen.

[0036] Furthermore, the magnetic resonance imaging system 10 includes a radio frequency antenna device 36 designed as a whole-body coil that is provided for applying a radio frequency excitation field B_1 to nuclei of or within the subject of interest 20 for magnetic resonance excitation during radio frequency transmit time periods to excite the nuclei of or within the subject of interest 20 for the purpose of magnetic resonance imaging. To this end, radio frequency power is fed, controlled by the control unit 26, from a radio frequency transmitter 40 to the whole-body coil. The whole-body coil has a center axis and, in the operational state, is arranged concentrically within the bore of the main magnet 14 such that the center axis of the whole-body coil and the center axis 18 of the scanning unit 12 coincide. As is well known in the art, a cylindrical metal radio frequency shield 34 is arranged concentrically between the magnetic gradient coil system 22 and the whole-body coil.

[0037] Moreover, the magnetic resonance imaging system 10 comprises a plurality of radio frequency antenna devices 38 provided for receiving magnetic resonance signals from the nuclei of or within the subject of interest 20 that have been excited by applying the radio frequency excitation field B_1. The radio frequency antenna devices 38 of the plurality of radio frequency antenna devices 38 are designed as an array of local coils that are intended to be positioned proximal to a region of the subject of interest 20 to be imaged, namely the liver. The local coils are configured for receiving magnetic resonance signals from the excited nuclei of or within the portion of the subject of interest 20 to be imaged during radio frequency receiving time periods which are distinct from the radio frequency transmit time periods.

[0038] Furthermore, the magnetic resonance imaging system 10 comprises an image processing unit 32 provided for processing magnetic resonance signals to determine magnetic resonance images of at least the portion of the subject of interest 20 from the received magnetic resonance signals.

[0039] The magnetic resonance imaging system 10 further comprises a respiration monitoring device 42. The respiration monitoring device 42 includes a respiration sensor that, in an operational state, is attached to the thorax of the subject of interest 20 and is held by a belt which is wound around the thorax. It is appreciated by the one skilled in the art that other types of respiration monitoring devices are as well employable. The respiration monitoring device 42 is configured to provide the control unit 26 with an output signal whose level represents a respiration state of the subject of interest 20. To this end, an output line of the respiration monitoring device 42 is connected to the control unit 26. The control unit 26 of the magnetic resonance imaging system 10 is configured for receiving an output signal from the respiration monitoring device 42. The output signal is displayed on the monitor unit of the human interface device 24. In this way, a breathing pattern and, in particular, breath-hold periods can be checked by an operator.

[0040] Magnetic resonance image acquisition during individual breath-holds is performed using a breath-hold adaptive sampling pattern. As an alternative, a related fast sampling scheme could be employed. In the mentioned adaptive sampling pattern, the spatial resolution of the magnetic resonance image is automatically adapted during image acquisition, and is combined with the output signal of the respiration monitoring device 42 in such a way that the acquisition of the magnetic resonance image is terminated at breathing onset. Premature onset of breathing results in an incomplete set of magnetic resonance image data. The adaptive sampling pattern is designed to ensure incoherence at every instance in time, which enables to apply a compressed sensing reconstruction method.

[0041] In the following, an embodiment of a method of operating the magnetic resonance imaging system 10 with regard to acquiring multiple-phase dynamic contrast-enhanced magnetic resonance images during breath-hold periods in the respiration of the subject of interest 20 is described. A principal flow chart of the method is given in Fig. 2. In preparation of operating the magnetic resonance imaging system 10, it shall be understood that all involved units and devices are in an operational state and configured as illustrated in Fig. 1.

[0042] In order to be able to carry out the method as a specific operation of the magnetic resonance imaging system 10, the control unit 26 comprises a software module 44 (Fig. 1). The method steps to be conducted are converted into a program code of the software module 44, wherein the program code is implementable in a memory unit 28 of the control unit 26 and is executable by a processor unit 30 of the control unit 26.

[0043] In a preparatory step 46, via the touch-sensitive screen of the human interface device 24, the operator selects a transversal plane of the portion of the subject of interest 20 to be imaged and the number of phases to be imaged from the portion of the subject of interest 20 before and after administering a contrast agent. In a preceding preparatory calibration measurement, threshold signal levels of the output signal of the respiration monitoring device 42 which correspond to a respiration breath-hold at full inspiration of the subject of interest 20 have been determined. A minimum value of the threshold signal level is stored in the memory unit 28 of the control unit 26.

[0044] In a first step 48 of the method, prior to administering the contrast agent to the subject of interest 20, a first set of magnetic resonance image data x_{pre} is acquired during a breath-hold period in the respiration of the subject of interest 20 at two different echo times.

[0045] From the acquired first set of magnetic resonance image data x_{pre}, a first image of the spatial distribution of fat I_{pre} of at least the portion of the subject of interest 20 is determined in another step 50 from a full image reconstruction, by employing a water/fat magnetic resonance signal separation technique that is based on the Dixon method, wherein magnetic resonance image data are acquired at one echo time or more than one different echo times. In this particular embodiment, the first set of magnetic resonance image data x_{pre} is acquired at two different echo times. The Dixon method, well known in the art, is based on the difference in the Larmor frequencies of excited nuclei, in this embodiment given by protons, due to chemical shift.

[0046] In the next step then, a gadolinium-based contrast agent is administered to the subject of interest 20 as an intravenous bolus injection.

[0047] In another step 52 of the method, after administering the contrast agent to the subject of interest 20, a second set of magnetic resonance image data x_2 of at least the portion of the subject of interest 20 is acquired in the arterial phase and during another breath-hold period in the respiration of the subject of interest 20, wherein the second set of magnetic resonance image data x2 is acquired at two (alternatively three) different echo times.

[0048] From the acquired second set of magnetic resonance image data x_2, a second image of the spatial distribution of fat I_2^{ph} of at least the portion of the subject of interest 20 is determined in another step 54 from an iterative image reconstruction using the water/fat magnetic resonance signal separation technique based on the Dixon method, as will be described later on.

[0049] In contrast to the excited protons bound in water, the magnetic resonance image signal stemming from the excited protons bound in the fat tissue of at least a portion of the subject of interest 20 is not affected by the administered contrast agent. Therefore, the image of the spatial distribution of fat I_{pre} obtained from the first set of magnetic resonance image data x_{pre} and the image of the spatial distribution of fat I_2^{ph} obtained from the second set of magnetic resonance image data x_2 are substantially congruent, and a transformation function D_{ph}^{21} exists that minimizes a difference between the first image of the spatial distribution of fat I_{pre} and the second image of the spatial distribution of fat I_2^{ph}. The difference is understood with regard to a suitable, specified mathematical norm.

[0050] The control unit 26 of the magnetic resonance imaging system 10 includes a rigid-type image registration using software residing in the memory unit 28 of the control unit 26 and being executable by the processor unit 30 of the control unit 26. By applying the image registration method to the second image of the spatial distribution of fat I_2^{ph} with reference to the first image of the spatial distribution of fat I_{pre} via the control unit 26 in a next step 56 of the method, the transformation D_{21}^{ph} is determined.

[0051] Then, in a following step 58 of the method, the determined transformation D_{21}^{ph} is applied to the acquired second set of magnetic resonance image data x_2 for correcting a potential motion of the subject of interest 20 having occurred in the time between acquiring the first set of magnetic resonance image data x_{pre} and the second set of magnetic resonance image data x_2.

[0052] In the phase after administering the contrast agent to the subject of interest 20, much narrower time constraints for image reconstruction exist than before administering the contrast agent. In a following step 60 of the method, the determined first image of the spatial distribution of fat I_{pre} is used as prior knowledge for applying image reconstruction to the second set of magnetic resonance image data x_2 which has been acquired after administering the contrast agent.

[0053] The second set of magnetic resonance image data x_2 is thereby obtained by employing parallel imaging or a compressed sensing method for image reconstruction, wherein prior knowledge is given by the existing determined first image of the spatial distribution of fat I_{pre}, which allows for potential higher under-sampling for the magnetic resonance images to be acquired after administering the contrast agent.

[0054] In the same manner as described above, a third set of magnetic resonance image data x_3 is acquired in the portal venous phase and during another breath-hold period in the respiration of the subject of interest 20, wherein magnetic resonance data are acquired at two (alternatively three) different echo times.

[0055] The third set of magnetic resonance image data x_3 is obtained by employing parallel imaging or the method of compressed sensing for image reconstruction, wherein the already existing starting basis, given by the determined first image of the spatial distribution of fat I_{pre}, again allows applying the under-sampling method as described before.

[0056] From the acquired third set of magnetic resonance image data x_3, a third image of the spatial distribution of fat I_3^{ph} of at least the portion of the subject of interest 20 is determined using the water/fat magnetic resonance signal separation technique based on the Dixon method.

[0057] By applying the image registration method to the third image of the spatial distribution of fat I_3^{ph} with reference to the first image of the spatial distribution of fat I_{pre} via the control unit 26, a transformation D_{31}^{ph} is obtained.

[0058] Then, the determined transformation D_{31}^{ph} is applied to the acquired third set of magnetic resonance image data x_3 for correcting a potential motion of the subject of interest 20 having occurred in the time between acquiring the second magnetic resonance image x_2 and the third magnetic resonance image x_3.

[0059] In the above-described manner, also a fourth set and a fifth set of magnetic resonance image data x_4, x_5 of at least the portion of the subject of interest 20 are acquired in the delayed venous phase and in the phase of equilibrium, respectively, during other breath-hold periods in the respiration of the subject of interest 20, wherein the magnetic resonance data are acquired at two (alternatively three) different echo times.

[0060] The fourth and the fifth set of magnetic resonance image data x_4, x_5 are obtained by employing the method of compressed sensing for image reconstruction, with the determined first image of the spatial distribution of fat I_{pre} as starting basis, and by applying the under-sampling method as described above.

[0061] From the acquired fourth and fifth set of magnetic resonance image data x_4, x_5, respectively, a fourth image of the spatial distribution of fat I_4^{ph} and a fifth image of the spatial distribution of fat I_5^{ph} of at least the portion of the subject of interest 20 are determined using the water/fat magnetic resonance signal separation technique based on the Dixon method.

[0062] Transformations D_{41}^{ph} and D_{51}^{ph} are determined by applying the image registration method to the fourth image of the spatial distribution of fat I_4^{ph} and the fifth image of the spatial distribution of fat I_5^{ph}, respectively, with reference to the first image of the spatial distribution of fat I_{pre}, via the control unit.

[0063] In an alternative approach, the second to fifth set of magnetic resonance image data x_2 to x_5 acquired after administering the contrast agent to the subject of interest 20 are commonly obtained by employing a compressed sensing method for image reconstruction, wherein

- the determined first image of the spatial distribution of fat I_{pre} is employed as prior knowledge for reconstruction, and
- an affine motion of the subject of interest 20 is involved for applying the registration method to the second to fifth image of the spatial distribution of fat ph to I_5^{ph}.

[0064] By using the a priori-knowledge about the fat distribution being common to all spatial distributions of fat, and the a priori knowledge that the images of the spatial distribution of fat I_{pre}, I_2^{ph} to I_5^{ph} are associated by a smooth motion of the very same patient, an improved accuracy for image reconstruction can be accomplished and under-sampling artifacts can at least be reduced or potentially prevented.

[0065] Another approach for the image reconstruction from acquired magnetic resonance data can be described as an optimization of the following mathematical expression, to be executed for all numbers of index i, indicating the temporal phase,

$$\min |\Psi x_i|_1 + \lambda_1 |UFx_i - y_i|_2 + \lambda_2 |I_{pre} - D_{i1}^{ph} I_i^{ph}|_2 + \lambda_3 |H\, F(D^{-1\,ph}_{i1}\ x_{pre}) - H(y_i)|_2$$

with the following denotation:

x_{pre} set of magnetic resonance image data acquired before administering contrast agent (first set)
x_i i-th set of magnetic resonance image data acquired after administering contrast agent
y_i k-space data representation of x_i
Ψ sparsifying transformation of compressed sensing method
U under-sampling operator
F Fourier transform operator
H high pass filter adapted to applicable domain, preferably represented by k-space
$| |_p$ mathematical p-norm
λ_1-λ_3 regularization parameters (real numbers)

[0066] The first term enforces sparsity of the acquired image in an adequate transform domain.

[0067] The second term of the expression ensures data consistency at locations in k-space that were acquired.

[0068] The third term of the expression considers the potential motion of the subject of interest 20, occurring between a point in time of acquiring the first set of magnetic resonance image data x_{pre} and a point in time of acquiring the i-th set of magnetic resonance image data x_i.

[0069] The fourth term of the expression reflects similarity of high frequencies in an applicable domain, which is preferably represented by the k-space, from data acquired prior to administering the contrast agent and after administering the contrast agent.

[0070] The regularization parameters λ_1, λ_2, λ_3 can be inputted by the operator via the human interface device 24 as weighting factors. At least one of the regularization parameters λ_1, λ_2, λ_3 can be chosen as zero.

[0071] It is interesting to note that the concept described in the equation above could also be applied to appropriate subsets of the data with the ability to correct also for potential motion inconsistencies within the individual wash-in/wash-out phase data sets.

[0072] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope. The invention is defined by the appended claims.

REFERENCE SYMBOL LIST

10	magnetic resonance imaging system	46	preparatory step
12	scanning unit	48	step of acquiring 1st set of magnetic resonance image data
14	main magnet	50	step of determining 1st image of spatial distribution of fat
16	examination space	52	step of of acquiring 2nd set of magnetic resonance image data
18	center axis	54	step of determining 2nd image of spatial distribution of fat
20	subject of interest	56	step of applying image registration method
22	magnetic gradient coil system	58	step of applying determined transformation
24	human interface device	60	step of using 1st image of spatial distribution of fat for image reconstruction
26	control unit	B_0	static magnetic field

(continued)

28	memory unit
30	processor unit
32	image processing unit
34	metal radio frequency shield
36	radio frequency antenna device (transmitting)
38	plurality of radio frequency antenna devices (receiving)
40	radio frequency transmitter
42	respiration monitoring device
44	software module
B_1	radio frequency excitation field
I_{pre}	1st image of spatial distribution of fat
I_i^{ph}	i-th image of the spatial distribution of fat
x_{pre}	1st set of magnetic resonance image data
x_i	i-th set of magnetic resonance image data

Claims

1. A magnetic resonance imaging system (10) configured for acquiring magnetic resonance images of at least a portion of a subject of interest (20), comprising:

- an examination space (16) provided to position at least the portion of the subject of interest (20) within;
- a main magnet (14) configured for generating a static magnetic field Bo in the examination space (16);
- a magnetic gradient coil system (22) configured for generating gradient magnetic fields superimposed to the static magnetic field Bo;
- at least one radio frequency antenna device (36) that is configured for applying a radio frequency excitation field B_1 to nuclei of or within the portion of the subject of interest (20) for magnetic resonance excitation;
- at least one radio frequency antenna device (38) that is configured for receiving magnetic resonance signals from the nuclei of or within the portion of the subject of interest (20) that have been excited by applying the radio frequency excitation field B_1;
- a control unit (26) configured for controlling functions of the magnetic resonance imaging system (10);
- an image processing unit (32) configured for processing magnetic resonance signals to determine magnetic resonance images of at least the portion of the subject of interest (20) from the received magnetic resonance signals;

wherein the control unit (26) is configured to carry a method of
acquiring multiple-phase dynamic contrast-enhanced magnetic resonance images, wherein one magnetic resonance image or more images are acquired before administering the contrast agent, and wherein multiple images are acquired at a specified number of phases after administering the contrast agent, the method comprising steps of

- acquiring (48) at least a first set of magnetic resonance image data (x_{pre}) prior to administering a contrast agent to the subject of interest (20),
- by employing a water/fat magnetic resonance signal separation technique, determining (52) a first image of a spatial distribution of fat (I_{pre}) of at least the portion of the subject of interest (20) from the first set of magnetic resonance image data (x_{pre}),
- acquiring (50) a plurality of sets of magnetic resonance image data (xi) of at least the portion of the subject of interest (20) after administering the contrast agent to the subject of interest (20),
- by employing a water/fat magnetic resonance signal separation technique, determining (54) at least a second image of the spatial distribution of fat (I_2^{ph}) of at least the portion of the subject of interest (20) from the second set of magnetic resonance image data (x_2),
- applying (56) an image registration method to at least the second image of the spatial distribution of fat (I_2^{ph}) with reference to the first image of the spatial distribution of fat (I_{pre}) for correcting a potential motion of the subject of interest (20) having occurred in the time between acquiring the first set of magnetic resonance image data (x_{pre}) and acquiring at least the second set of magnetic resonance image data (x_2)
- using (60) the determined first image of the spatial distribution of fat (I_{pre}) as prior knowledge for image reconstruction of each set of magnetic resonance image data of the plurality of sets of magnetic resonance image data (xi) acquired after administering the contrast agent.

2. A magnetic resonance imaging system according to any one of the preceding claims, wherein the water/fat magnetic resonance signal separation technique is based on the difference in the Larmor frequencies of excited nuclei due to chemical shift.

3. A magnetic resonance imaging system according to any one of the preceding claims, wherein the control unit is further configured to carry out a method comprising steps of

- obtaining, from determining the first image of the spatial distribution of fat (I_{pre}) of at least the portion of the subject of interest (20) from the first set of magnetic resonance image data (x_{pre}), a spatial distribution of a local static magnetic field strength B_0,
- reconstructing magnetic resonance images from any of the sets of magnetic resonance image data (x_i) after administrating the contrast agent to the subject of interest (20) by using the obtained spatial distribution of the local static magnetic field strength B_0.

4. The magnetic resonance imaging system as claimed in any one of the preceding claims, wherein at least one of the second set of magnetic resonance image data (x_2) or at least one set of magnetic resonance image data of the plurality of sets of magnetic resonance image data (x_i) acquired after administering the contrast agent is obtained by employing a compressed sensing method.

5. A magnetic resonance imaging system according to any one of the preceding claims, wherein the control unit is further configured to carry out a method comprising the step of,

- applying a filter to magnetic resonance image data acquired prior to administering the contrast agent to the subject of interest (20), wherein the filter is equivalent to a high pass filter in k-space.

6. A software module (44) for carrying out the operatiopn of a magnetic resonance imaging system (10) with regard to acquiring multiple-phase dynamic contrast-enhanced magnetic resonance images, wherein one magnetic resonance image or more images are acquired before administering the contrast agent, and wherein multiple images are acquired at a specified number of phases after administering the contrast agent, wherein the method (48-60) to be conducted is converted into a program code of the software module (44), wherein the program code is implementable in a memory unit (28) of the magnetic resonance imaging system (10) and is executable by a processor unit (30) of the magnetic resonance imaging system (10), wherein the method comprises the steps of

- acquiring (48) at least a first set of magnetic resonance image data (x_{pre}) prior to administering a contrast agent to the subject of interest (20),
- by employing a water/fat magnetic resonance signal separation technique, determining (52) a first image of a spatial distribution of fat (I_{pre}) of at least the portion of the subject of interest (20) from the first set of magnetic resonance image data (x_{pre}),
- acquiring (50) a plurality of sets of magnetic resonance image data (xi) of at least the portion of the subject of interest (20) after administering the contrast agent to the subject of interest (20),
- by employing a water/fat magnetic resonance signal separation technique, determining (54) at least a second image of the spatial distribution of fat (I_2^{ph}) of at least the portion of the subject of interest (20) from the second set of magnetic resonance image data (x_2),
- applying (56) an image registration method to at least the second image of the spatial distribution of fat (I_2^{ph}) with reference to the first image of the spatial distribution of fat (I_{pre}) for correcting a potential motion of the subject of interest (20) having occurred in the time between acquiring the first set of magnetic resonance image data (x_{pre}) and acquiring at least the second set of magnetic resonance image data (x_2)
- using (60) the determined first image of the spatial distribution of fat (I_{pre}) as prior knowledge for image reconstruction of each set of magnetic resonance image data of the plurality of sets of magnetic resonance image data (xi) acquired after administering the contrast agent.

7. The software module according to preceding claim 6 wherein the water/fat magnetic resonance signal separation technique is based on the difference in the Larmor frequencies of excited nuclei due to chemical shift.

8. The software module according to any one of the preceding claims 6 or 7, wherein the method further comprises the steps of

- obtaining, from determining the first image of the spatial distribution of fat (I_{pre}) of at least the portion of the

subject of interest (20) from the first set of magnetic resonance image data (x_{pre}), a spatial distribution of a local static magnetic field strength B_0,
- reconstructing magnetic resonance images from any of the sets of magnetic resonance image data (x_i) after administrating the contrast agent to the subject of interest (20) by using the obtained spatial distribution of the local static magnetic field strength B_0.

9. The software module according to any one of the preceding claims 6 - 8, wherein at least one of the second set of magnetic resonance image data (x_2) or at least one set of magnetic resonance image data of the plurality of sets of magnetic resonance image data (x_i) acquired after administering the contrast agent is obtained by employing a compressed sensing method.

10. The software module according to any one of the preceding claims 6 - 9, wherein the method further comprises the step of

- applying a filter to magnetic resonance image data acquired prior to administering the contrast agent to the subject of interest (20), wherein the filter is equivalent to a high pass filter in k-space.

Patentansprüche

1. Magnetresonanz-Bildgebungssystem (10), das konfiguriert ist, um Magnetresonanzbilder mindestens eines Abschnitts eines Subjekts von Interesse (20) zu erfassen, das Folgendes umfasst:

- einen Untersuchungsraum (16), der bereitgestellt ist, um mindestens den Abschnitt des Subjekts von Interesse (20) darin zu positionieren;
- einen Hauptmagnet (14), der konfiguriert ist, um ein statisches Magnetfeld Bo in dem Untersuchungsraum (16) zu erzeugen;
- ein magnetisches Gradientenspulensystem (22), das konfiguriert ist, um Gradientenmagnetfelder zu erzeugen, die dem statischen Magnetfeld Bo überlagert sind;
- mindestens eine Funkfrequenz-Antennenvorrichtung (36), die konfiguriert ist, um ein Funkfrequenz-Erregungsfeld B_1 an Kerne des oder innerhalb des Abschnitts des Subjekts von Interesse (20) zur Magnetresonanzerregung anzulegen;
- mindestens eine Funkfrequenz-Antennenvorrichtung (38), die konfiguriert ist, um Magnetresonanzsignale von den Kernen oder innerhalb des Abschnitts des Subjekts von Interesse (20), die durch Anlegen des Funkfrequenzerregungsfelds B_1 erregt wurden, zu empfangen;
- eine Steuereinheit (26), die konfiguriert ist, um Funktionen des Magnetresonanzbildgebungssystems (10) zu steuern;
- eine Bildverarbeitungseinheit (32), die konfiguriert ist, um Magnetresonanzsignale zu verarbeiten, um Magnetresonanzbilder mindestens des Abschnitts des Subjekts von Interesse (20) aus den empfangenen Magnetresonanzsignalen zu bestimmen;

wobei die Steuereinheit (26) konfiguriert ist, um ein Verfahren zum Erfassen dynamischer Mehrphasen-Magnetresonanzbilder mit verbessertem Kontrast auszuführen, wobei ein Magnetresonanzbild oder mehrere Bilder erfasst werden, bevor das Kontrastmittel verabreicht wird, und wobei mehrere Bilder an einer spezifizierten Anzahl von Phasen erfasst werden, nachdem das Kontrastmittel verabreicht wurde, wobei das Verfahren die folgenden Schritte umfasst:

- Erfassen (48) mindestens eines ersten Satzes von Magnetresonanzbilddaten (x_{pre}) vor dem Verabreichen eines Kontrastmittels an das Subjekt von Interesse (20),
- durch Einsetzen einer Wasser-/Fett-Magnetresonanzsignal-Trennungstechnik Bestimmen (52) eines ersten Bilds einer räumlichen Fettverteilung (I_{pre}) mindestens des Abschnitts des Subjekts von Interesse (20) aus dem ersten Satz von Magnetresonanzbilddaten (x_{pre}),
- Erfassen (50) einer Vielzahl von Sätzen von Magnetresonanzbilddaten (x_i) mindestens des Abschnitts des Subjekts von Interesse (20) nach dem Verabreichen des Kontrastmittels an das Subjekt von Interesse (20),
- durch Einsetzen einer Wasser-/Fett-Magnetresonanzsignal-Trennungstechnik Bestimmen (54) mindestens eines zweiten Bilds der räumlichen Fettverteilung (I_2^{ph}) mindestens des Abschnitts des Subjekts von Interesse (20) aus dem zweiten Satz von Magnetresonanzbilddaten (x_2),
- Anwenden (56) eines Bildregistrierungsverfahrens an mindestens das zweite Bild der räumlichen Fettverteilung

(I_2^{ph}) unter Bezugnahme auf das erste Bild der räumlichen Fettverteilung (I_{pre}) zum Korrigieren einer potentiellen Bewegung des Subjekts von Interesse (20), die in der Zeit zwischen dem Erfassen des ersten Satzes von Magnetresonanzbilddaten (x_{pre}) und dem Erfassen mindestens des zweiten Satzes von Magnetresonanzbilddaten (x_2) aufgetreten ist,
- Verwenden (60) des bestimmten ersten Bilds der räumlichen Fettverteilung (I_{pre}) als Vorabkenntnis für die Bildrekonstruktion jedes Satzes von Magnetresonanzbilddaten der Vielzahl von Sätzen von Magnetresonanzbilddaten (x_i), die nach dem Verabreichen des Kontrastmittels erfasst wird.

2. Magnetresonanzbildgebungssystem nach einem der vorstehenden Ansprüche, wobei die Wasser-/Fett-Magnetresonanzsignal-Trennungstechnik auf dem Unterschied der Larmor-Frequenzen erregter Kerne aufgrund chemischer Verschiebung basiert.

3. Magnetresonanzbildgebungssystem nach einem der vorstehenden Ansprüche, wobei die Steuereinheit ferner konfiguriert ist, um ein Verfahren auszuführen, das folgende Schritte umfasst:

- aus dem Bestimmen des ersten Bilds der räumlichen Fettverteilung (I_{pre}) mindestens des Abschnitts des Subjekts von Interesse (20) aus dem ersten Satz von Magnetresonanzbilddaten (x_{pre}) Erhalten einer räumlichen Verteilung einer lokalen statischen Magnetfeldstärke B_0,
- Rekonstruieren von Magnetresonanzbildern aus den Sätzen von Magnetresonanzbilddaten (x_i) nach dem Verabreichen des Kontrastmittels an das Subjekt von Interesse (20) durch Verwenden der erhaltenen räumlichen Verteilung der lokalen statischen Magnetfeldstärke Bo.

4. Magnetresonanzbildgebungssystem nach einem der vorstehenden Ansprüche, wobei mindestens einer des zweiten Satzes von Magnetresonanzbilddaten (x_2) oder mindestens ein Satz von Magnetresonanzbilddaten der Vielzahl von Sätzen von Magnetresonanzbilddaten (x_i), die nach dem Verabreichen des Kontrastmittels erhalten werden, durch Einsetzen eines komprimierten Abtastverfahrens erhalten wird.

5. Magnetresonanzbildgebungssystem nach einem der vorstehenden Ansprüche, wobei die Steuereinheit ferner konfiguriert ist, um ein Verfahren auszuführen, das den Schritt aufweist des

- Anwendens eines Filters an Magnetresonanzbilddaten, die vor dem Verabreichen des Kontrastmittels an das Subjekt von Interesse (20) erfasst werden, wobei das Filter mit einem k-Space-Hochpassfilter gleichwertig ist.

6. Softwaremodul (44) zum Ausführen des Betriebs eines Magnetresonanzbildgebungssystem (10) in Zusammenhang mit dem Erfassen dynamischer Mehrphasen-Magnetresonanzbilder mit verstärktem Kontrast, wobei ein Magnetresonanzbild oder mehrere Bilder erfasst werden, bevor das Kontrastmittel verabreicht wird, und wobei mehrere Bilder an einer spezifizierten Anzahl von Phasen nach dem Verabreichen des Kontrastmittels erfasst werden, wobei das Verfahren (48-60), das auszuführen ist, in einen Programmcode des Softwaremoduls (44) umgewandelt wird, wobei der Programmcode in einer Speichereinheit (28) des Magnetresonanzbildgebungssystems (10) umsetzbar und von einer Prozessoreinheit (30) des Magnetresonanzbildgebungssystems (10) ausführbar ist, wobei das Verfahren die Schritte umfasst des

- Erfassens (48) mindestens eines Satzes von Magnetresonanzbilddaten (x_{pre}) vor dem Verabreichen eines Kontrastmittels an das Subjekt von Interesse (20),
- durch Einsetzen einer Wasser-/Fett-Magnetresonanzsignal-Trennungstechnik Bestimmen (52) eines ersten Bilds einer räumlichen Fettverteilung (I_{pre}) mindestens des Abschnitts des Subjekts von Interesse (20) aus dem ersten Satz von Magnetresonanzbilddaten (x_{pre}),
- Erfassen (50) einer Vielzahl von Sätzen von Magnetresonanzbilddaten (x_i) mindestens des Abschnitts des Subjekts von Interesse (20) nach dem Verabreichen des Kontrastmittels an das Subjekt von Interesse (20),
- durch Einsetzen einer Wasser-/Fett-Magnetresonanzsignal-Trennungstechnik Bestimmen (54) mindestens eines zweiten Bilds der räumlichen Fettverteilung (I_2^{ph}) mindestens des Abschnitts des Subjekts von Interesse (20) aus dem zweiten Satz von Magnetresonanzbilddaten (x_2),
- Anwenden (56) eines Bildaufzeichnungsverfahrens an mindestens das zweite Bild der räumlichen Fettverteilung (I_2^{ph}) bezüglich des ersten Bilds der räumlichen Fettverteilung (I_{pre}) zum Korrigieren einer potentiellen Bewegung des Subjekts von Interesse (20), die in der Zeit zwischen dem Erfassen des ersten Satzes von Magnetresonanzbilddaten (x_{pre}) und dem Erfassen mindestens des zweiten Satzes von Magnetresonanzbilddaten (x_2) aufgetreten ist,
- Verwenden (60) des bestimmten ersten Bilds der räumlichen Fettverteilung (I_{pre}) als Vorabkenntnis für Bildre-

konstruktion jedes Satzes von Magnetresonanzbilddaten der Vielzahl von Sätzen von Magnetresonanzbilddaten (x_i), die nach dem Verabreichen des Kontrastmittels erfasst wird.

7. Softwaremodul nach dem vorstehenden Anspruch 6, wobei die Wasser-/Fett-Magnetresonanzsignal-Trennungstechnik auf dem Unterschied der Larmor-Frequenzen erregter Kerne aufgrund chemischer Verschiebung basiert.

8. Softwaremodul nach einem der vorstehenden Ansprüche 6 oder 7, wobei das Verfahren ferner die Schritte aufweist des

- Erhaltens aus dem Bestimmen des ersten Bilds der räumlichen Fettverteilung (I_{pre}) mindestens des Abschnitts des Subjekts von Interesse (20) aus dem ersten Satz von Magnetresonanzbilddaten (x_{pre}) einer räumlichen Verteilung einer lokalen statischen Magnetfeldstärke Bo,
- Rekonstruierens von Magnetresonanzbildern aus einem der Sätze von Magnetresonanzbildern (x_i) nach dem Verabreichen des Kontrastmittels an das Subjekt von Interesse (20) durch Verwenden der erhaltenen räumlichen Verteilung der lokalen statischen Magnetfeldstärke B_0.

9. Softwaremodul nach einem der vorstehenden Ansprüche 6 bis 8, wobei mindestens einer des zweiten Satzes von Magnetresonanzbilddaten (x_2) oder mindestens einer des Satzes von Magnetresonanzbilddaten der Vielzahl von Sätzen von Magnetresonanzbilddaten (x_i), die nach dem Verabreichen des Kontrastmittels erfasst wird, durch Einsetzen eines komprimierten Abtastverfahrens erhalten wird.

10. Softwaremodul nach einem der Ansprüche 6 bis 9, wobei das Verfahren ferner die Schritte umfasst des

- Anwendens eines Filters an Magnetresonanzbilddaten, die vor dem Verabreichen des Kontrastmittels an das Subjekt von Interesse (20) erfasst werden, wobei das Filter mit einem k-Space-Hochpassfilter gleichwertig ist.

Revendications

1. Système d'imagerie par résonance magnétique (10) configuré pour acquérir des images par résonance magnétique d'au moins une partie d'un sujet d'intérêt (20), comprenant :

- un espace d'examen (16) prévu pour positionner au moins la partie du sujet d'intérêt (20) à l'intérieur ;
- un aimant principal (14) configuré pour générer un champ magnétique statique Bo dans l'espace d'examen (16) ;
- un système de bobine de gradient magnétique (22) configuré pour générer des champs magnétiques à gradients superposés au champ magnétique statique B_0 ;
- au moins un dispositif d'antenne radiofréquence (36) qui est configuré pour appliquer un champ d'excitation radiofréquence B_1 aux noyaux du sujet d'intérêt (20) ou à l'intérieur de la partie de celui-ci pour excitation par résonance magnétique ;
- au moins un dispositif d'antenne radiofréquence (38) qui est configuré pour recevoir des signaux de résonance magnétique des noyaux du sujet d'intérêt (20) ou à l'intérieur de la partie de celui-ci, qui ont été excités en appliquant le champ d'excitation radiofréquence B_1 ;
- une unité de commande (26) configurée pour commander des fonctions du système d'imagerie par résonance magnétique (10) ;
- une unité de traitement d'image (32) configurée pour traiter des signaux de résonance magnétique pour déterminer des images par résonance magnétique d'au moins la partie du sujet d'intérêt (20) à partir des signaux de résonance magnétique reçus ;

dans lequel l'unité de commande (26) est configurée pour réaliser un procédé d'acquisition d'images dynamiques par résonance magnétique à contraste amélioré à phases multiples, dans lequel une image par résonance magnétique ou plusieurs images sont acquises avant administration de l'agent de contraste, et dans lequel des images multiples sont acquises au niveau d'un nombre spécifié de phases après administration de l'agent de contraste, le procédé comprenant les étapes suivantes :

- acquisition (48) d'au moins un premier ensemble de données d'images par résonance magnétique (x_{pre}) avant administration d'un agent de contraste au sujet d'intérêt (20),
- en utilisant une technique de séparation de signal de résonance magnétique eau/graisse, détermination (52)

d'une première image d'une distribution spatiale de graisse (I_{pre}) d'au moins la partie du sujet d'intérêt (20) à partir du premier ensemble de données d'image par résonance magnétique (X_{pre}),
- acquisition (50) d'une pluralité d'ensembles de données d'image par résonance magnétique (xi) d'au moins la partie du sujet d'intérêt (20) après administration de l'agent de contraste au sujet d'intérêt (20),
- en utilisant une technique de séparation de signal de résonance magnétique eau/graisse, détermination (54) d'au moins une seconde image de la distribution spatiale de graisse (I_2^{ph}) d'au moins la partie du sujet d'intérêt (20) à partir du second ensemble de données d'image par résonance magnétique (x_2),
- application (56) d'un procédé d'enregistrement d'image à au moins la seconde image de la distribution spatiale de graisse (I_2^{ph}) en référence à la première image de la distribution spatiale de graisse (I_{pre}) pour corriger un mouvement potentiel du sujet d'intérêt (20) s'étant produit au moment entre l'acquisition du premier ensemble de données d'image par résonance magnétique (x_{pre}) et l'acquisition d'au moins le second ensemble de données d'image par résonance magnétique (x_2)
- utilisation (60) de la première image déterminée de la distribution spatiale de graisse (I_{pre}) en tant que connaissance préalable pour la reconstruction d'image de chaque ensemble de données d'image par résonance magnétique de la pluralité d'ensembles de données d'image par résonance magnétique (x_i) acquis après administration de l'agent de contraste.

2. Système d'imagerie par résonance magnétique selon l'une quelconque des revendications précédentes, dans lequel la technique de séparation de signal de résonance magnétique eau/graisse est basée sur la différence des fréquences de Larmor des noyaux excités due au déplacement chimique.

3. Système d'imagerie par résonance magnétique selon l'une quelconque des revendications précédentes, dans lequel l'unité de commande est configurée en outre pour réaliser un procédé comprenant les étapes suivantes :

- obtention, à partir de la détermination de la première image de la distribution spatiale de graisse (I_{pre}) d'au moins la partie du sujet d'intérêt (20) à partir du premier ensemble de données d'image par résonance magnétique (x_{pre}), d'une distribution spatiale d'une intensité de champ magnétique statique local B_0,
- reconstruction d'images de résonance magnétique à partir de l'un quelconque des ensembles de données d'image par résonance magnétique (x_i) après administration de l'agent de contraste au sujet d'intérêt (20) en utilisant la distribution spatiale obtenue de l'intensité du champ magnétique statique local B_0.

4. Système d'imagerie par résonance magnétique selon l'une quelconque des revendications précédentes, dans lequel au moins l'un du second ensemble de données d'image par résonance magnétique (x_2) ou au moins un ensemble de données d'image par résonance magnétique de la pluralité d'ensembles de données d'image par résonance magnétique (x_i) acquis après administration de l'agent de contraste est obtenu par utilisation d'un procédé d'acquisition comprimée.

5. Système d'imagerie par résonance magnétique selon l'une quelconque des revendications précédentes, dans lequel l'unité de commande est configurée en outre pour réaliser un procédé comprenant l'étape suivante :

- application d'un filtre aux données d'image par résonance magnétique acquises avant administration de l'agent de contraste au sujet d'intérêt (20), dans lequel le filtre est équivalent à un filtre passe-haut dans l'espace k.

6. Module logiciel (44) pour réaliser les opérations d'un système d'imagerie par résonance magnétique (10) relatives à l'acquisition d'images par résonance magnétique à contraste amélioré dynamique à phases multiples, dans lequel une image par résonance magnétique ou plusieurs images sont acquises avant administration de l'agent de contraste, et dans lequel de multiples images sont acquises au niveau d'un nombre spécifié de phases après administration de l'agent de contraste, dans lequel le procédé (48-60) devant être opéré est converti en un code de programme du module logiciel (44), dans lequel le code de programme peut être mis en œuvre dans une unité de mémoire (28) du système d'imagerie par résonance magnétique (10) et exécuté par une unité de processeur (30) du système d'imagerie par résonance magnétique (10), dans lequel le procédé comprend les étapes suivantes :

- acquisition (48) d'au moins un premier ensemble de données d'images par résonance magnétique (x_{pre}) avant administration d'un agent de contraste au sujet d'intérêt (20),
- en utilisant une technique de séparation de signal de résonance magnétique eau/graisse, détermination (52) d'une première image d'une distribution spatiale de graisse (I_{pre}) d'au moins la partie du sujet d'intérêt (20) à partir du premier ensemble de données d'image par résonance magnétique (x_{pre}),
- acquisition (50) d'une pluralité d'ensembles de données d'image par résonance magnétique (x_i) d'au moins

la partie du sujet d'intérêt (20) après administration de l'agent de contraste au sujet d'intérêt (20),
- en utilisant une technique de séparation de signal de résonance magnétique eau/graisse, détermination (54) d'au moins une seconde image de la distribution spatiale de graisse (I_2^{ph}) d'au moins la partie du sujet d'intérêt (20) à partir du second ensemble de données d'image par résonance magnétique (x_2),
- application (56) d'un procédé d'enregistrement d'image à au moins la seconde image de la distribution spatiale de graisse (I_2^{ph}) en référence à la première image de la distribution spatiale de graisse (I_{pre}) pour corriger un mouvement potentiel du sujet d'intérêt (20) s'étant produit au moment entre l'acquisition du premier ensemble de données d'image par résonance magnétique (x_{pre}) et l'acquisition d'au moins le second ensemble de de données d'image par résonance magnétique (x_2)
- utilisation (60) de la première image déterminée de la distribution spatiale de graisse (I_{pre}) en tant que connaissance préalable pour la reconstruction d'image de chaque ensemble de données d'image par résonance magnétique de la pluralité d'ensembles de données d'image par résonance magnétique (x_i) acquis après administration de l'agent de contraste.

7. Module logiciel selon la revendication 6 précédente, dans lequel la technique de séparation de signal de résonance magnétique eau/graisse est basée sur la différence des fréquences de Larmor des noyaux excités due au déplacement chimique.

8. Module logiciel selon l'une quelconque des revendications 6 ou 7 précédentes, dans lequel le procédé comprend en outre les étapes suivantes :

- obtention, à partir de la détermination de la première image de la distribution spatiale de graisse (I_{pre}) d'au moins la partie du sujet d'intérêt (20) du premier ensemble de données d'image par résonance magnétique (x_{pre}), d'une distribution spatiale d'une intensité de champ magnétique statique local B_0,
- reconstruction d'images de résonance magnétique à partir de l'un quelconque des ensembles de données d'image par résonance magnétique (x_i) après administration de l'agent de contraste au sujet d'intérêt (20) en utilisant la distribution spatiale obtenue de l'intensité du champ magnétique statique local Bo.

9. Module logiciel selon l'une quelconque des revendications 6 à 8 précédentes, dans lequel au moins l'un du second ensemble de données d'image par résonance magnétique (x_2) ou au moins un ensemble de données d'image par résonance magnétique de la pluralité d'ensembles de données d'image par résonance magnétique (x_i) acquis après administration de l'agent de contraste est obtenu par utilisation d'un procédé d'acquisition comprimée.

10. Module logiciel selon l'une quelconque des revendications 6 à 9 précédentes, dans lequel le procédé comprend en outre l'étape suivante :

- application d'un filtre aux données d'image par résonance magnétique acquises avant administration de l'agent de contraste au sujet d'intérêt (20), dans lequel le filtre est équivalent à un filtre passe-haut dans l'espace k.

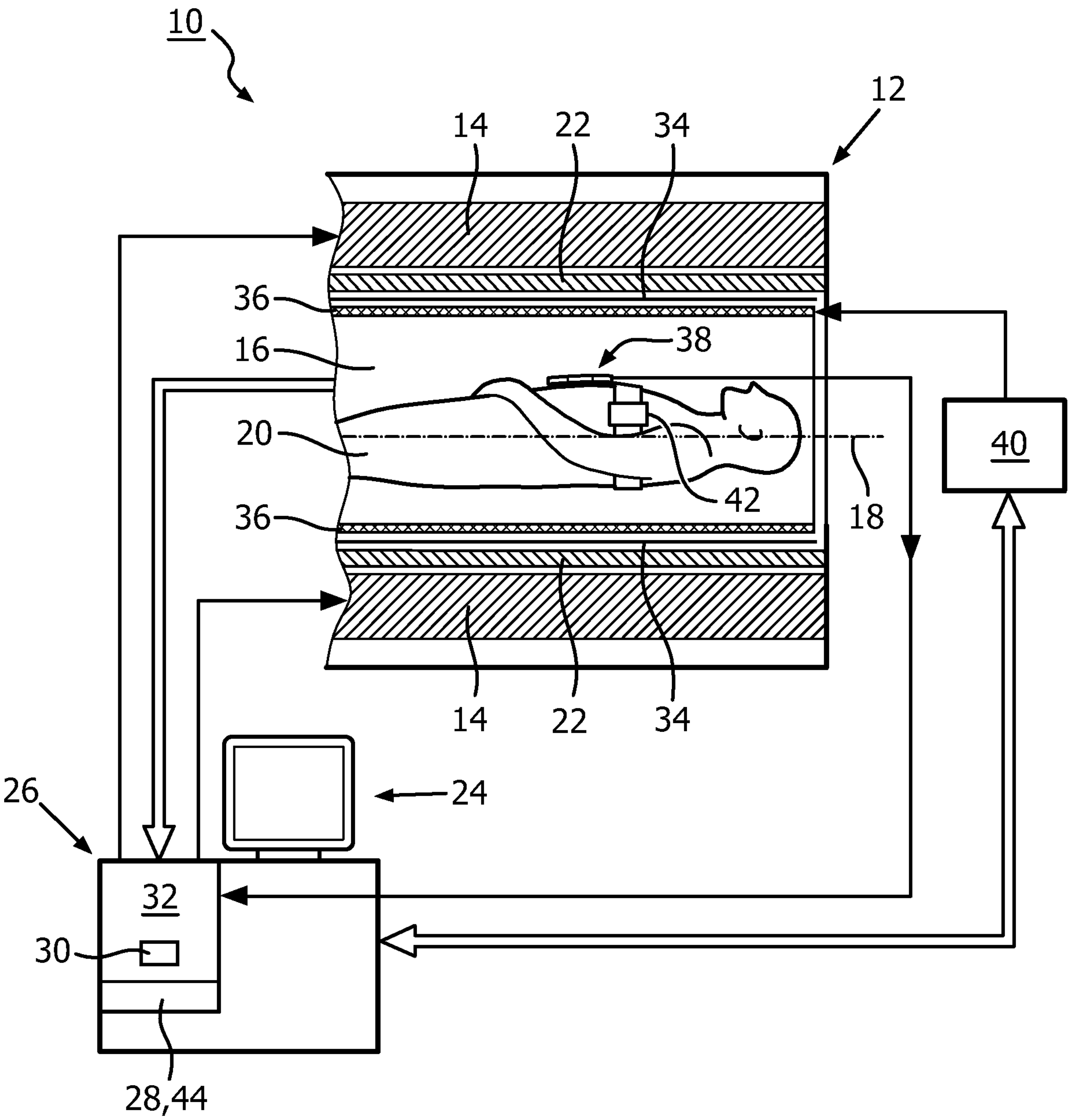

FIG. 1

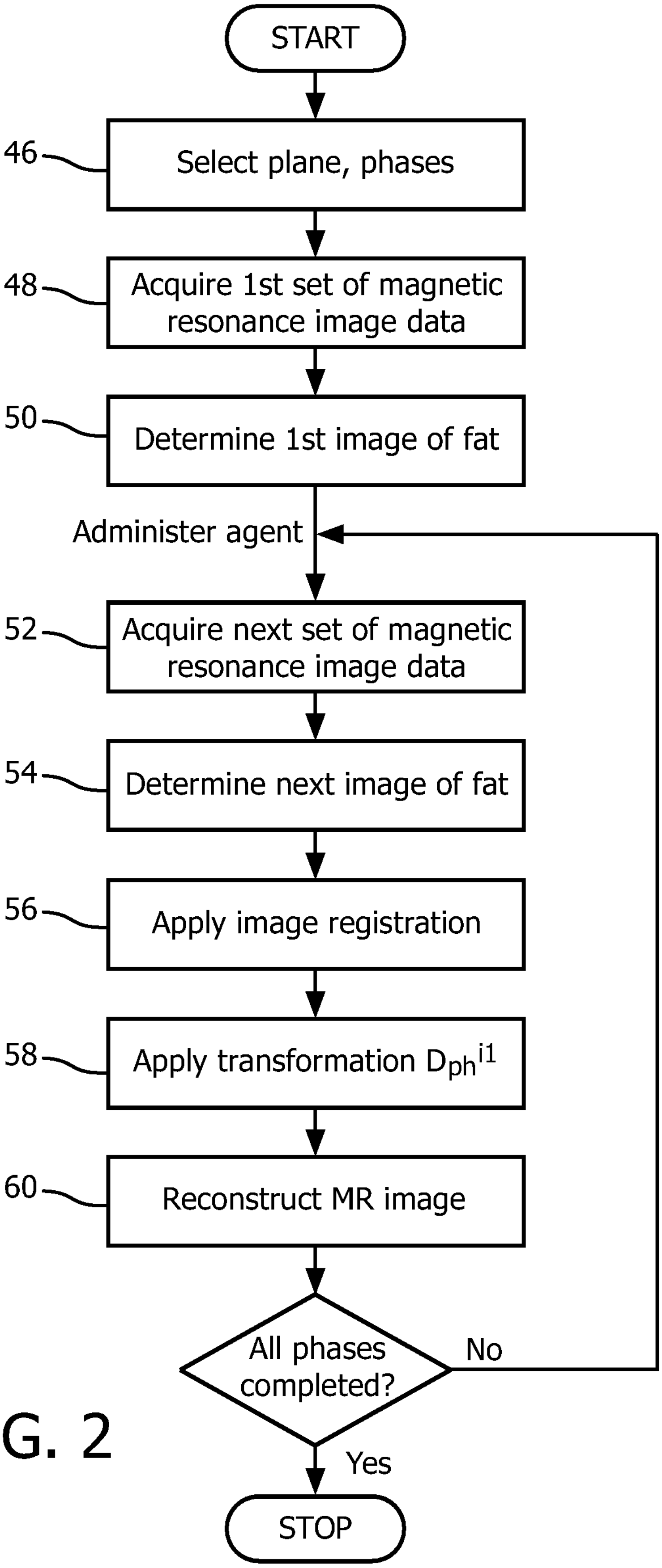
START
46
Select plane, phases
48
Acquire 1st set of magnetic resonance image data
50
Determine 1st image of fat
Administer agent
52
Acquire next set of magnetic resonance image data
54
Determine next image of fat
56
Apply image registration
58
Apply transformation D_{ph}^{i1}
60
Reconstruct MR image
All phases completed?
No
Yes
STOP

FIG. 2

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 2626718 A1 **[0005]**

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- **M. LUSTIG et al.** Sparse MRI: The Application of Compressed Sensing for Rapid MR Imaging. *Magnetic Resonance in Medicine,* 2007, vol. 58, 1182-1195 **[0023]**

patsnap

专利名称(译)	改进的多相动态对比增强磁共振成像方法		
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摘要(译)

一种关于获取多相动态对比度增强的磁共振图像的磁共振成像系统（10）的操作方法，该方法包括以下步骤：在管理之前获取（48）第一组磁共振图像数据（xpre） 通过采用水/脂肪磁共振信号分离技术对目标对象进行对比的造影剂（20），确定（52）目标对象至少一部分的脂肪（Ipre）空间分布的第一图像 （20），通过将造影剂施用于关注对象（20），获取（50）关注对象（20）的至少一部分的至少第二组磁共振图像数据（x2）。 一种水/脂肪磁共振信号分离技术，确定（54）至少一部分感兴趣对象的脂肪（I2ph）空间分布的第二张图像（20），应用（56）图像配准方法 到山高 参考脂肪空间分布的第一幅图像（Ipre）的脂肪空间分布的第二幅图像，用于校正感兴趣对象的潜在运动（20）；磁共振成像系统（10）具有控制单元（26），该控制单元被配置为执行这种方法的步骤（56-64）； 以及用于执行这种方法的软件模块（44），其中将要执行的方法步骤（56-64）转换为可在存储单元（30）中实现并且可由处理器单元（ 磁共振成像系统（10）的32）。