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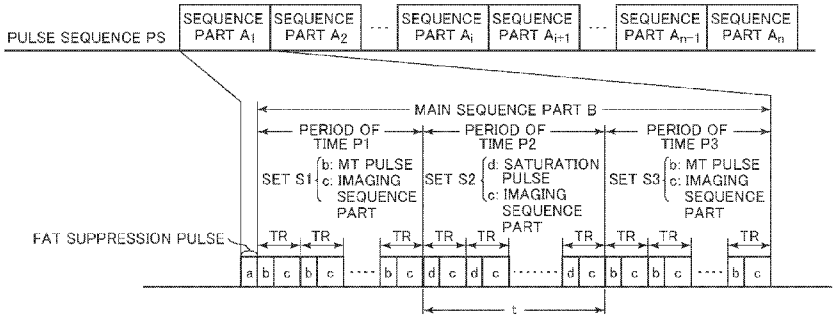
(54) Title: MAGNETIC RESONANCE APPARATUS

FIG. 9



(57) Abstract: An MR apparatus 100 comprises scanning unit for performing a pulse sequence PS including an MT pulse b for lessening signals from the cerebral parenchyma (white matter and gray matter). The scanning unit performs the pulse sequence PS in periods of time P1 and P3 in the pulse sequence PS so that the MT pulse b is applied every repetition time TR, while it performs the pulse sequence PS in a period of time P2 in the pulse sequence PS so that no MT pulse b is applied.

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MAGNETIC RESONANCE APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Japanese patent application number 2014-262969, filed on December 25, 2015, the entirety of which is incorporated herein by reference.

BACKGROUND

[0002] The present invention relates to a magnetic resonance apparatus performing a pulse sequence including an RF pulse for inducing transfer of magnetization.

[0003] Known techniques for rendering blood in the head and neck include a method comprising defining a slab in the head and neck, and acquiring data from the slab using 3D time-of-flight MR angiography (TOF-MRA). In the 3D TOF-MRA method, an inflow effect by blood flowing from a region outside of the slab into the slab enables rendering of the blood flowing within the slab.

[0004] A slab, however, contains not only blood that is an object to be rendered, but also various kinds of background tissue that are not an object to be rendered. Therefore, it is necessary to fully suppress signals from the background tissue. For example, in rendering blood in the head, the cerebral parenchyma (white matter and gray matter) is tissue unnecessary for rendering blood, and thus, signals from the cerebral parenchyma should be suppressed as much as possible. Known methods for sufficiently lessening signals from the cerebral parenchyma include a method using an MT (Magnetization Transfer) pulse for suppressing signals from the cerebral parenchyma (white matter and gray matter) taking advantage of a magnetization transfer effect.

SUMMARY

[0005] The MT pulse is an effective RF pulse for suppressing signals from the cerebral parenchyma and is introduced in many and various references of the 3D TOF-MRA technique using the MT pulse. The MT pulse, however, has a large flip angle

(for example, 900 degrees), which poses a problem that the specific absorption rate SAR in imaging a subject increases. Accordingly, in performing a 3D TOF-MRA pulse sequence using the MT pulse, it is necessary to extend the repetition time TR so that an upper limit value of the specific absorption rate SAR is not exceeded, resulting in a problem that the scan time needed to perform the pulse sequence is lengthened.

[0006] Therefore, there is a need for a technique to minimize lengthening of the scan time even when a pulse sequence using an MT pulse should be performed.

[0007] The present invention, in its one aspect, is a magnetic resonance apparatus comprising:

dividing unit for dividing k-space into a plurality of segments so that each of all or some of said plurality of segments includes a first region lying near to a center of k-space and second and third regions lying farther from the center of k-space than said first region does; and

scanning unit for performing a pulse sequence including a first RF pulse for lessening signals from first background tissue in a region to be imaged by inducing transfer of magnetization, said pulse sequence being for acquiring a plurality of first data elements disposed at a plurality of grid points included in said first region, a plurality of second data elements disposed at a plurality of grid points included in said second region, and a plurality of third data elements disposed at a plurality of grid points included in said third region, said scanning unit performing said pulse sequence so that data are acquired in each of said all or some segments in the order of said plurality of first data elements, said plurality of second data elements, and said plurality of third data elements, wherein:

in a first period of time for acquiring said plurality of first data elements in said first region within a period of time over which said pulse sequence is performed, said scanning unit performs said pulse sequence so that said first RF pulse is applied every first time interval,

in a second period of time for acquiring said plurality of second data elements in said second region within the period of time over which said pulse sequence is performed, said scanning unit performs said pulse sequence so that no said first RF

pulse is applied in a second time interval longer than said first time interval, and

in a third period of time for acquiring said plurality of third data elements in said third region within the period of time over which said pulse sequence is performed, said scanning unit performs said pulse sequence so that said first RF pulse is applied every third time interval shorter than said second time interval.

[0008] Since in acquiring data in the second region, the first RF pulse for lessening signals in the first background tissue by inducing transfer of magnetization is not applied in the second time interval, the number of first RF pulses to be applied while acquiring data in one segment may be reduced. This enables the specific absorption rate (SAR) to be reduced, and therefore, lengthening of the scan time may be minimized.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a schematic diagram of a magnetic resonance apparatus in one embodiment of the present invention;

[0010] FIG. 2 is a diagram showing processing a processor 9 executes;

[0011] FIG. 3 is a diagram showing scans executed in the present embodiment;

[0012] FIG. 4 is a diagram showing a flow chart for performing the scans shown in FIG. 3;

[0013] FIG. 5 is a diagram schematically showing an image LD obtained by a localizer scan LX;

[0014] FIG. 6 is a diagram schematically showing a slab SL;

[0015] FIG. 7 is an explanatory diagram of dividing k-space into a plurality of segments;

[0016] FIG. 8 is a diagram generally explaining a main scan MS;

[0017] FIG. 9 is a diagram explaining a sequence part A_1;

[0018] FIG. 10 is an explanatory diagram of acquiring data by performing the sequence part A_1;

[0019] FIG. 11 is an explanatory diagram of acquiring data by performing a sequence part A_2;

[0020] FIG. 12 is an explanatory diagram of acquiring data by performing a sequence part A_i;

[0021] FIG. 13 is an explanatory diagram of acquiring data by performing a sequence part A_{i+1};

[0022] FIG. 14 is an explanatory diagram of acquiring data by performing a sequence part A_n;

[0023] FIG. 15 is a diagram showing a case in which the MT pulse is applied in a period of time P2;

[0024] FIG. 16 is a diagram explaining a difference in time of application of the MT pulse;

[0025] FIG. 17 is a diagram showing a result of experimentation; and

[0026] FIG. 18 is a picture showing images.

DETAILED DESCRIPTION

[0027] Now embodiments for practicing the invention will be described hereinbelow, although the present invention is not limited thereto.

[0028] FIG. 1 is a schematic diagram of a magnetic resonance apparatus in one embodiment of the present invention.

[0029] A magnetic resonance apparatus (referred to hereinbelow as "MR apparatus") 100 comprises a magnet 2, a table 3, and an RF receive coil (referred to hereinbelow as "receive coil") 4.

[0030] The magnet 2 has therein a bore 21 through which a subject 13 is inserted. The magnet 2 comprises a superconductive coil for generating a static magnetic field, a gradient coil for applying a gradient magnetic field, and an RF coil for applying RF pulses. A permanent magnet may be used in place of the superconductive coil.

[0031] The table 3 has a cradle 3a. The cradle 3a is configured to be movable into the bore 21. The subject 13 is carried into the bore 21 by the cradle 3a.

[0032] The receive coil 4 is attached to the head of the subject 13. The receive coil 4 receives magnetic resonance signals from the subject 13.

[0033] The MR apparatus 100 further comprises a transmitter 5, a gradient power supply 6, a receiver 7, a computer 8, an operating section 11, and a display section 12.

[0034] The transmitter 5 supplies electric current to the RF coil, and the gradient magnetic field power source 6 supplies electric current to the gradient coil. The receiver 7 applies signal processing such as modulation/detection to signals received from the receive coil 4. A combination of the magnet 2, receive coil 4, transmitter 5, gradient power supply 6, and receiver 7 corresponds to the scanning unit.

[0035] The computer 8 controls operation of several sections in the MR apparatus 100 to implement several kinds of operation of the MR apparatus 100, such as an operation of transmitting required information to the display section 12, and an operation of reconstructing images. The computer 8 comprises a processor 9 and a memory 10.

[0036] The memory 10 stores therein programs etc. executed by the processor 9. The memory 10 is an example of recording media readable by the processor 9. The programs executed in the processor 9 may be stored in a non-transitory recording medium such as a hard disk. The programs executed in the processor 9 may be stored in a storage medium, such as, for example, RAM (Random Access Memory), ROM (Read Only Memory), a CD (Compact Disk), a DVD (Digital Versatile Disk), a flexible disk, a magneto-optical disk, or a hard disk. The processor 9 executes processing written in the programs. FIG. 2 shows processing the processor 9

executes. The processor 9 constitutes defining unit 91, dividing unit 92, etc. by loading a program stored in the memory 10.

[0037] The defining unit 91 defines scan conditions and the like, such as a slab SL (see FIG. 6), which will be discussed later. The dividing unit 92 divides k-space into a plurality of segments based on the scan conditions defined by the defining unit 91.

[0038] The processor 9 is an example that constitutes the defining unit 91 and dividing unit 92, and it functions as these unit by executing programs stored in the memory 10.

[0039] The operating section 11 is operated by an operator for inputting several kinds of information to the computer 8. The display section 12 displays several kinds of information.

[0040] The MR apparatus 100 is configured as described above.

[0041] The present embodiment will address a case in which the MR apparatus is used to acquire an image of arterial blood flowing through the head of a subject.

[0042] FIG. 3 is a diagram showing scans executed in the present embodiment.

[0043] In the present embodiment, a localizer scan LX and a main scan MS are performed.

[0044] The localizer scan LX is a scan for acquiring an image used for defining a slab SL (see FIG. 6), which will be discussed later.

[0045] The main scan MS is a 3D scan for imaging arterial blood in the head of the subject using a pulse sequence PS (see FIG. 9), which will be discussed later.

[0046] Now flow in performing the localizer scan LX and main scan MS will be described.

[0047] FIG. 4 is a diagram showing a flow chart for performing the scans shown in FIG. 3.

[0048] At Step ST1, the localizer scan LX is performed. FIG. 5 schematically shows an image LD acquired by the localizer scan LX. After performing the localizer scan LX, the flow goes to Step ST2.

[0049] At Step ST2, the operator specifies scan conditions. The scan conditions include, for example, a slab representing the imaging coverage in the main scan MS, a resolution in a frequency-encoding direction, and a resolution in a phase-encoding direction. The operator inputs information for defining a slab from the operating section. Once the information has been input, the defining unit 91 (see FIG. 2) defines a slab based on the information input from the operating section. FIG. 6 schematically shows a slab SL. The operator also inputs information for specifying other scan conditions (for example, a resolution in the frequency-encoding direction and a resolution in the phase-encoding direction) from the operating section. Once the information has been input, the defining unit 91 defines the other scan conditions based on the information input from the operating section. After the scan conditions have been defined, the flow goes to Step ST3.

[0050] At Step ST3, the dividing unit 92 (see FIG. 2) divides k-space into a plurality of segments SEG_1 to SEG_n (see FIG. 7) based on the scan conditions specified by the operator.

[0051] FIG. 7 is an explanatory diagram of dividing k-space into a plurality of segments.

[0052] The dividing unit 92 divides a k-space (ky, kz) plane into a region for which data acquisition is performed and that for which no data acquisition is performed. FIG. 7 schematically shows only a region R_a for which data acquisition is performed within the k-space (ky, kz) plane. The dividing unit 92 divides the region R_a in k-space into the plurality of segments SEG_1 to SEG_n based on the scan conditions defined at Step ST2. FIG. 7 shows in its lower portion an enlarged view of representative ones of the plurality of segments SEG_1 to SEG_n: segments SEG_1 and SEG_2.

[0053] The segments SEG_1 and SEG_2 include a region r1 lying near to the center of k-space, and a region r2 lying farther from the center than the region r1 does, and a region r3 lying farther from the center than the region r2 does.

[0054] While the two segments SEG_1 and SEG_2 are described as having three regions r1, r2, and r3 in FIG. 7, the other segments have three regions r1, r2, and r3 similarly to the segments SEG_1 and SEG_2.

[0055] After k-space has been divided into the plurality of segments SEG_1 to SEG_n, the flow goes to Step ST4.

[0056] At Step ST4, a main scan MS is performed for acquiring an image of arterial blood from the slab SL. Now the main scan MS will be described.

[0057] FIG. 8 is a diagram generally explaining the main scan MS.

[0058] In the main scan MS, a pulse sequence PS employing the 3D TOF (Time-of-Flight) method is performed for rendering arterial blood in the head of the subject. The pulse sequence PS has sequence parts A_j (j is an integer ranging from j = 1 to n). Next, the sequence parts A_1 to A_n will be described one by one.

[0059] FIG. 9 is a diagram explaining the sequence part A_1.

[0060] The sequence part A_1 has a fat suppression pulse a. The fat suppression pulse a is a pulse for suppressing fat signals in the slab SL. The sequence part A_1 also has a main sequence part B.

[0061] The main sequence part B is divided into three periods of time P1, P2, and P3.

[0062] In the period of time P1, a set S1 of an MT (Magnetization Transfer) pulse b and an imaging sequence part c is performed in a repetition time TR. The MT pulse b is a pulse for suppressing signals from the cerebral parenchyma (white matter and gray matter) using the magnetization transfer effect. The imaging sequence part c is a sequence part for acquiring imaging data disposed at grid points in k-space. In the

period of time P1, the set S1 of the MT pulse b and imaging sequence part c is performed a plurality of number of times.

[0063] In the period of time P2, a set S2 of a saturation pulse d and the imaging sequence part c is performed in the repetition time TR. The saturation pulse d is a pulse for suppressing signals from venous blood. The imaging sequence part c is a sequence part for acquiring imaging data disposed at grid points in k-space. In the period of time P2, the set S2 of the saturation pulse d and imaging sequence part c is performed a plurality of number of times.

[0064] In the period of time P3, a set S3 of the MT pulse b and imaging sequence part c is performed in the repetition time TR, as in the period of time P1. In the period of time P3, the set S3 of the MT pulse b and imaging sequence part c is performed a plurality of number of times.

[0065] Therefore, the MT pulse is applied in the periods of time P1 and P3, while no MT pulse is applied in the period of time P2. Since a time interval t from the start to the end of the period of time P2 is $t = x \cdot TR$ (x is an integer satisfying $x \geq 2$), the period of time P2 is defined such that no MT pulse is applied over $t = x \cdot TR$.

[0066] While the sequence part A_1 is illustrated in FIG. 9, the other sequence parts A_2 to A_n have the fat suppression pulse a and main sequence part B, as in the sequence part A_1.

[0067] In the main scan MS, the pulse sequence PS shown in FIG. 9 is used to acquire data in a region R_a (see FIG. 7) in k-space. A method of acquiring data disposed in the region R_a in k-space will now be described.

[0068] In the main scan MS, the sequence part A_1 in the pulse sequence PS is first performed (see FIG. 10).

[0069] FIG. 10 is an explanatory diagram of acquiring data by performing the sequence part A_1.

[0070] In the period of time P1 in the sequence part A_1, imaging data disposed at grid points in the region r1 in a segment SEG_1 are acquired. In the period of time P2 in the sequence part A_1, imaging data disposed at grid points in the region r2 in the segment SEG_1 are acquired. In the period of time P3 in the sequence part A_1, imaging data disposed at grid points in the region r3 in the segment SEG_1 are acquired.

[0071] Therefore, while imaging data in the region r1 in the segment SEG_1 are being acquired (period of time P1), the MT pulse b is applied every repetition time TR. However, while imaging data in the region r2 in the segment SEG_1 are being acquired (period of time P2), the saturation pulse d is applied in place of the MT pulse b. The saturation pulse d is applied every repetition time TR. Moreover, while imaging data in the region r3 in the segment SEG_1 are being acquired (period of time P3), the MT pulse b is applied every repetition time TR, as in the period of time P1.

[0072] In the period of time P1 in the sequence part A_1, the MT pulse b is applied every repetition time TR. By thus applying the MT pulse b, magnetization transfer for lessening longitudinal magnetization in the cerebral white matter and gray matter may be intensively induced while acquiring imaging data disposed in the region r1 lying near to the center of k-space on the low-frequency side, and therefore, signals from the cerebral white matter and gray matter may be suppressed.

[0073] In the period of time P2 in the sequence part A_1, the saturation pulse d is applied every repetition time TR. By thus applying the saturation pulse d, signals from venous blood may be lessened.

[0074] After performing the sequence part A_1, a next sequence part A_2 is performed (see FIG. 11).

[0075] FIG. 11 is an explanatory diagram of acquiring data by performing the sequence part A_2. In FIG. 11, the period of time P3 in the sequence A_1 is shown, in addition to periods of time P1, P2, and P3 in the sequence part A_2 for convenience of explanation.

[0076] In the period of time P1 in the sequence part A_2, imaging data disposed at grid points in the region r1 in a segment SEG_2 are acquired. In the period of time P2 in the sequence part A_2, imaging data disposed at grid points in the region r2 in the segment SEG_2 are acquired. In the period of time P3 in the sequence part A_2, imaging data disposed at grid points in the region r3 in the segment SEG_2 are acquired.

[0077] Therefore, while imaging data in the region r1 in the segment SEG_2 are being acquired (period of time P1), the MT pulse b is applied every repetition time TR. However, while imaging data in the region r2 in the segment SEG_2 are being acquired (period of time P2), the saturation pulse d is applied in place of the MT pulse b. The saturation pulse d is applied every repetition time TR. Moreover, while imaging data in the region r3 in the segment SEG_2 are being acquired (period of time P3), the MT pulse b is applied every repetition time TR, as in the period of time P1.

[0078] In the period of time P1 in the sequence part A_2, the MT pulse b is applied every repetition time TR. By thus applying the MT pulse b, magnetization transfer for lessening longitudinal magnetization in the cerebral white matter and gray matter may be intensively induced while acquiring imaging data disposed in the region r1 lying near to the center of k-space on the low-frequency side. Moreover, according to the present embodiment, the MT pulse b is applied every repetition time TR in the period of time P3 in the sequence part A_1 immediately before the sequence part A_2. Therefore, before acquiring data in the region r1 in the segment SEG_2 in the sequence part A_2, longitudinal magnetization in the cerebral white matter and gray matter may be lessened to a certain degree by the MT pulse b applied in the period of time P3 in the sequence part A_1. Thus, since according to the present embodiment, longitudinal magnetization in the cerebral white matter and gray matter is lessened to a certain degree in the period of time P3 in the sequence part A_1, and thereafter, the MT pulse b is applied in the period of time P1 in the next sequence part A_2, longitudinal magnetization in the cerebral white matter and gray matter may be brought sufficiently close to the steady state within the period of time P1 in the sequence part A_2. Since longitudinal magnetization in the cerebral white matter and gray matter may be thus

sufficiently lessened within the period of time P1 in the sequence part A_2, signals from the cerebral white matter and gray matter may be fully suppressed.

[0079] In the period of time P2 in the sequence part A_2, the saturation pulse d is applied every repetition time TR. By thus applying the saturation pulse d, signals from venous blood may be lessened.

[0080] Similarly, thereafter, the sequence part is performed.

[0081] FIG. 12 is an explanatory diagram of acquiring data by performing a sequence part A_i.

[0082] In the period of time P1 in the sequence part A_i, imaging data disposed at grid points in the region r1 in a segment SEG_i are acquired. In the period of time P2 in the sequence part A_i, imaging data disposed at grid points in the region r2 in the segment SEG_i are acquired. In the period of time P3 in the sequence part A_i, imaging data disposed at grid points in the region r3 in the segment SEG_i are acquired.

[0083] Therefore, while imaging data in the region r1 in the segment SEG_i are being acquired (period of time P1), the MT pulse b is applied every repetition time TR. However, while imaging data in the region r2 in the segment SEG_i are being acquired (period of time P2), the saturation pulse d is applied in place of the MT pulse b. The saturation pulse d is applied every repetition time TR. Moreover, while imaging data in the region r3 in the segment SEG_i are being acquired (period of time P3), the MT pulse b is applied every repetition time TR, as in the period of time P1.

[0084] After performing the sequence part A_i, a next sequence part A_{i+1} is performed.

[0085] FIG. 13 is an explanatory diagram of acquiring data by performing the sequence part A_{i+1}. In FIG. 13, the period of time P3 in the sequence A_i is shown, in addition to periods of time P1, P2, and P3 in the sequence part A_{i+1} for convenience of explanation.

[0086] In the period of time P1 in the sequence part A_{i+1}, imaging data disposed at grid points in the region r1 in a segment SEG_{i+1} are acquired. In the period of time P2 in the sequence part A_{i+1}, imaging data disposed at grid points in the region r2 in the segment SEG_{i+1} are acquired. In the period of time P3 in the sequence part A_{i+1}, imaging data disposed at grid points in the region r3 in the segment SEG_{i+1} are acquired.

[0087] Therefore, while imaging data in the region r1 in the segment SEG_{i+1} are being acquired (period of time P1), the MT pulse b is applied every repetition time TR. However, while imaging data in the region r2 in the segment SEG_{i+1} are being acquired (period of time P2), the saturation pulse d is applied in place of the MT pulse b. The saturation pulse d is applied every repetition time TR. Moreover, while imaging data in the region r3 in the segment SEG_{i+1} are being acquired (period of time P3), the MT pulse b is applied every repetition time TR, as in the period of time P1.

[0088] In the period of time P1 in the sequence part A_{i+1}, the MT pulse b is applied every repetition time TR. By thus applying the MT pulse b, magnetization transfer for lessening longitudinal magnetization in the cerebral white matter and gray matter may be intensively induced while acquiring imaging data disposed in the region r1 lying near to the center of k-space on the low-frequency side. Moreover, according to the present embodiment, the MT pulse b is applied every repetition time TR in the period of time P3 in the sequence part A_i immediately before the sequence part A_{i+1}. Therefore, before acquiring data in the region r1 in the segment SEG_2 in the sequence part A_{i+1}, longitudinal magnetization in the cerebral white matter and gray matter may be lessened to a certain degree by the MT pulse b applied in the period of time P3 in the sequence part A_i. Thus, since according to the present embodiment, longitudinal magnetization in the cerebral white matter and gray matter is lessened to a certain degree in the period of time P3 in the sequence part A_i, and thereafter, the MT pulse b is applied in the period of time P1 in the next sequence part A_{i+1}, longitudinal magnetization in the cerebral white matter and gray matter may be brought sufficiently close to the steady state within the period of time P1 in the sequence part A_{i+1}. Since longitudinal magnetization in the cerebral white matter and gray matter may be thus

sufficiently lessened within the period of time P1 in the sequence part A_{i+1}, signals from the cerebral white matter and gray matter may be fully suppressed.

[0089] Similarly, thereafter, the sequence part is performed, and a sequence part A_n is finally performed (see FIG. 14).

[0090] FIG. 14 is an explanatory diagram of acquiring data by performing the sequence part A_n.

[0091] In the period of time P1 in the sequence part A_n, imaging data disposed at grid points in the region r1 in a segment SEG_n are acquired. In the period of time P2 in the sequence part A_n, imaging data disposed at grid points in the region r2 in the segment SEG_n are acquired. In the period of time P3 in the sequence part A_n, imaging data disposed at grid points in the region r3 in the segment SEG_n are acquired.

[0092] Therefore, while imaging data in the region r1 in the segment SEG_n are being acquired (period of time P1), the MT pulse b is applied every repetition time TR. However, while imaging data in the region r2 in the segment SEG_n are being acquired (period of time P2), the saturation pulse d is applied in place of the MT pulse b. The saturation pulse d is applied every repetition time TR. Moreover, while imaging data in the region r3 in the segment SEG_n are being acquired (period of time P3), the MT pulse b is applied every repetition time TR, as in the period of time P1.

[0093] In this way, data in all the segments SEG_1 to SEG_n in k-space are acquired. Once the data in the segments SEG_1 to SEG_n in k-space have been acquired, the data in the segments SEG_1 to SEG_n may be Fourier-transformed to obtain an image for the slab SL.

[0094] According to the present embodiment, the MT pulse b is applied every repetition time TR in the periods of time P1 and P3 among the periods of time P1, P2, and P3 in the sequence part A_j (j = 1 to n-1). Therefore, according to the present embodiment, in the meantime from the start of the period of time P3 in the sequence part A_j (j = 1 to n-1) to the end of the period of time P1 in the next sequence part A_{j+1}, the MT pulse b is applied every repetition time TR. Since by thus applying the MT

pulse b, longitudinal magnetization in the cerebral white matter and gray matter is lessened to a certain degree within the period of time P3 in the sequence part A_j, and thereafter, the MT pulse b is applied in the period of time P1 in the next sequence part A_{j+1}, longitudinal magnetization in the cerebral white matter and gray matter may be brought sufficiently close to the steady state within the period of time P1 in the sequence part A_{j+1}. Since longitudinal magnetization in the cerebral white matter and gray matter may be thus sufficiently lessened within the period of time P1 in the sequence part A_{j+1}, signals from the cerebral white matter and gray matter may be fully suppressed.

[0095] Moreover, according to the present embodiment, the MT pulse b may be intensively applied in the meantime from the start of the period of time P3 in the sequence part A_j (j = 1 to n-1) to the end of the period of time P1 in the next sequence part A_{j+1}, whereby longitudinal magnetization in the cerebral white matter and gray matter may be sufficiently lessened without applying the MT pulse b in the period of time P2. Therefore, the total number of MT pulses required in the one sequence part A_j to sufficiently lessen longitudinal magnetization in the white matter and gray matter may be reduced. Thus, the pulse sequence PS according to the present embodiment can reduce the specific absorption rate SAR during imaging of a subject, as compared with ordinary pulse sequences using the MT pulse. Moreover, since the specific absorption rate SAR can be reduced, extension of TR can be minimized. This in turn enables lengthening of the scan time of the pulse sequence PS to be minimized.

[0096] According to the present embodiment, when acquiring data in each segment, data are acquired in the order of the regions r1, r2, and r3. However, the data may be acquired in the order of the regions r1, r3, and r2. However, to fully bring out the fat suppression effect of the fat suppression pulse a, it is preferable to acquire data in an ascending order of the distance from the center of k-space, that is, in the order of the regions r1, r2, and r3.

[0097] Moreover, although no MT pulse b is applied in the period of time P2 in the example provided above, the MT pulse may be applied in the period of time P2 insofar as lengthening of the scan time may be fully suppressed (see FIG. 15).

[0098] FIG. 15 is a diagram showing a case in which the MT pulse is applied in the period of time P2.

[0099] FIG. 15 shows a case in which MT pulses b1 and b2 are applied in the period of time P2. Therefore, three time intervals t_{b1}, t_{b2}, and t_{b3} in which no MT pulse is applied are present in the period of time P2. The time interval t_{b1} represents a time from a time point t1 of the start of the period of time P2 to a time point t2 of the start of application of an MT pulse. The time interval t_{b2} represents a time from a time point t3 of the end of application of the MT pulse b1 to a time point t4 of the start of application of the MT pulse b2. The time interval t_{b3} represents a time from a time point t5 of the end of application of the MT pulse b2 to a time point t6 of the end of the period of time P2. In FIG. 15, the longest one of the three time intervals t_{b1}, t_{b2}, and t_{b3} is assumed to be t_{b1}. The time interval t_{b1} is defined to be longer than the repetition time TR, and is, for example, t_{b1} = 10TR. Thus, in the period of time P2, the time interval t_{b1} in which no MT pulse is applied may be defined to be longer than the repetition time TR for the MT pulse in the periods of time P1 and P3, whereby the number of MT pulses applied in the period of time P2 may be sufficiently reduced. Since the total number of MT pulses required in one sequence part A_j may be thus reduced, an increase of the specific absorption rate SAR in imaging the subject can be reduced. Moreover, since an increase of the specific absorption rate SAR can be reduced, extension of TR may be reduced to as short a time interval as possible. This in turn enables lengthening of the scan time of the pulse sequence PS to be reduced to as short a time interval as possible.

[00100] Next, description will be made of a difference between the time of application of the MT pulse b used in acquiring data in k-space according to the present embodiment, and that of an MT pulse used in acquiring data in k-space according to PTL 2.

[00101] FIG. 16 is a diagram explaining the difference in time of application of the MT pulse.

[00102] FIG. 16(a) shows a graph representing the time at which the MT pulse is applied. The horizontal axis of the graph represents a ky-coordinate, while the vertical axis represents a kz-coordinate. A dot in the graph indicates application of an MT pulse. Referring to FIG. 16(a), it can be seen that the MT pulse is intensively applied when acquiring data in the region r1 in the vicinity of the center of k-space and data in the region r3 away from the center of k-space, and almost no MT pulse is applied when acquiring data in the region r2 between the region r1 and region r3.

[00103] On the other hand, FIG. 16(b) is a diagram showing the time of application of the MT pulse used in acquiring data in k-space according to PTL 2. A dot in the graph in FIG. 16(b) indicates the time at which an MT pulse is applied. Therefore, comparing FIG. 16(a) with (b), it can be seen that the total number of the MT pulses may be reduced by the method according to the present embodiment as compared with the method according to PTL 2.

[00104] Next, to demonstrate that the signal value for background tissue may be suppressed by applying the MT pulse at the time shown in FIG. 16(a), experimentation using an egg white was made. Results of the experimentation will be described hereinbelow.

[00105] FIG. 17 shows a result of the experimentation. In Experiment 1, a sequence that applies the MT pulse at the time shown in FIG. 16(a) was used to acquire data for an egg white, and the MTR (Magnetization Transfer Ratio) was determined based on the acquired data. The MTR refers to an index representing how much the signal value can be suppressed by the MT pulse. Moreover, Experiment 2 was made as comparative example. In Experiment 2, a sequence that applies the MT pulse according to the method in PTL 2 was used to acquire data for an egg white, and the MTR was determined based on the acquired data. It should be noted that the total number of MT pulses used in the sequence in Experiment 1 and that in Experiment 2 are the same.

[00106] In Experiment 1, MTR = 0.2892, while MTR = 0.2436 in Experiment 2. Since the sequence that applies the MT pulse at the time shown in FIG. 16(a) may thus

increase the MTR as compared with the sequence that applies the MT pulse according to the method in PTL 2, the former proves to have a higher effect of background signal suppression.

[00107] Moreover, to demonstrate that the signal value for background tissue may be suppressed by applying the MT pulse at the time shown in FIG. 16(a), a human head was actually imaged. FIG. 18 shows images obtained by the imaging.

[00108] FIG. 18(a) is a picture showing an image IM1 of the head obtained by performing the sequence that applies the MT pulse at the time shown in FIG. 16(a). FIG. 18(b) is a picture showing an image IM2 of the head obtained by performing the sequence that applies the MT pulse at the time shown in FIG. 16(b).

[00109] The average value of signals in an ROI of the image IM1 in FIG. 18(a) is 402, while that in an ROI of the image IM2 in FIG. 18(b) is 439. Therefore, comparing the two images with each other, the image IM1 has signals from the parenchyma lower than the image IM2 has, which proves that signals from background tissue are successfully suppressed.

[00110] The present embodiment addresses a case in which an image of blood flow in the head of a subject is acquired. However, the present invention is not limited to the case in which an image of blood flow is acquired, and it may be applied to imaging using an MT pulse.

CLAIMS

What is Claimed Is:

1. A magnetic resonance apparatus comprising:

dividing unit configured to divide k-space into a plurality of segments so that each of all or some of said plurality of segments includes a first region lying near to a center of k-space and second and third regions lying farther from the center of k-space than said first region does; and

scanning unit configured to perform a pulse sequence including a first RF pulse for lessening signals from first background tissue in a region to be imaged by inducing transfer of magnetization, said pulse sequence being for acquiring a plurality of first data elements disposed at a plurality of grid points included in said first region, a plurality of second data elements disposed at a plurality of grid points included in said second region, and a plurality of third data elements disposed at a plurality of grid points included in said third region, said scanning unit performing said pulse sequence so that data are acquired in each of said all or some segments in the order of said plurality of first data elements, said plurality of second data elements, and said plurality of third data elements, wherein:

in a first period of time for acquiring said plurality of first data elements in said first region within a period of time over which said pulse sequence is performed, said scanning unit performs said pulse sequence so that said first RF pulse is applied every first time interval,

in a second period of time for acquiring said plurality of second data elements in said second region within the period of time over which said pulse sequence is performed, said scanning unit performs said pulse sequence so that no said first RF pulse is applied in a second time interval longer than said first time interval, and

in a third period of time for acquiring said plurality of third data elements in said third region within the period of time over which said pulse sequence is performed, said scanning unit performs said pulse sequence so that said first RF pulse is applied every third time interval shorter than said second time interval.

2. The magnetic resonance apparatus as recited in claim 1, wherein: said pulse sequence has a plurality of sequence parts for acquiring data disposed in said plurality of segments.

3. The magnetic resonance apparatus as recited in claim 2, wherein: each of said plurality of sequence parts has said first, second, and third periods of time.

4. The magnetic resonance apparatus as recited in claim 3, wherein:

said scanning unit performs said first RF pulse and a first imaging sequence part for acquiring said first data disposed in said first region in said first period of time.

5. The magnetic resonance apparatus as recited in claim 4, wherein:

said scanning unit repetitively performs a set including said first RF pulse and said first imaging sequence part in said first period of time.

6. The magnetic resonance apparatus as recited in any one of claims 1 through 5, wherein: said pulse sequence is a pulse sequence for rendering blood, and said first background tissue is cerebral white matter and gray matter.

7. The magnetic resonance apparatus as recited in any one of claims 3 through 6, wherein:

said scanning unit performs a second RF pulse for lessening signals from second background tissue in said region to be imaged and a second imaging sequence part for acquiring said second data disposed in said second region in said second period of time.

8. The magnetic resonance apparatus as recited in claim 7, wherein: said pulse sequence is a pulse sequence for rendering arterial blood, and said second background tissue is venous blood.

9. The magnetic resonance apparatus as recited in claim 7 or 8, wherein: said scanning unit repetitively performs a set including said second RF pulse and said

second imaging sequence part in said second period of time.

10. The magnetic resonance apparatus as recited in any one of claims 3 through 9, wherein:

said scanning unit performs said first RF pulse and a third imaging sequence part for acquiring said third data disposed in said third region in said third period of time.

11. The magnetic resonance apparatus as recited in claim 10, wherein:

said scanning unit repetitively performs a set including said first RF pulse and said third imaging sequence part in said third period of time.

12. The magnetic resonance apparatus as recited in any one of claims 3 through 11, wherein:

said scanning unit applies no said first RF pulse in said second period of time.

13. The magnetic resonance apparatus as recited in any one of claims 1 through 12, wherein: each of said plurality of sequence parts has a fat suppression pulse for suppressing fat before said first period of time.

14. The magnetic resonance apparatus as recited in claim 13, wherein: said second region lies nearer to said first region than said third region does.

15. The magnetic resonance apparatus as recited in any one of claims 1 through 14, wherein: said third time interval is equal to said first time interval.

FIG. 1

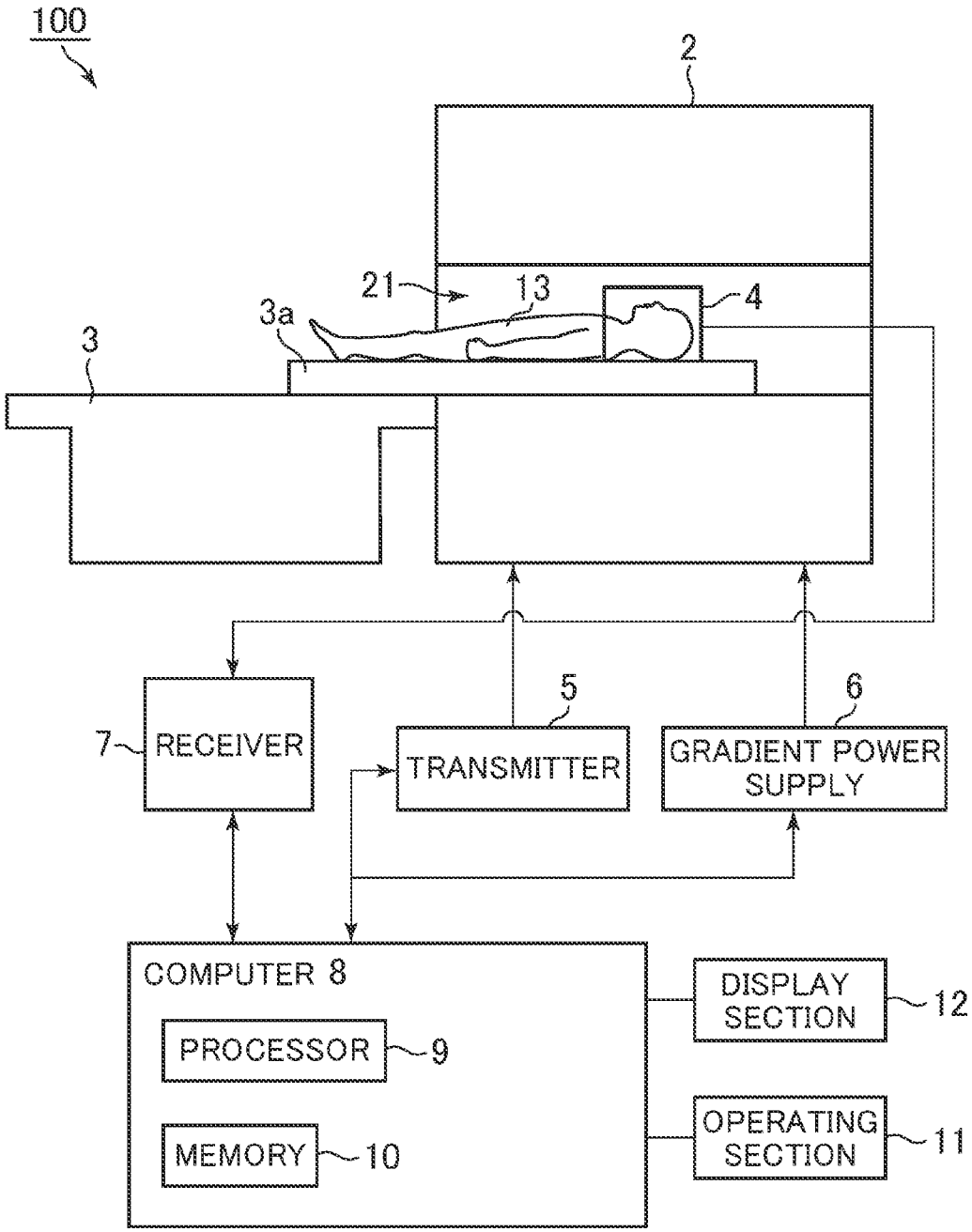

100
2
21
13
4
3a
3
5
6
7
RECEIVER
TRANSMITTER
GRADIENT POWER SUPPLY
COMPUTER 8
PROCESSOR
9
MEMORY
10
DISPLAY SECTION
12
OPERATING SECTION
11

FIG. 2

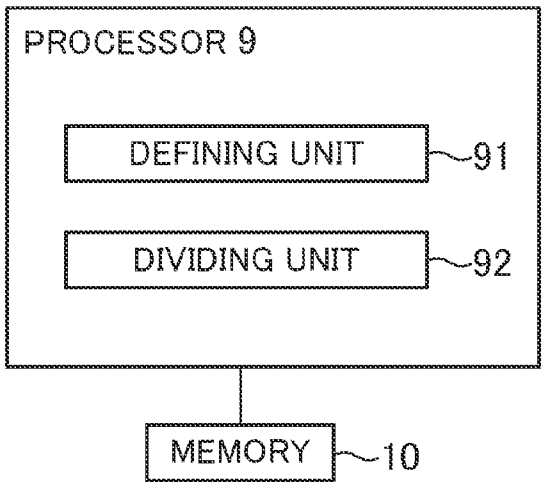

PROCESSOR 9
DEFINING UNIT
91
DIVIDING UNIT
92
MEMORY
10

FIG. 3


LOCALIZER SCAN LX
MAIN SCAN MS

FIG. 4

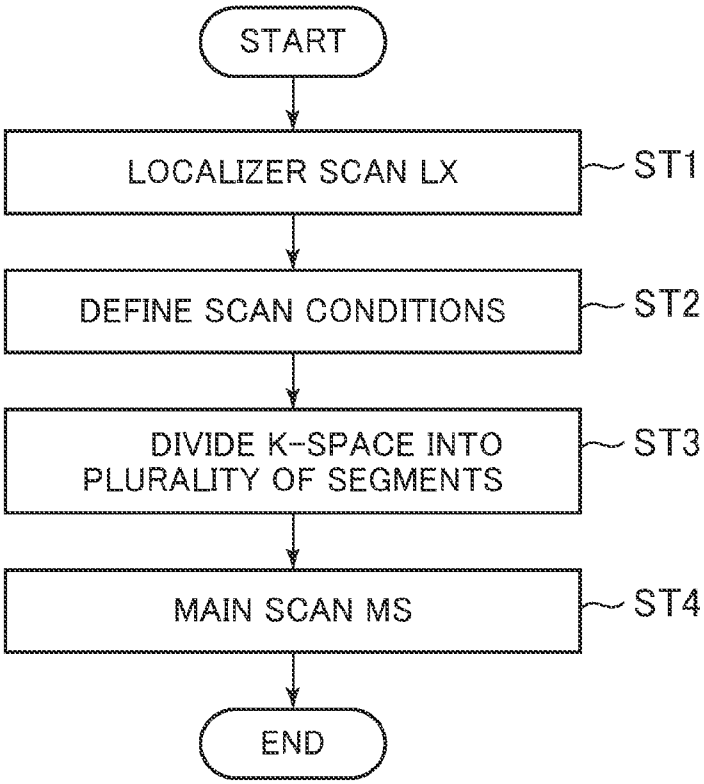

START
LOCALIZER SCAN LX
ST1
DEFINE SCAN CONDITIONS
ST2
DIVIDE K-SPACE INTO PLURALITY OF SEGMENTS
ST3
MAIN SCAN MS
ST4
END

FIG. 5

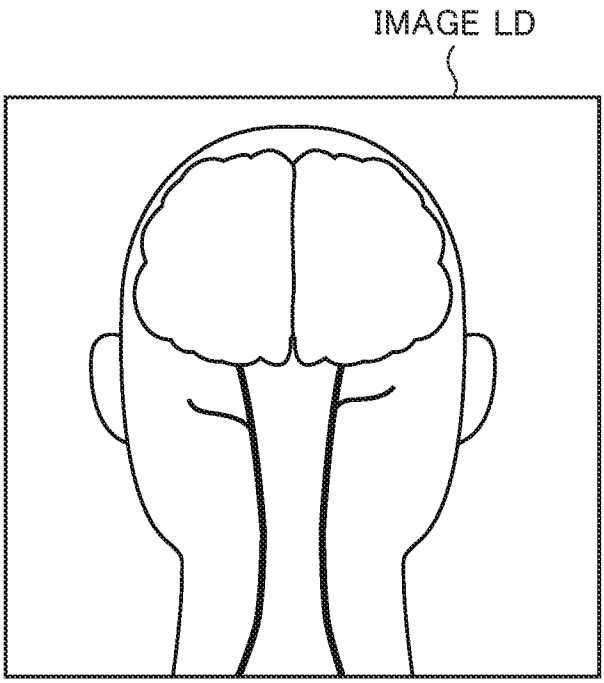


FIG. 6

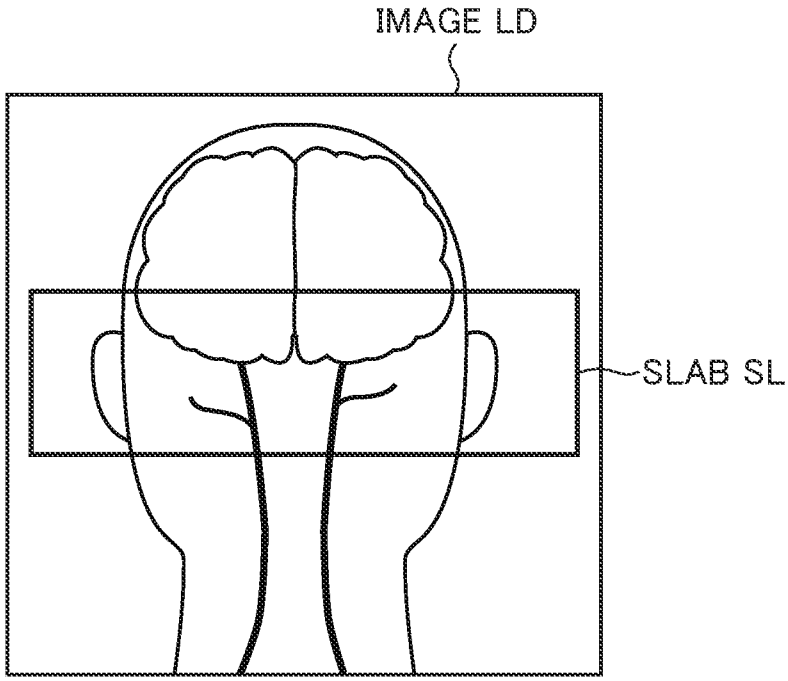


FIG. 7

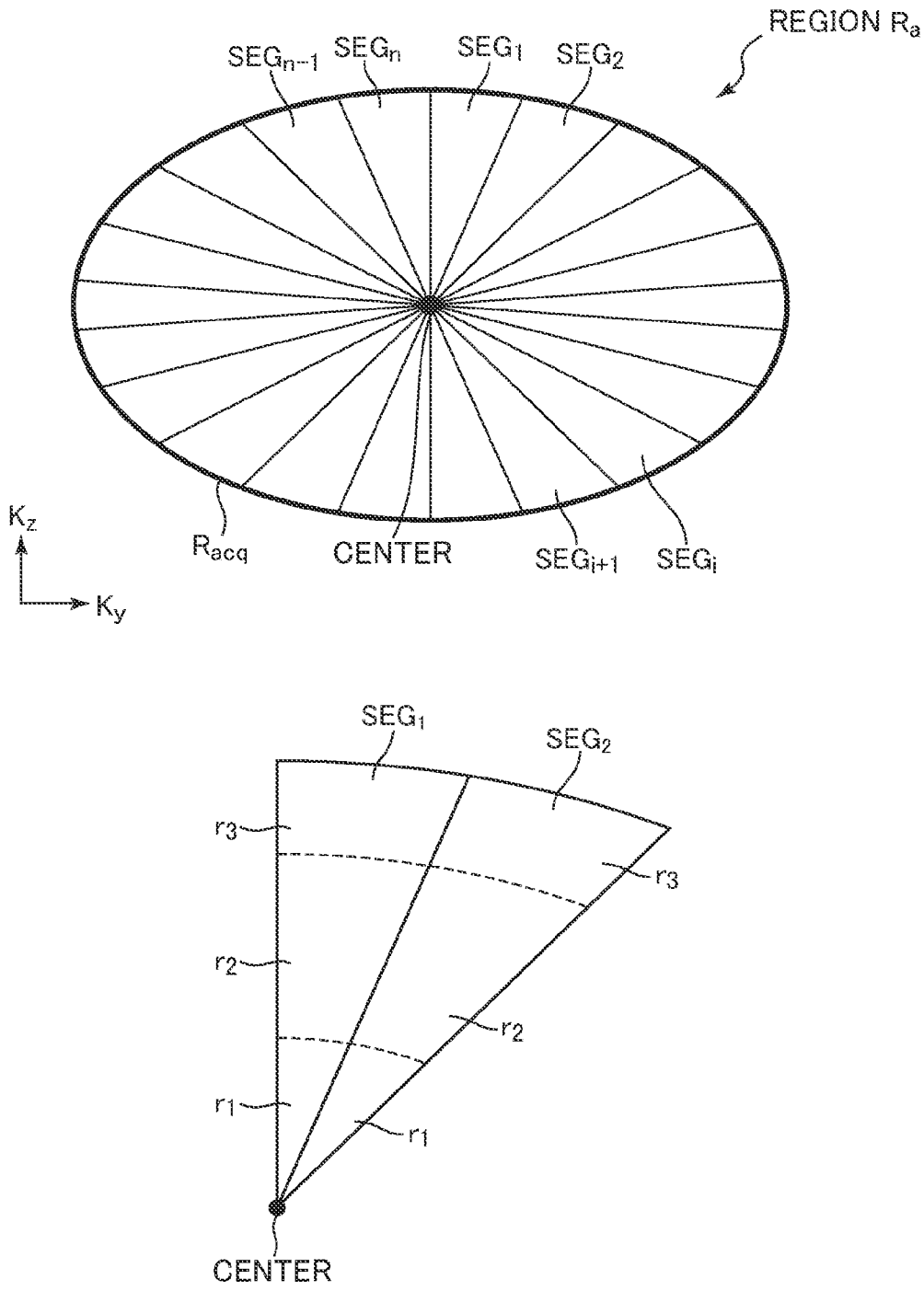

REGION R_a
SEG_{n-1}
SEG_n
SEG_1
SEG_2
K_z
K_y
R_{acq}
CENTER
SEG_{i+1}
SEG_i
SEG_1
SEG_2
r3
r3
r2
r2
r1
r1
CENTER

FIG. 8

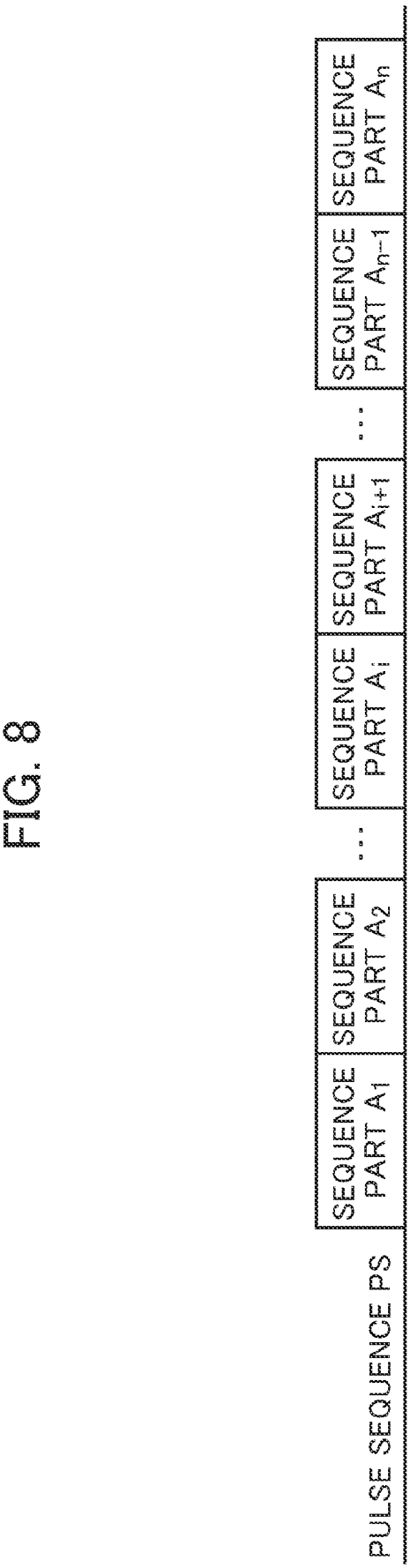

PULSE SEQUENCE PS
SEQUENCE PART A1
SEQUENCE PART A2
...
SEQUENCE PART Ai
SEQUENCE PART Ai+1
...
SEQUENCE PART An−1
SEQUENCE PART An

FIG. 9

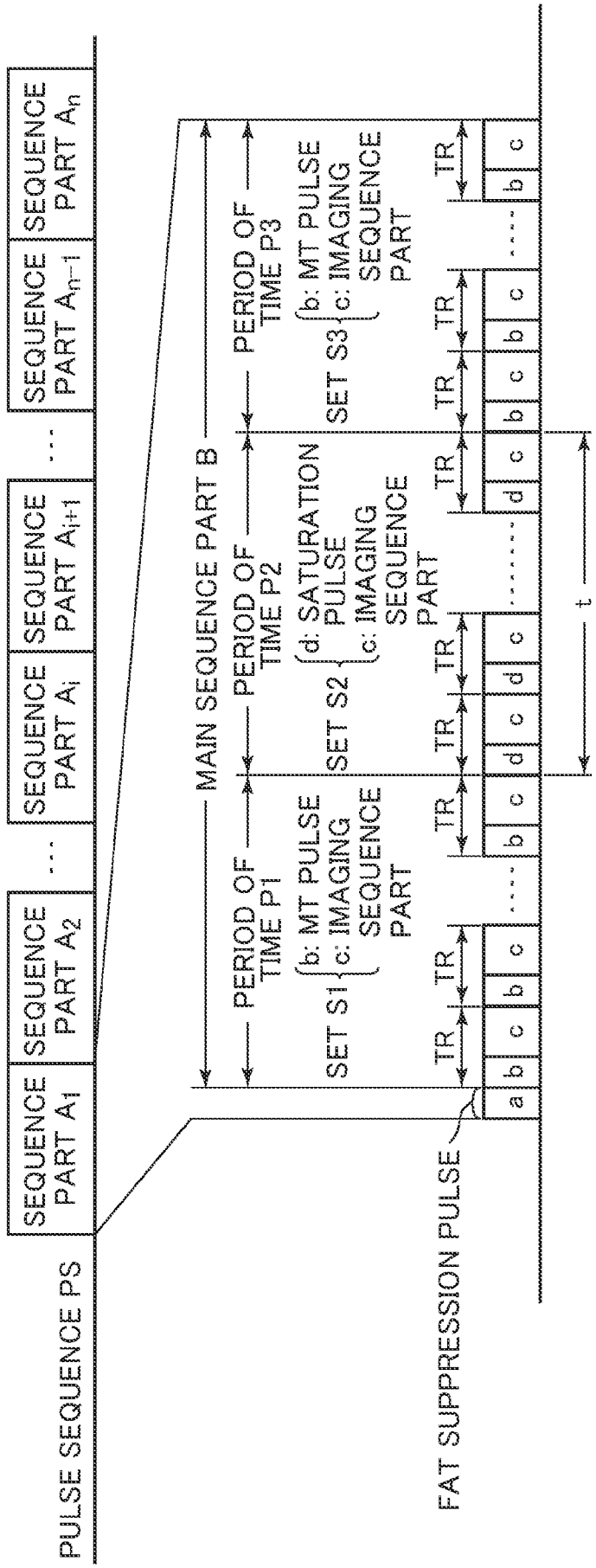

PULSE SEQUENCE PS
SEQUENCE PART A1
SEQUENCE PART A2
SEQUENCE PART Ai
SEQUENCE PART Ai+1
SEQUENCE PART An−1
SEQUENCE PART An
MAIN SEQUENCE PART B
PERIOD OF TIME P1
PERIOD OF TIME P2
PERIOD OF TIME P3
SET S1
SET S2
SET S3
b: MT PULSE
c: IMAGING SEQUENCE PART
d: SATURATION PULSE
TR
FAT SUPPRESSION PULSE
t

FIG. 10

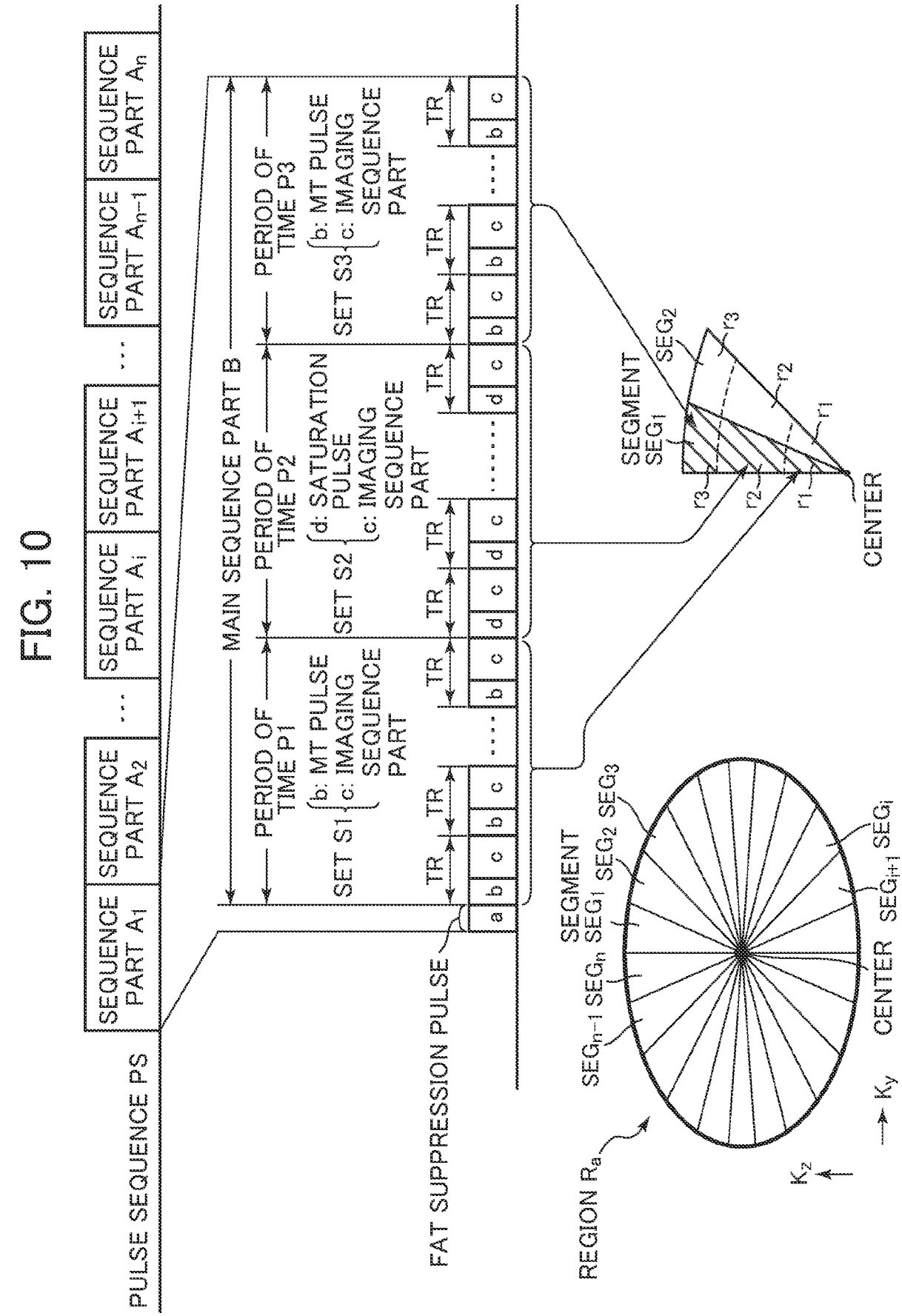

PULSE SEQUENCE PS
SEQUENCE PART A1
SEQUENCE PART A2
SEQUENCE PART Ai
SEQUENCE PART Ai+1
SEQUENCE PART An−1
SEQUENCE PART An
MAIN SEQUENCE PART B
PERIOD OF TIME P1
PERIOD OF TIME P2
PERIOD OF TIME P3
SET S1 {b: MT PULSE c: IMAGING SEQUENCE PART
SET S2 {d: SATURATION PULSE c: IMAGING SEQUENCE PART
SET S3 {b: MT PULSE c: IMAGING SEQUENCE PART
FAT SUPPRESSION PULSE
TR
a b c b c .... b c d c d c ..... d c b c b c .... b c
SEGMENT SEG1
SEG2
r3
r2
r1
CENTER
REGION Ra
SEGMENT SEGn−1 SEGn SEG1 SEG2 SEG3
SEGi+1 SEGi
CENTER
Ky
Kz

FIG. 11

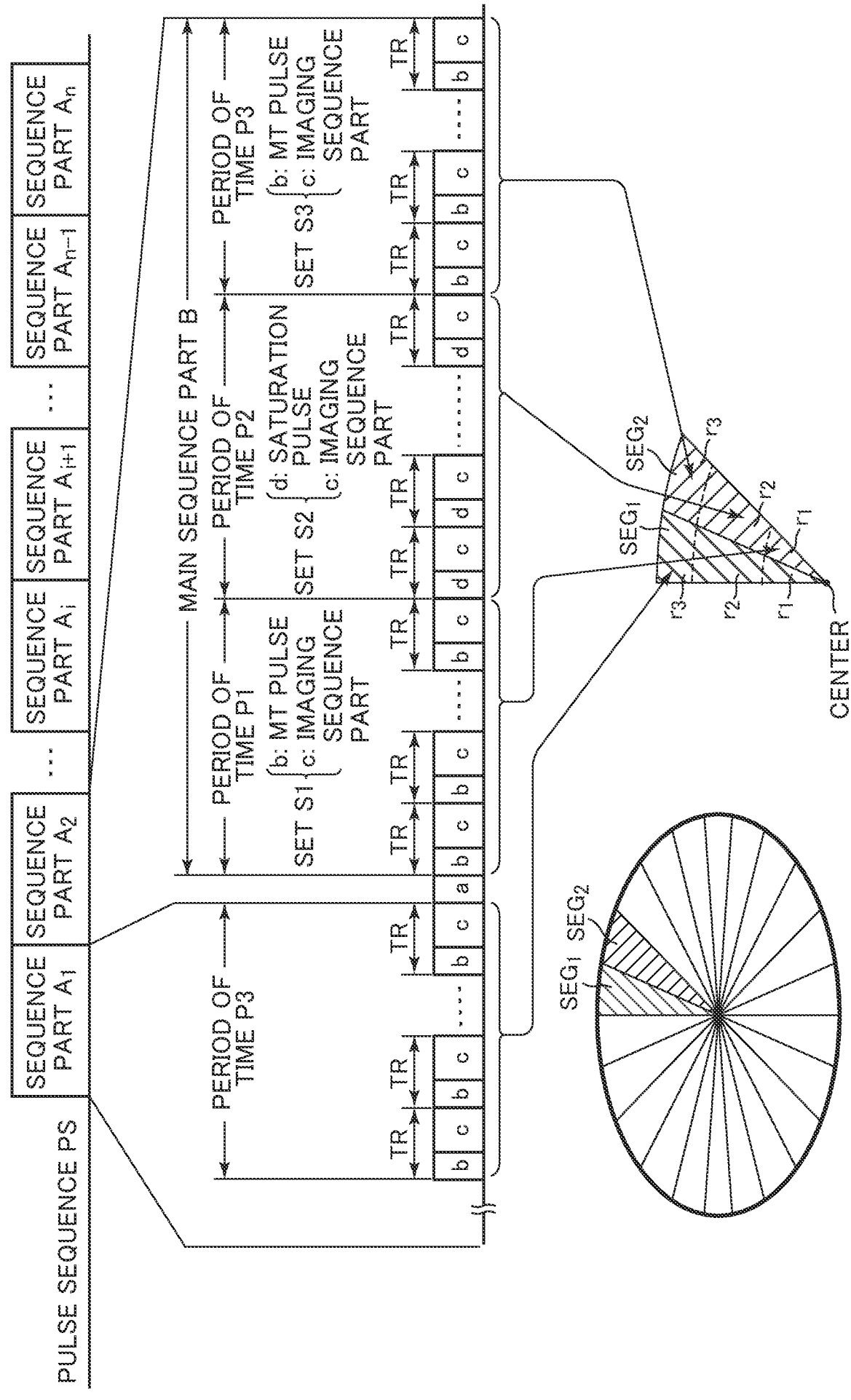

PULSE SEQUENCE PS
SEQUENCE PART A1
SEQUENCE PART A2
SEQUENCE PART Ai
SEQUENCE PART Ai+1
SEQUENCE PART An−1
SEQUENCE PART An
MAIN SEQUENCE PART B
PERIOD OF TIME P1
PERIOD OF TIME P2
PERIOD OF TIME P3
SET S1
SET S2
SET S3
b: MT PULSE
c: IMAGING SEQUENCE PART
d: SATURATION PULSE
TR
SEG1
SEG2
r1
r2
r3
CENTER

FIG. 12

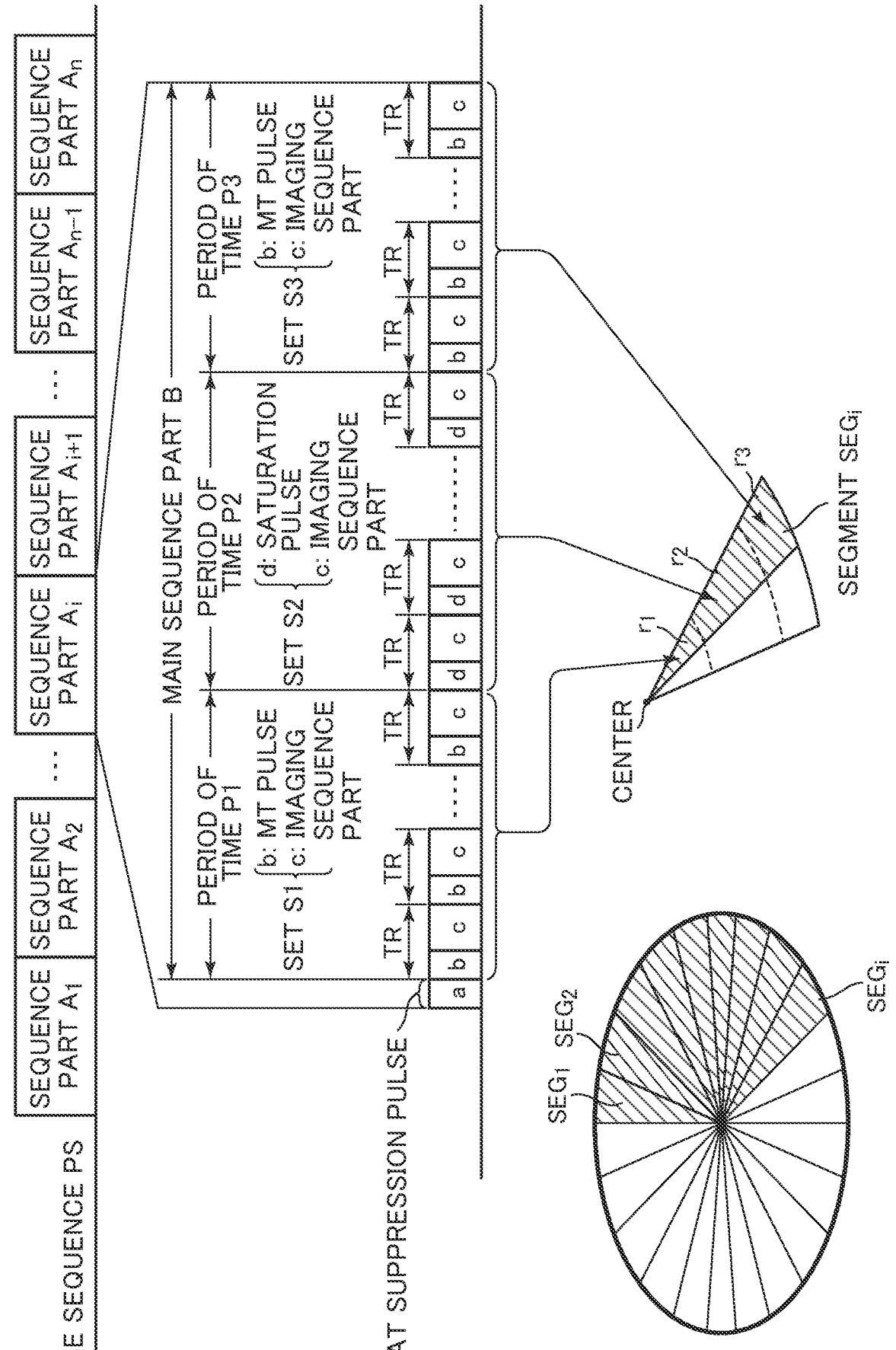

PULSE SEQUENCE PS
SEQUENCE PART A1
SEQUENCE PART A2
SEQUENCE PART Ai
SEQUENCE PART Ai+1
SEQUENCE PART An-1
SEQUENCE PART An
MAIN SEQUENCE PART B
PERIOD OF TIME P1
PERIOD OF TIME P2
PERIOD OF TIME P3
SET S1
SET S2
SET S3
b: MT PULSE
c: IMAGING SEQUENCE PART
d: SATURATION PULSE
TR
FAT SUPPRESSION PULSE
CENTER
r1
r2
r3
SEGMENT SEGi
SEG1
SEG2
SEGi

FIG. 13

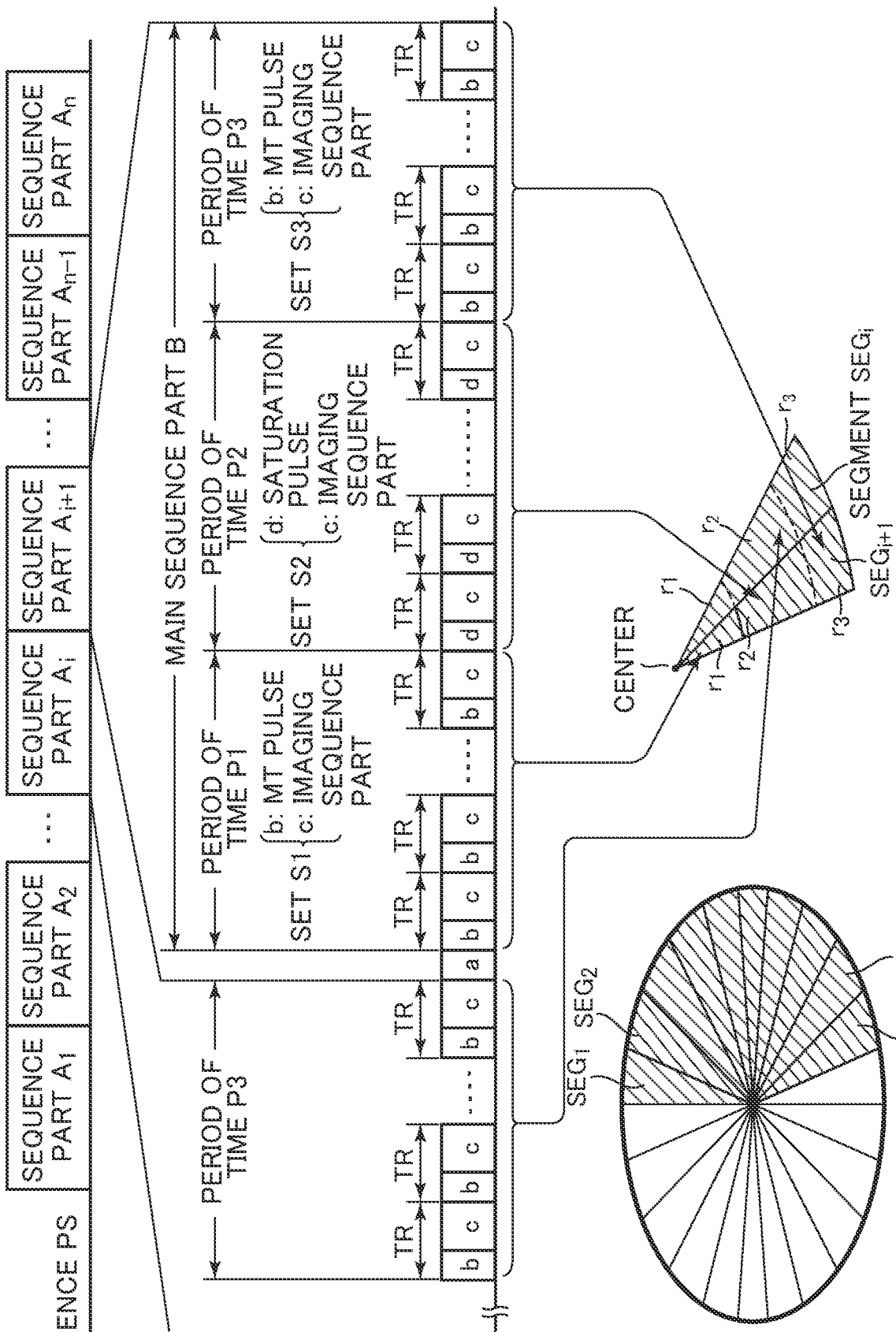

PULSE SEQUENCE PS
SEQUENCE PART A1
SEQUENCE PART A2
SEQUENCE PART Ai
SEQUENCE PART Ai+1
SEQUENCE PART An-1
SEQUENCE PART An
MAIN SEQUENCE PART B
PERIOD OF TIME P1
PERIOD OF TIME P2
PERIOD OF TIME P3
SET S1
SET S2
SET S3
b: MT PULSE
c: IMAGING SEQUENCE PART
d: SATURATION PULSE
TR
CENTER
SEGMENT SEGi
SEGi+1
SEG1
SEG2

FIG. 14

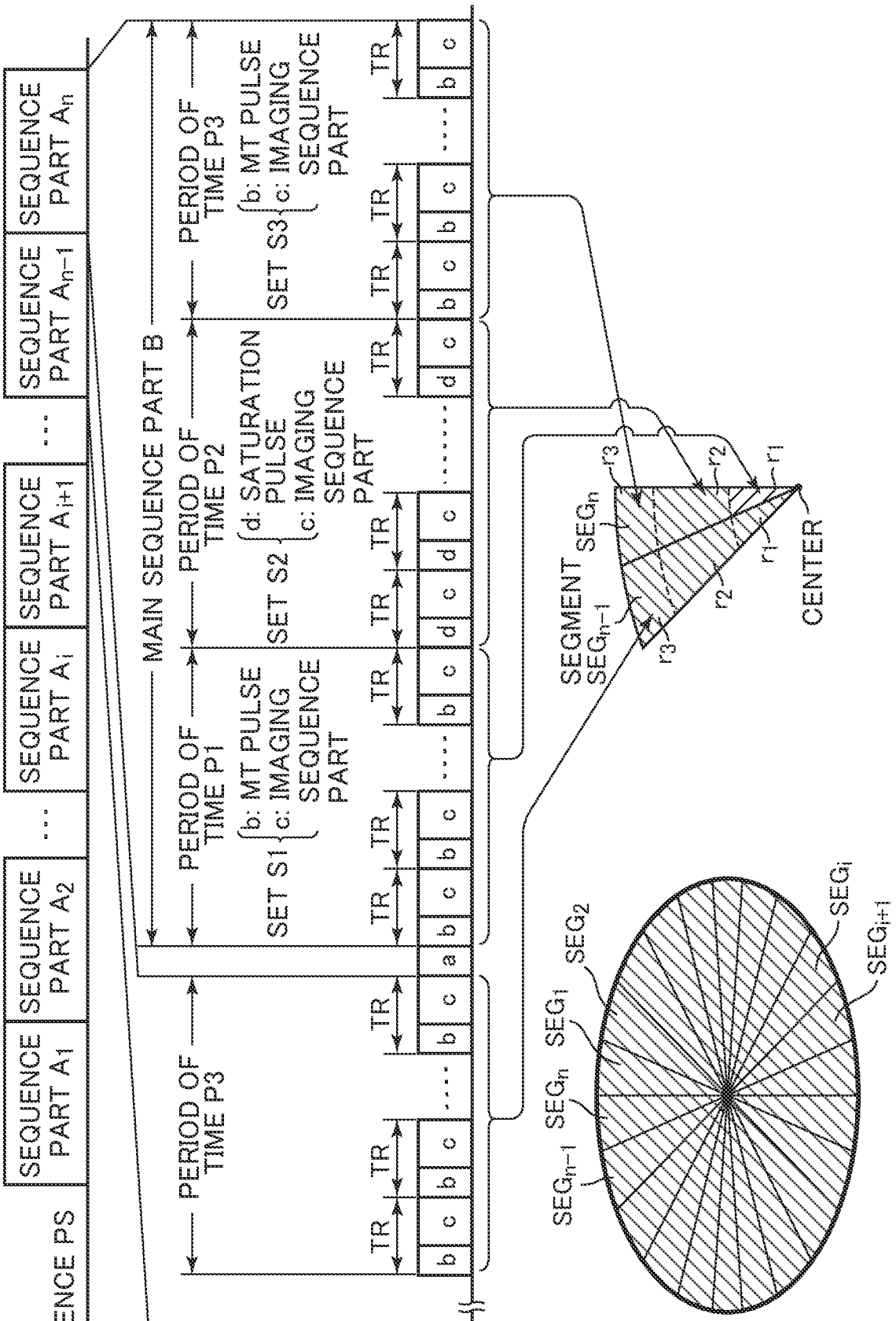
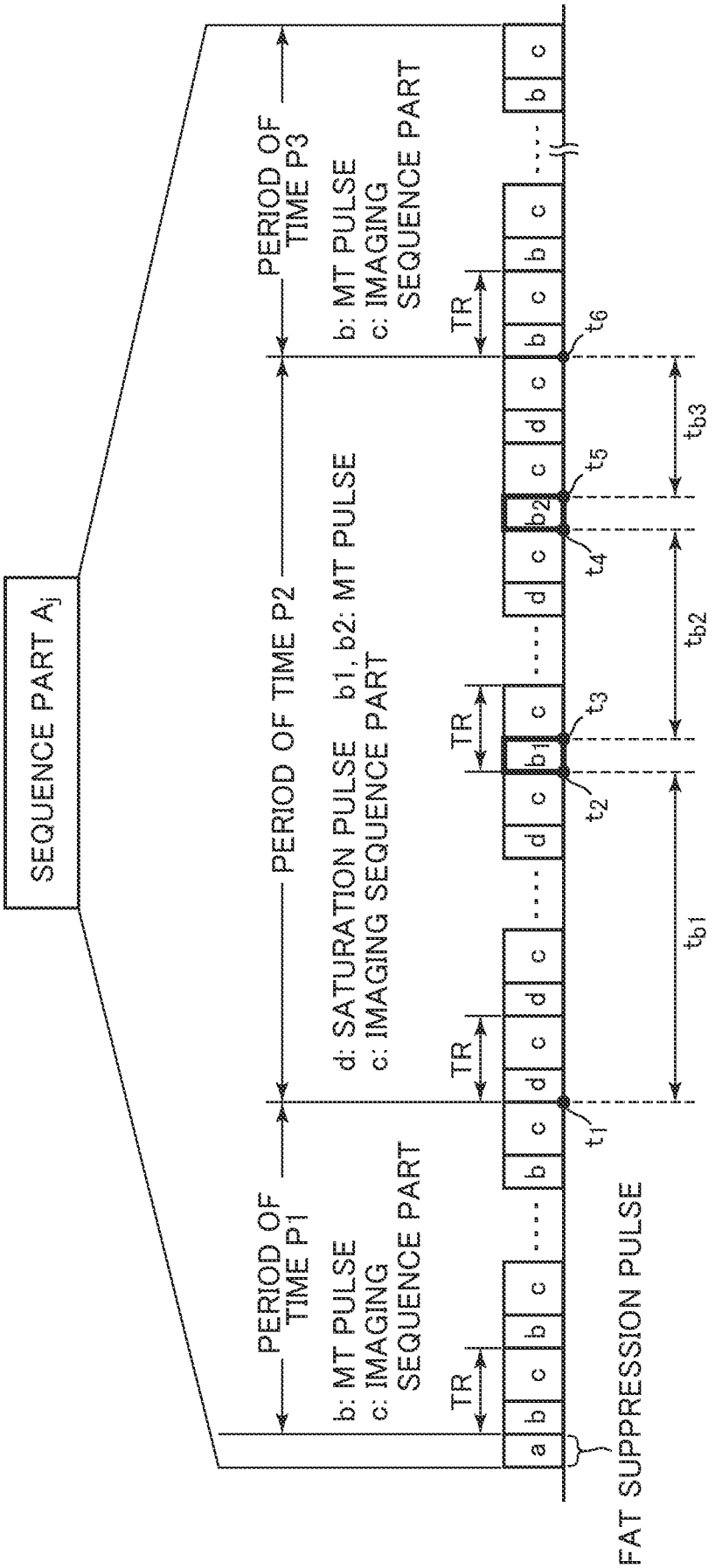

PULSE SEQUENCE PS
SEQUENCE PART A1
SEQUENCE PART A2
SEQUENCE PART Ai
SEQUENCE PART Ai+1
SEQUENCE PART An−1
SEQUENCE PART An
MAIN SEQUENCE PART B
PERIOD OF TIME P1
PERIOD OF TIME P2
PERIOD OF TIME P3
SET S1
SET S2
SET S3
b: MT PULSE
c: IMAGING SEQUENCE PART
d: SATURATION PULSE
TR
SEGMENT SEGn
SEGn−1
CENTER
r1
r2
r3
SEG1
SEG2
SEGi
SEGi+1
SEGn
SEGn−1

FIG. 15


SEQUENCE PART A_j
PERIOD OF TIME P1
PERIOD OF TIME P2
PERIOD OF TIME P3
b: MT PULSE
c: IMAGING SEQUENCE PART
d: SATURATION PULSE
b1, b2: MT PULSE
c: IMAGING SEQUENCE PART
TR
FAT SUPPRESSION PULSE
t_1
t_2
t_3
t_4
t_5
t_6
t_{b1}
t_{b2}
t_{b3}

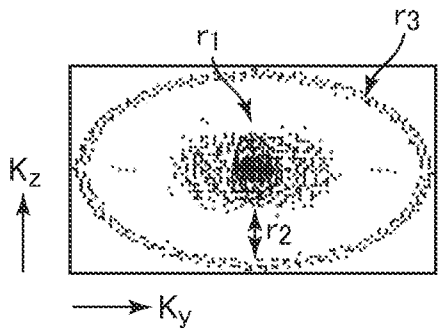


FIG. 16A

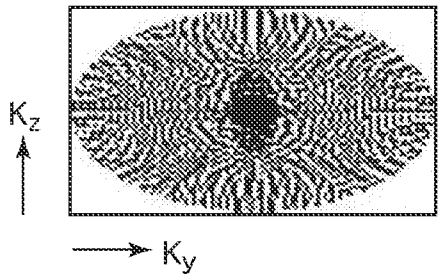


FIG. 16B

FIG. 17

	MTR
EXPERIMENT 1 (THE PRESENT EMBODIMENT)	0.2892
EXPERIMENT 2 (COMPARATIVE EXAMPLE)	0.2436

FIG. 18A

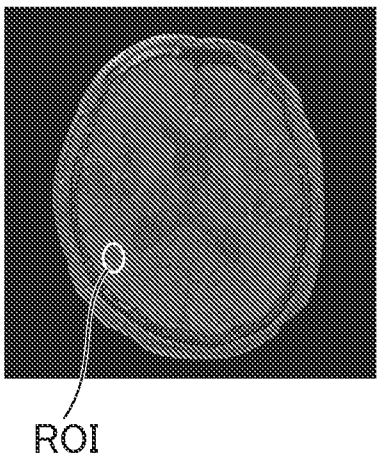


IMAGE IM1

FIG. 18B

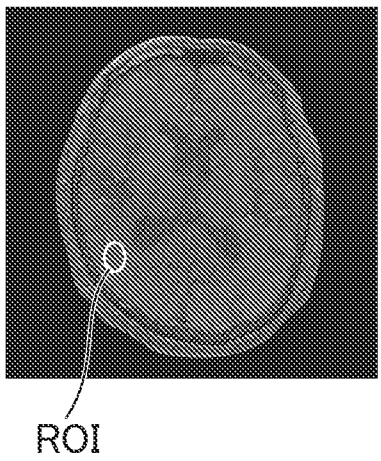


IMAGE IM2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/067083

A. CLASSIFICATION OF SUBJECT MATTER

A61B 5/055(2006.01)i, G01R 33/36(2006.01)i, G01R 33/48(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B 5/055; G01V 3/00; A61B 5/026; G06K 9/00; G01R 33/48; G01R 33/36

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: divide, k-space, segment, pulse, sequence, grid, point, period

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013-0123611 A1 (STEPHEN J. RIEDERER et al.) 16 May 2013 See abstract, paragraphs [20]-[68] and claim 1.	1-6
A	US 5621321 A (HAIYING LIU et al.) 15 April 1997 See abstract, column 3, lines 39-42, column 7, lines 54-56, column 9, lines 34-41 and figure 1.	1-6
A	US 2008-0061779 A1 (THORSTEN FEIWEIER) 13 March 2008 See abstract, paragraphs [17]-[60] and figures 1,2.	1-6
A	JP 2010-042245 A (TOSHIBA CORP. et al.) 25 February 2010 See abstract, paragraphs [62]-[90],[124]-[149] and figures 1(A)-11(B).	1-6
A	KR 10-2010-0002148 A (ALLEGHENY SINGER RESEARCH INSTITUTE) 06 January 2010 See abstract, paragraphs [3]-[12],[34]-[39] and figures 2-11.	1-6

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 April 2016 (29.04.2016)	**04 May 2016 (04.05.2016)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
CHO, KI YUN
Telephone No. +82-42-481-5655

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/067083

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 8,11,14
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claims 8,11,14 are unclear since they are referring to multiple dependent claims 7,10,13 which do not comply with PCT Rule 6.4(a).

3. ☒ Claims Nos.: 7,9,10,12,13,15
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2015/067083

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