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Nishihara et al.

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(54) **MAGNETIC RESONANCE IMAGING APPARATUS AND MAGNETIC RESONANCE IMAGING METHOD**

(58) **Field of Classification Search**
None
See application file for complete search history.

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(56) **References Cited**

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(73) Assignee: **Hitachi, Ltd.**, Tokyo (JP)

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(65) **Prior Publication Data**
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(57) **ABSTRACT**

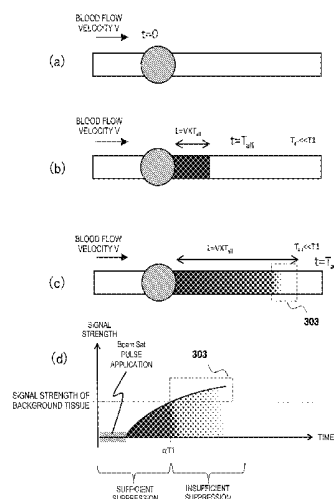
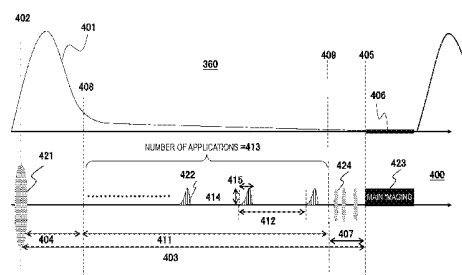
(30) **Foreign Application Priority Data**
Jul. 12, 2013 (JP) 2013-146818

Provided is a technique in MRI to efficiently suppress downstream blood in a specific region in a blood vessel having a slow flow velocity, such as the portal vein. For this purpose, a plurality of Beam Sat pulses are applied so as to equally suppress signals of blood flowing into a desired imaging region from a desired blood vessel during the period from applying an IR pulse to starting main imaging. Downstream blood in a specific region in a blood vessel having a slow flow velocity, such as the portal vein, can be suppressed efficiently by determining application conditions of the plurality of Beam Sat pulses that achieve the above based on a flow velocity of blood in a desired blood vessel and T1 of the said blood.

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(Continued)

14 Claims, 19 Drawing Sheets



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G01R 33/483 (2006.01)
G01R 33/56 (2006.01)
G01R 33/565 (2006.01)
G01R 33/567 (2006.01)
A61B 5/113 (2006.01)

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(2013.01); *G01R 33/5673* (2013.01); *G01R*
33/56509 (2013.01)

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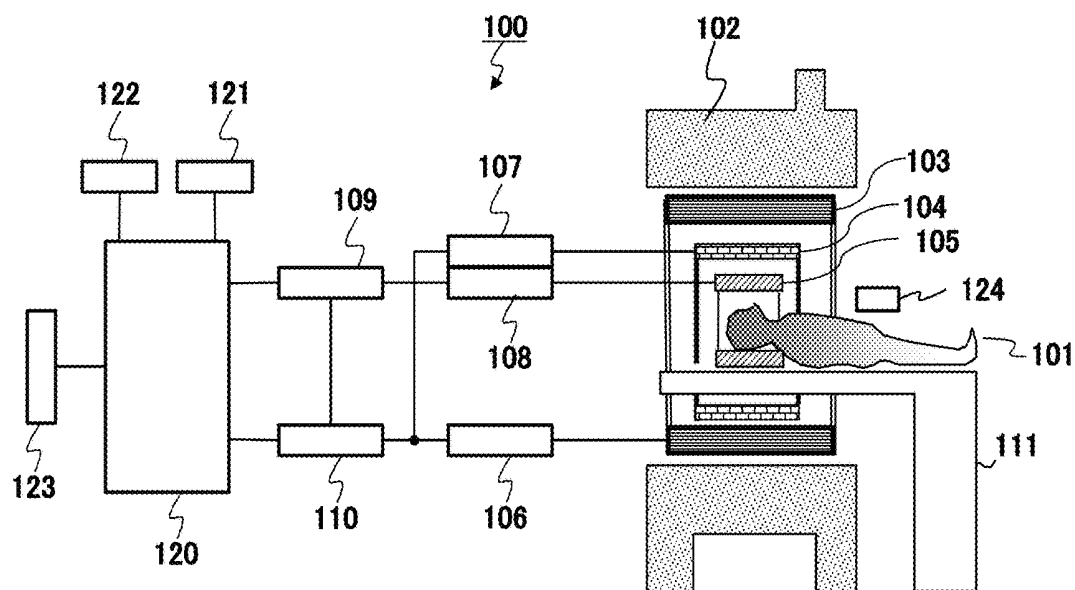
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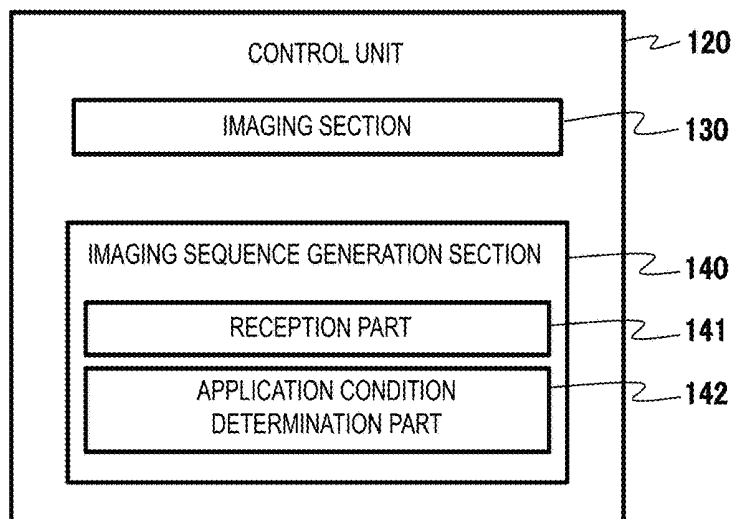
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FIG. 1

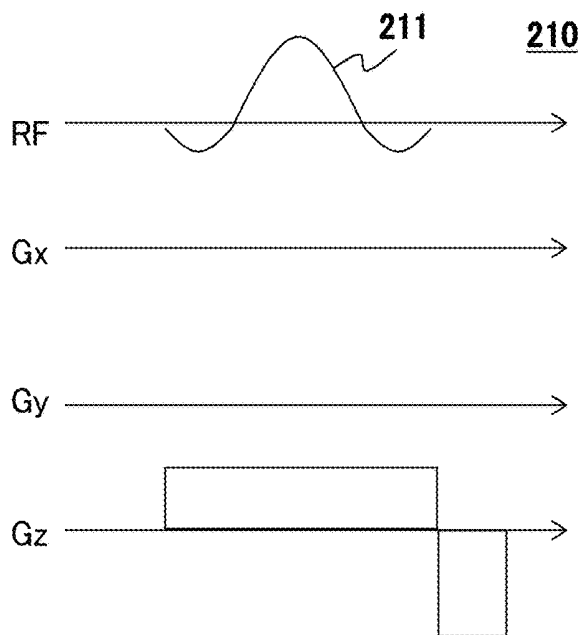


(a)

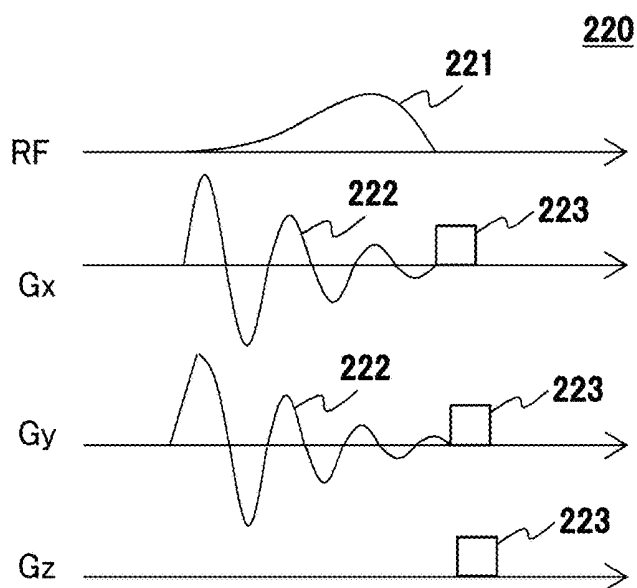


(b)

FIG.2



(a)



(b)

FIG. 3

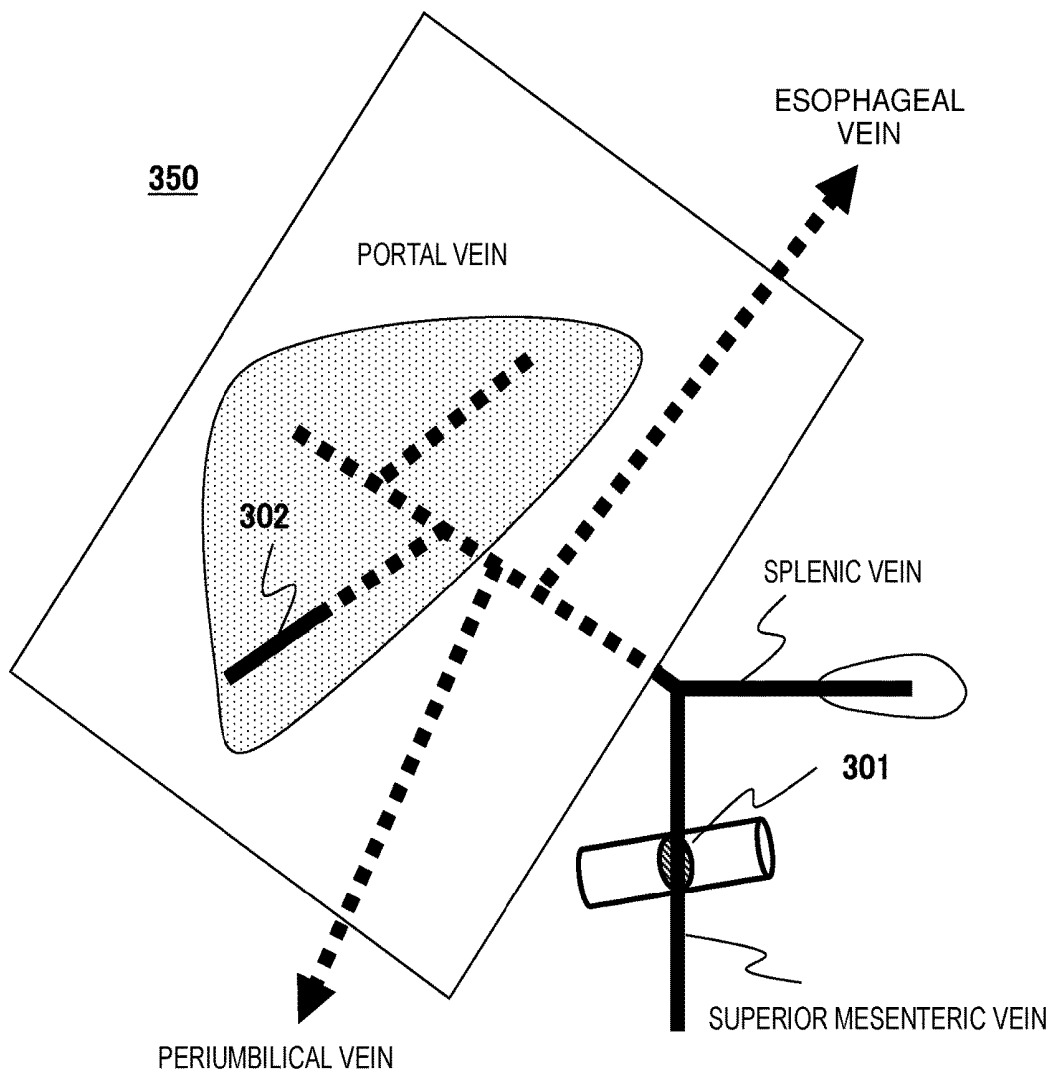


FIG. 4

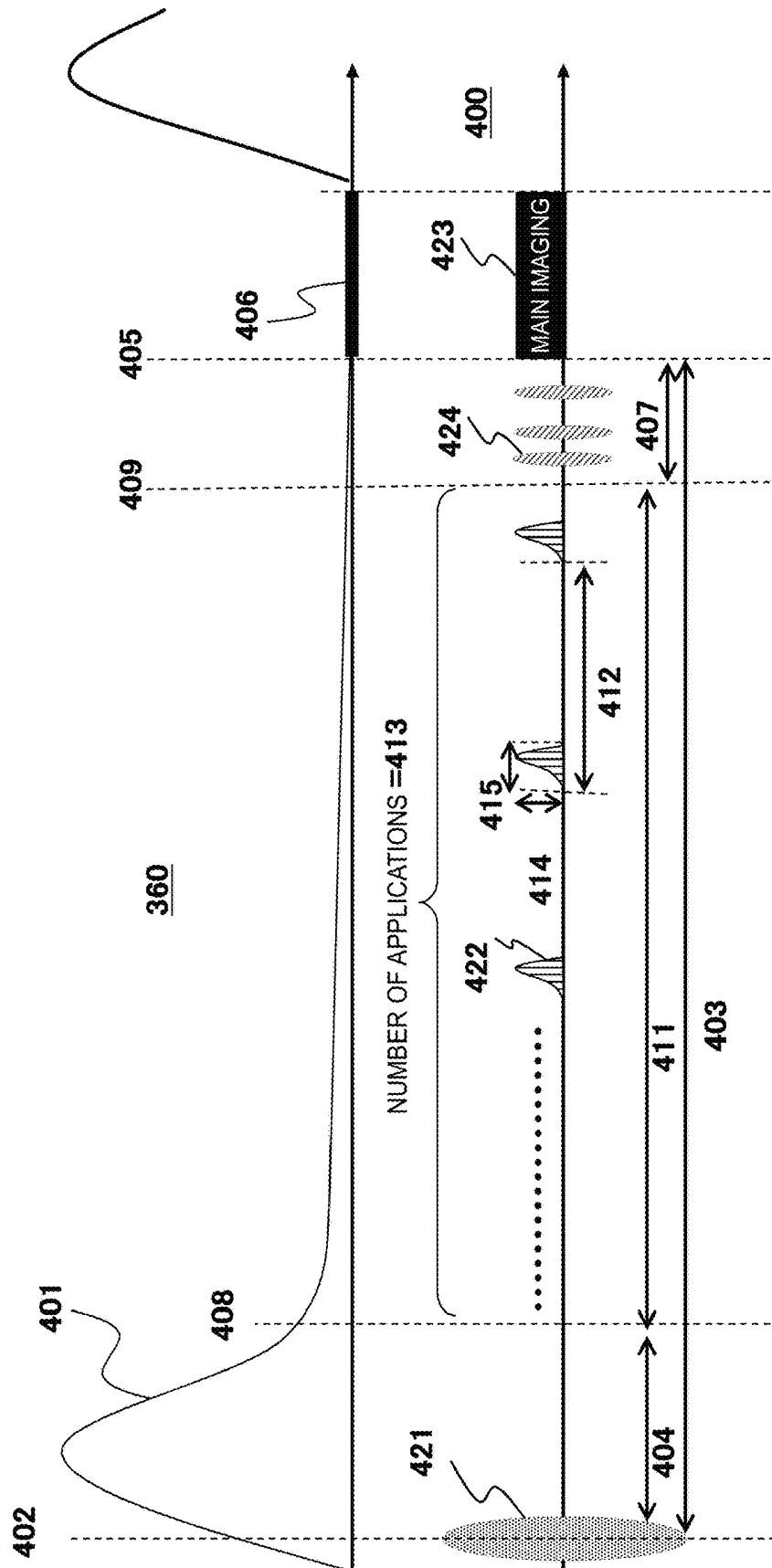


FIG. 5

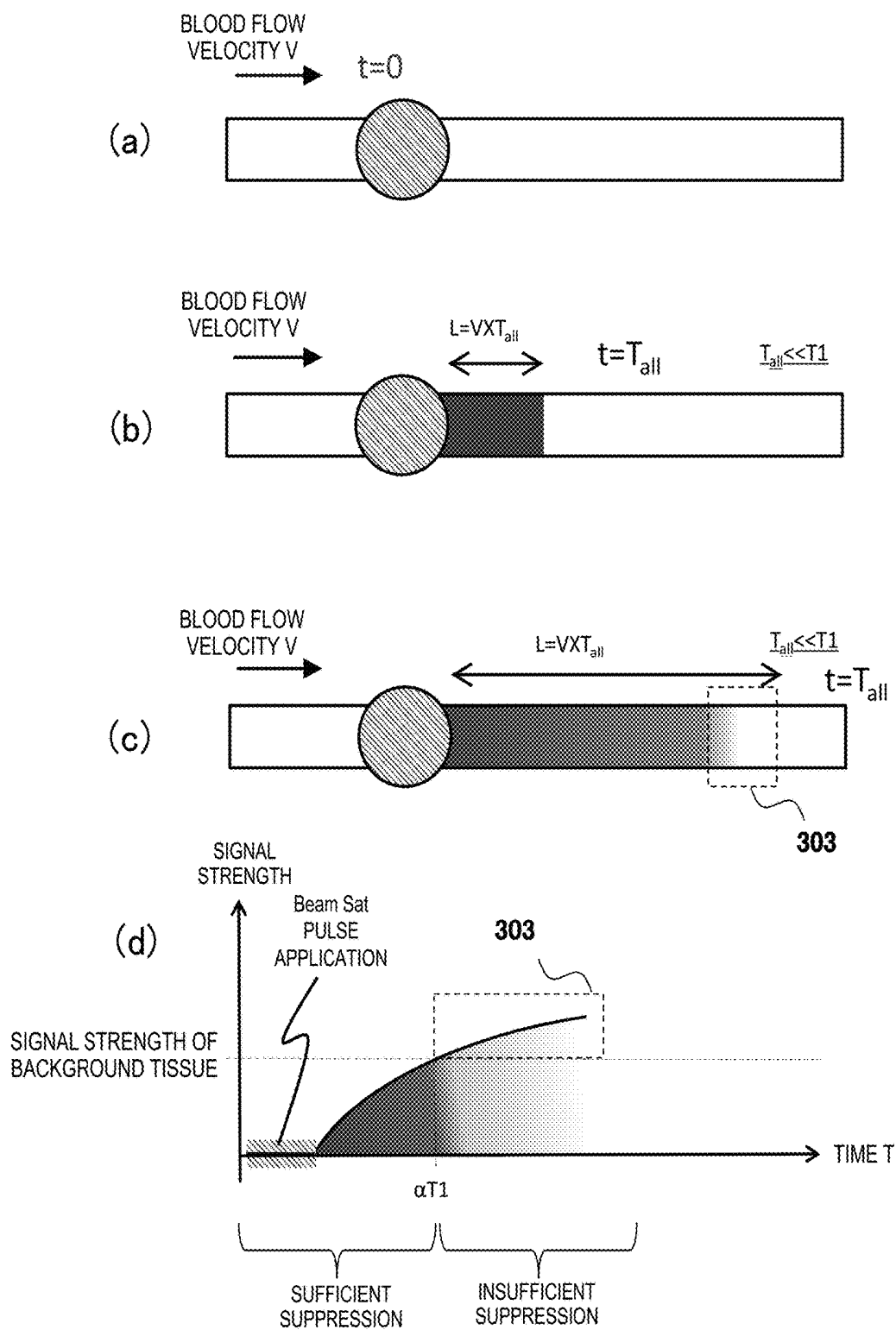


FIG.6

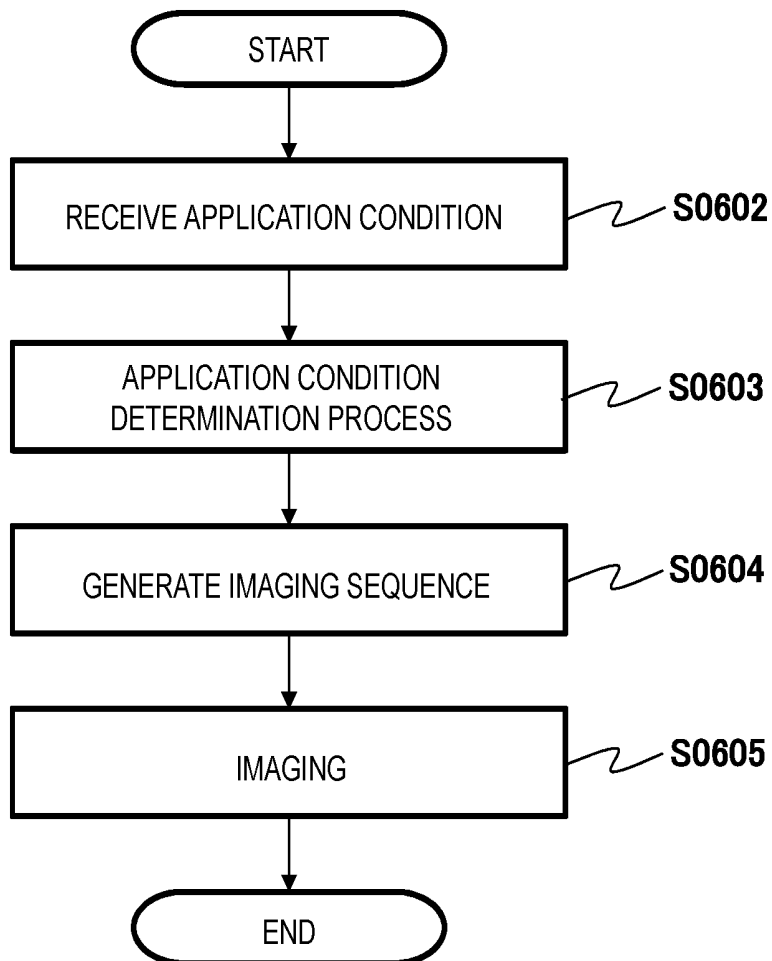


FIG. 7

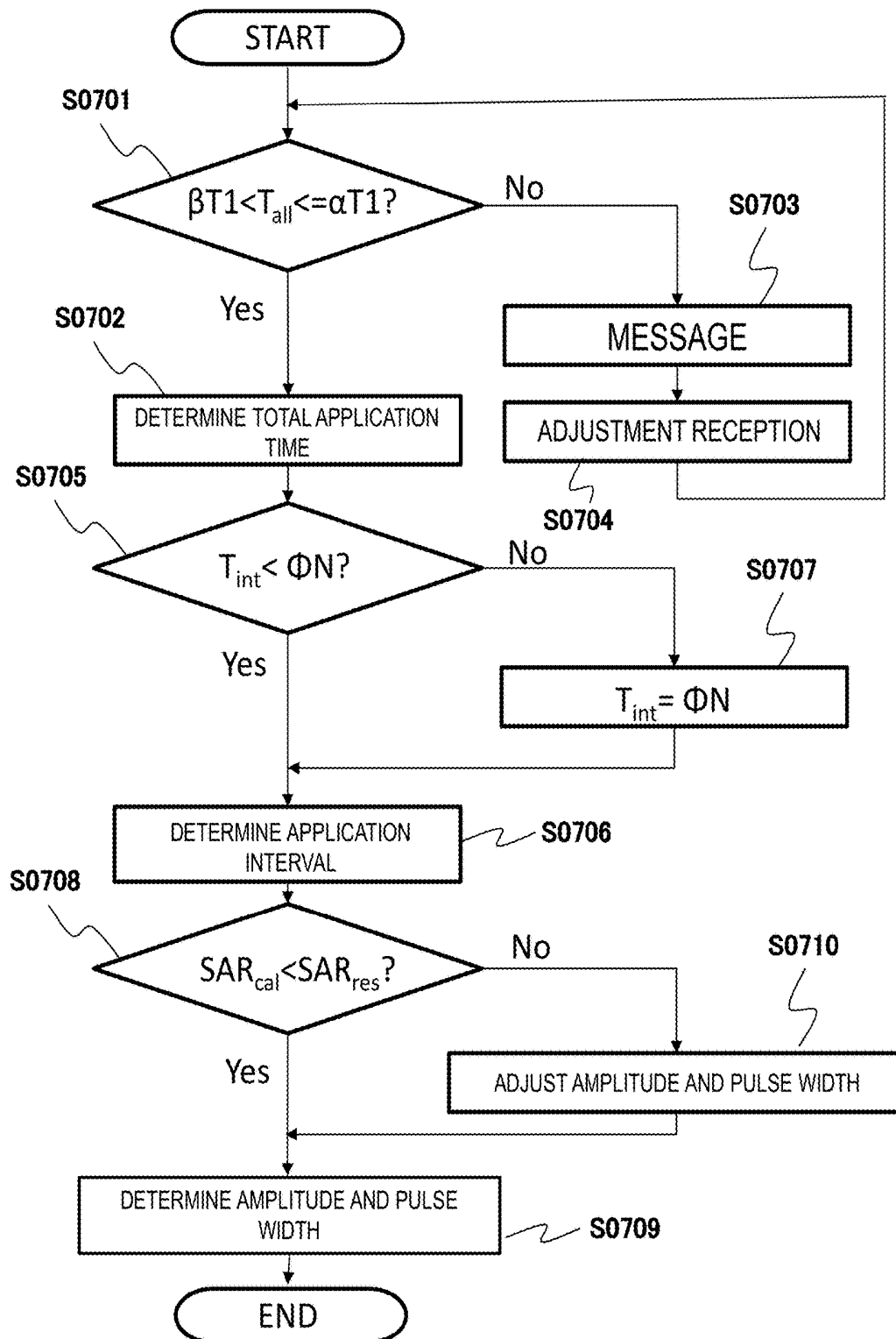


FIG. 8

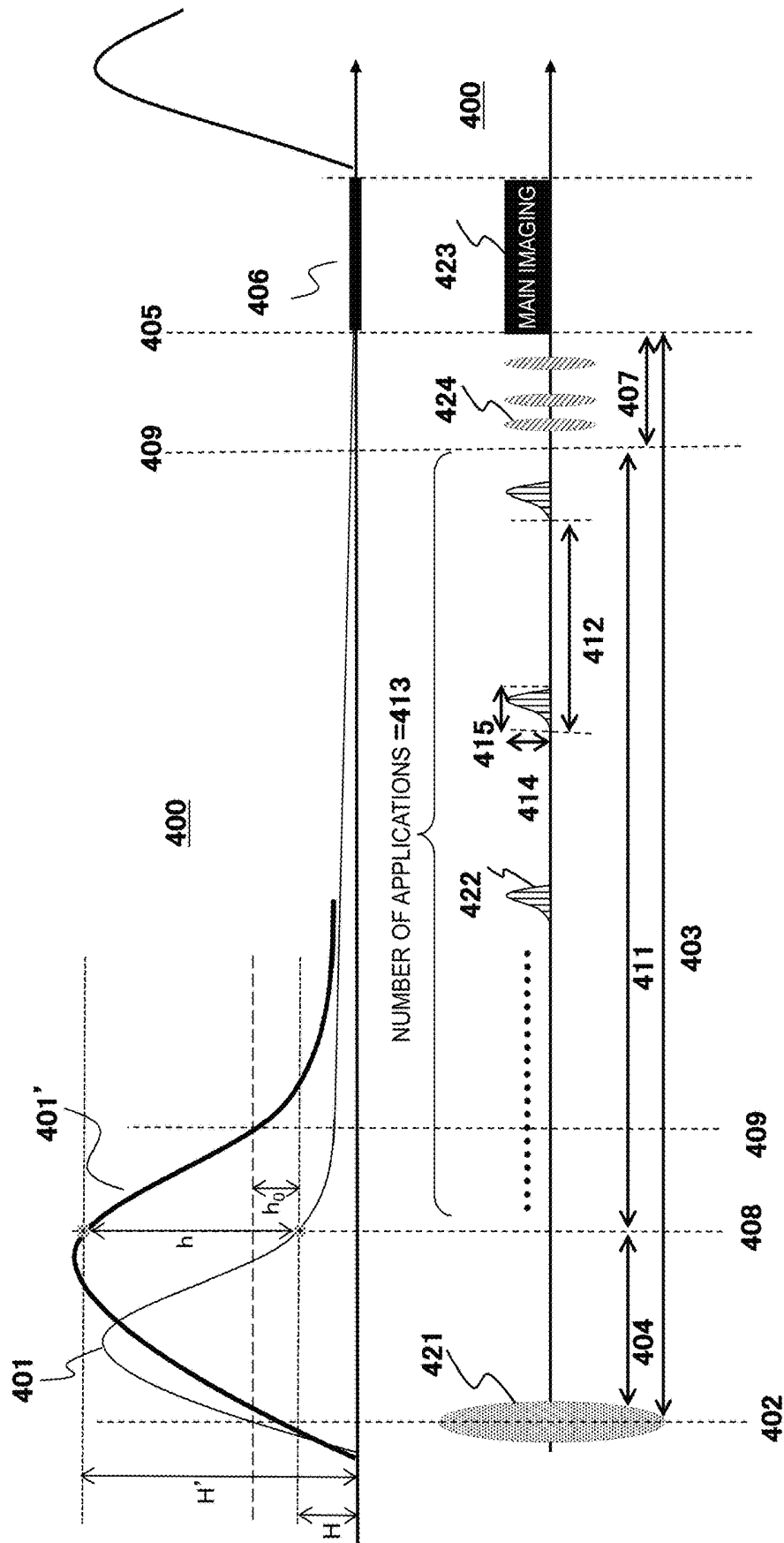


FIG. 9

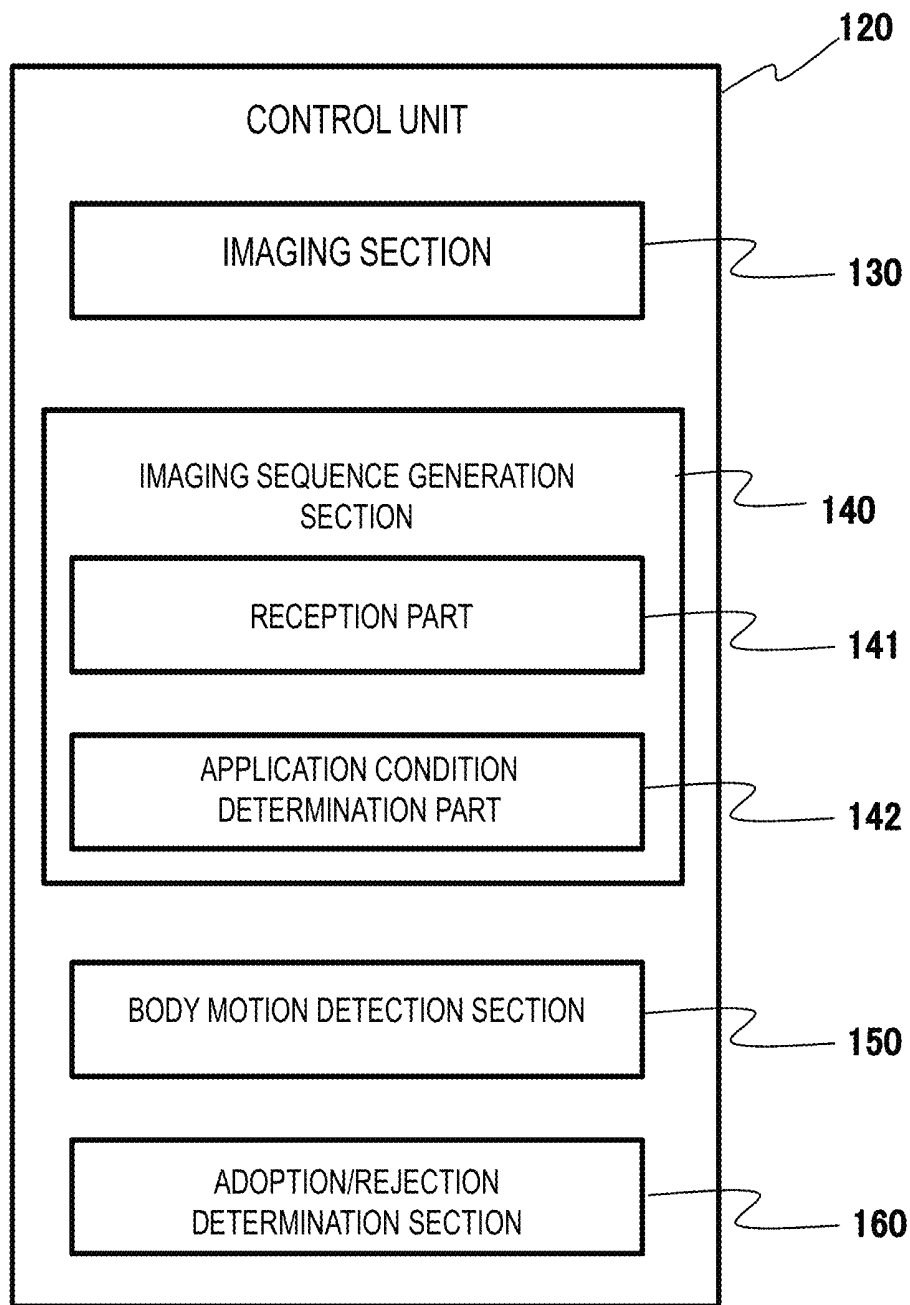


FIG.10

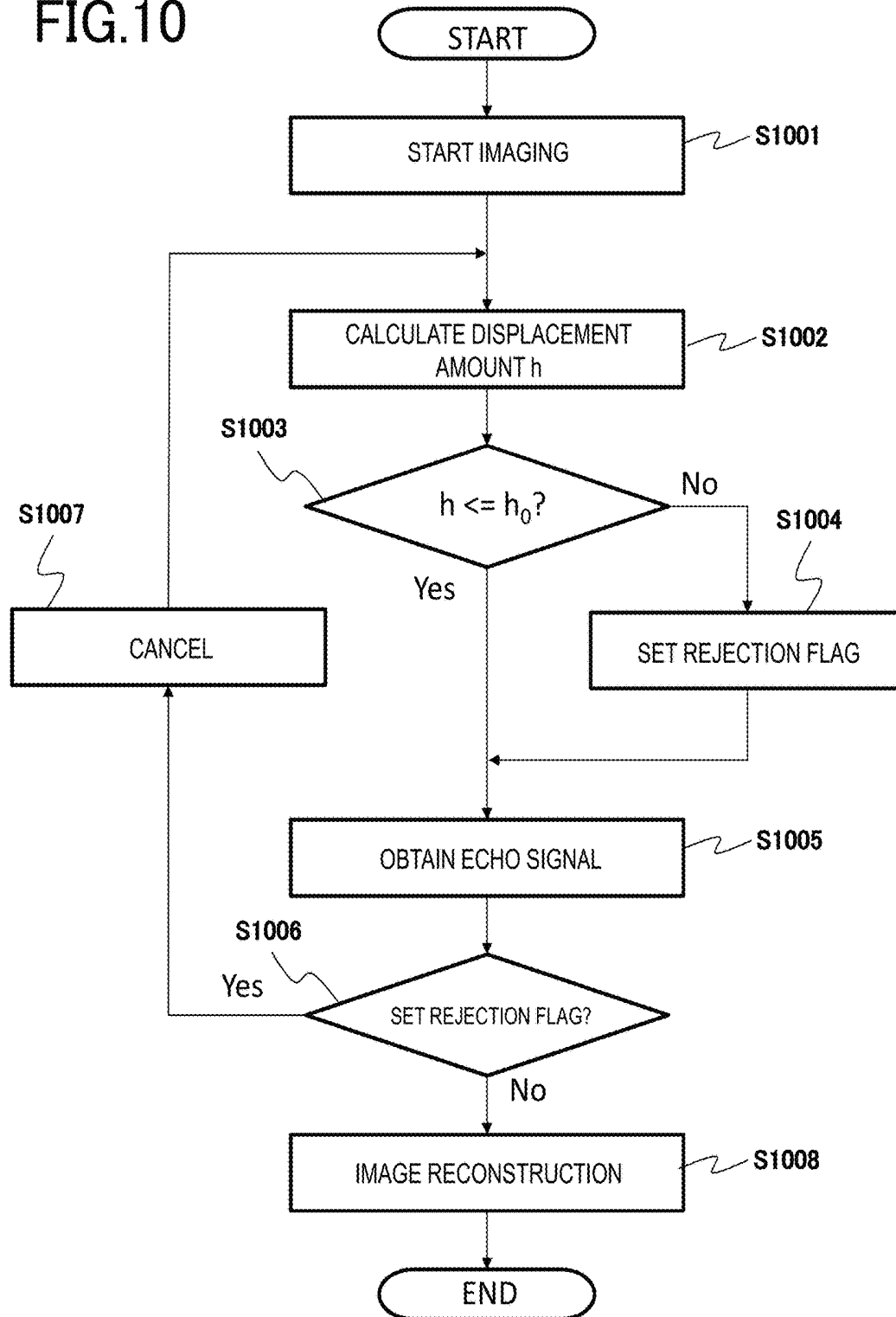


FIG. 11

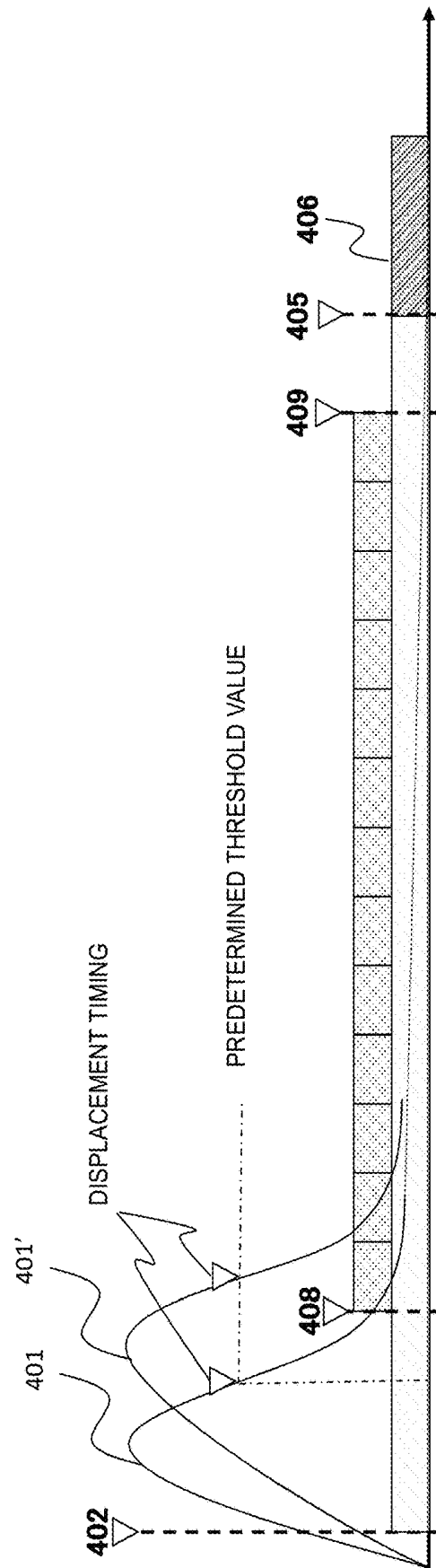


FIG. 12

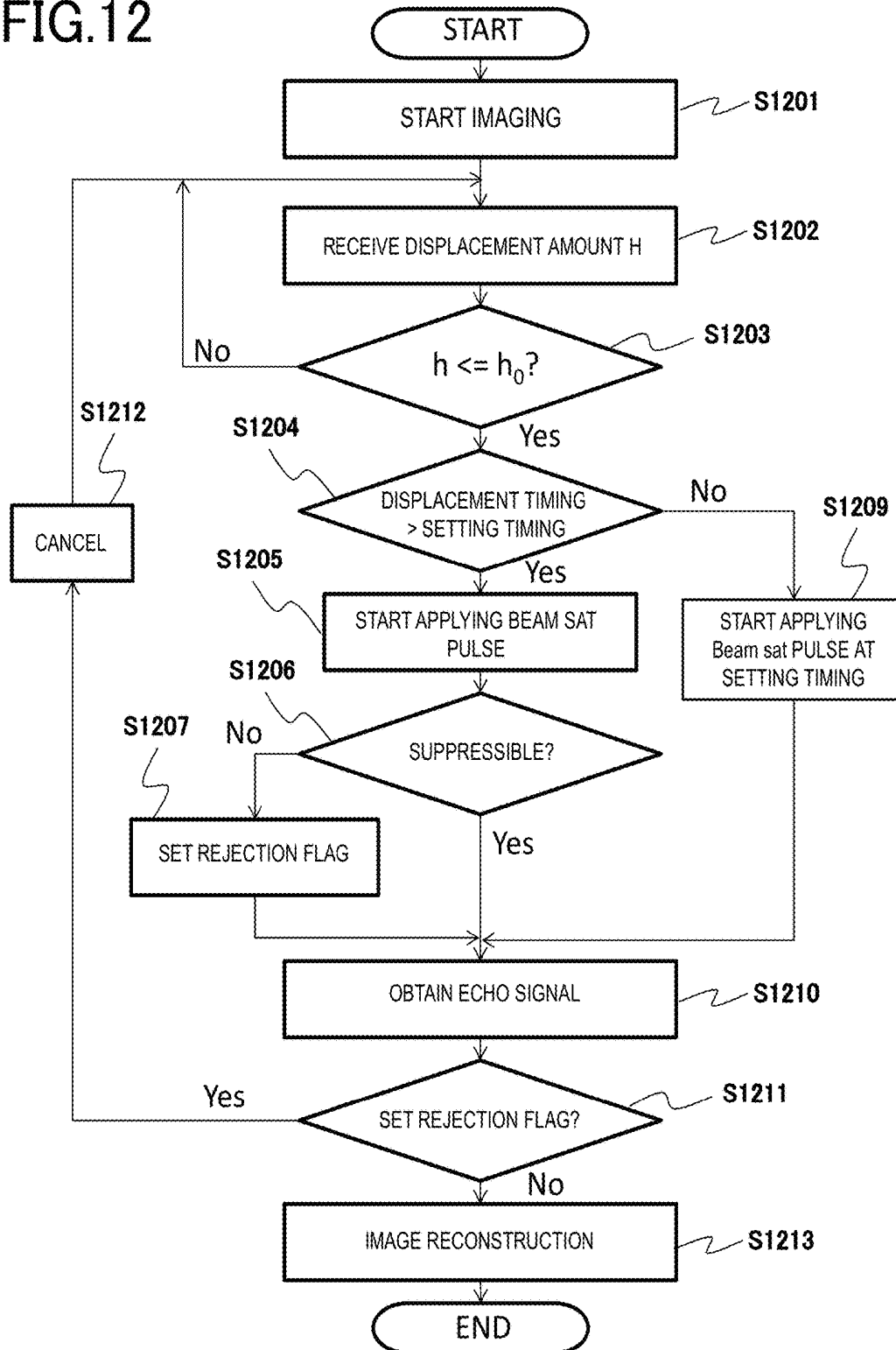


FIG. 13

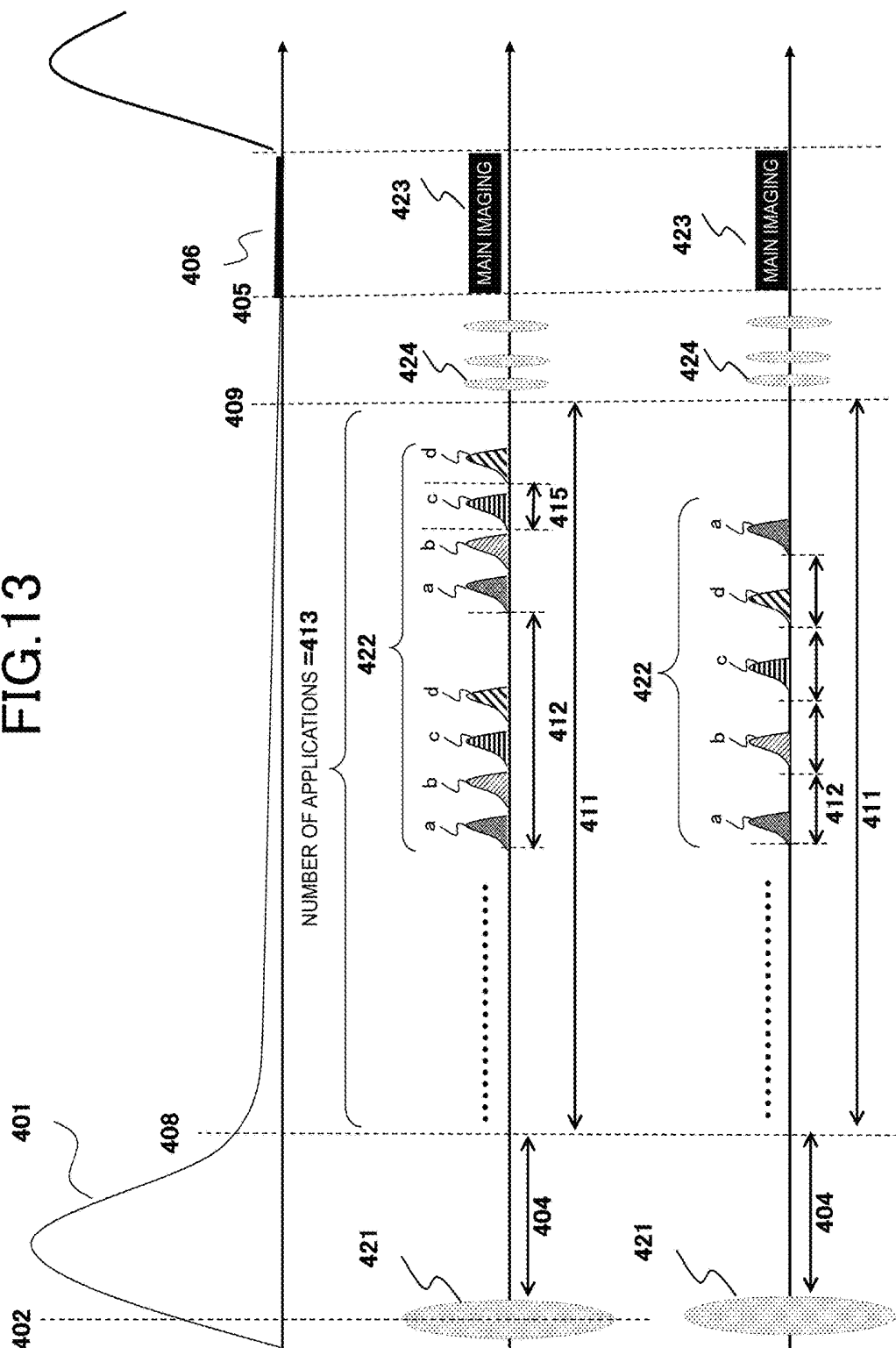


FIG. 14

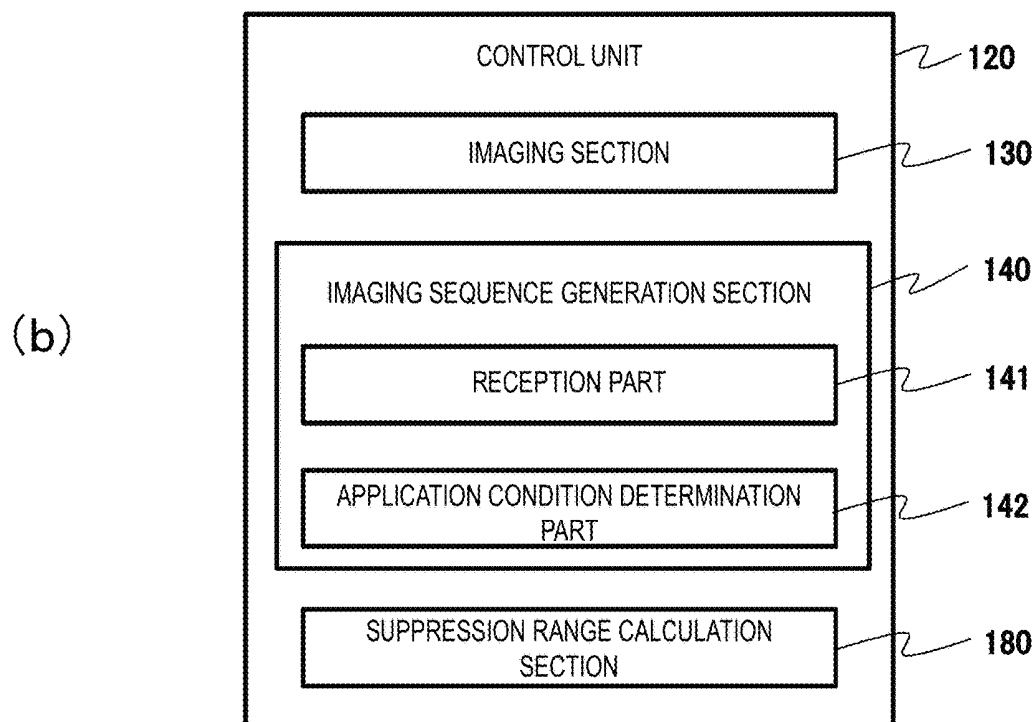
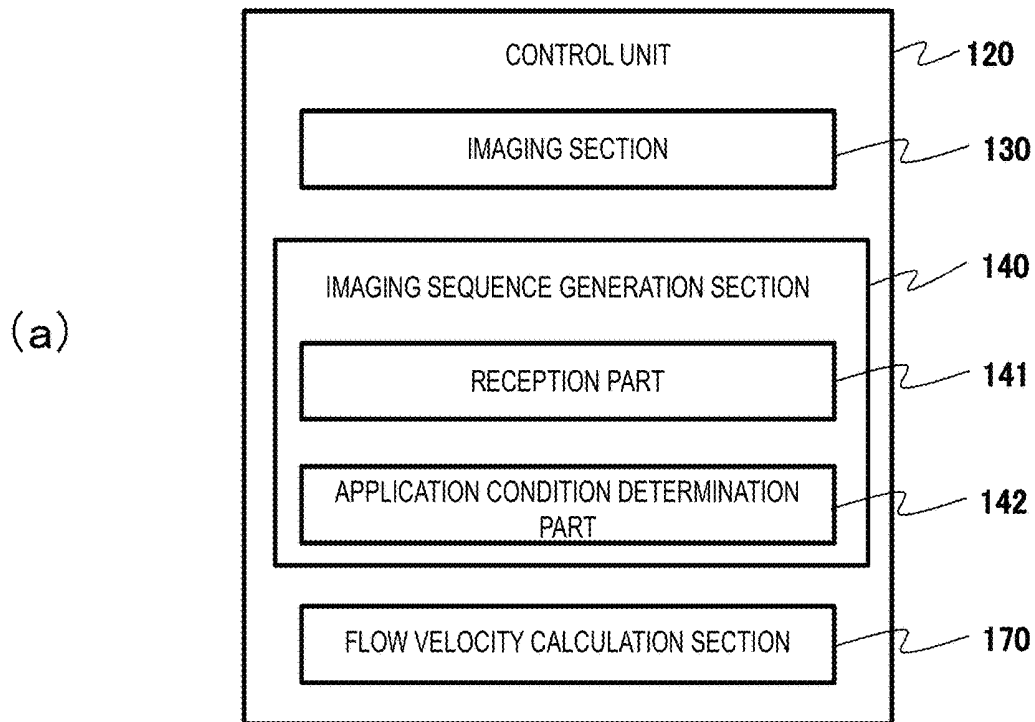


FIG. 15

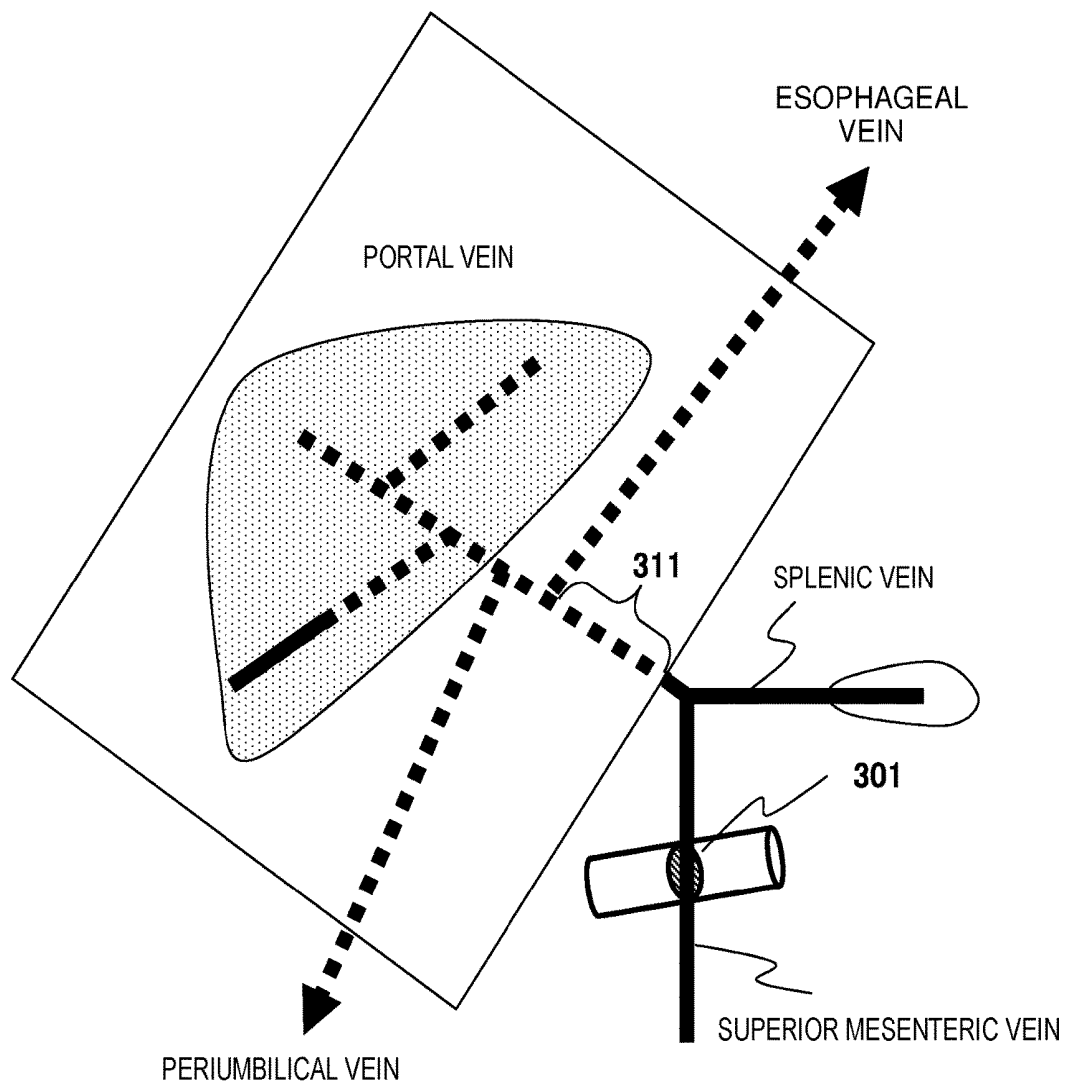


FIG. 16

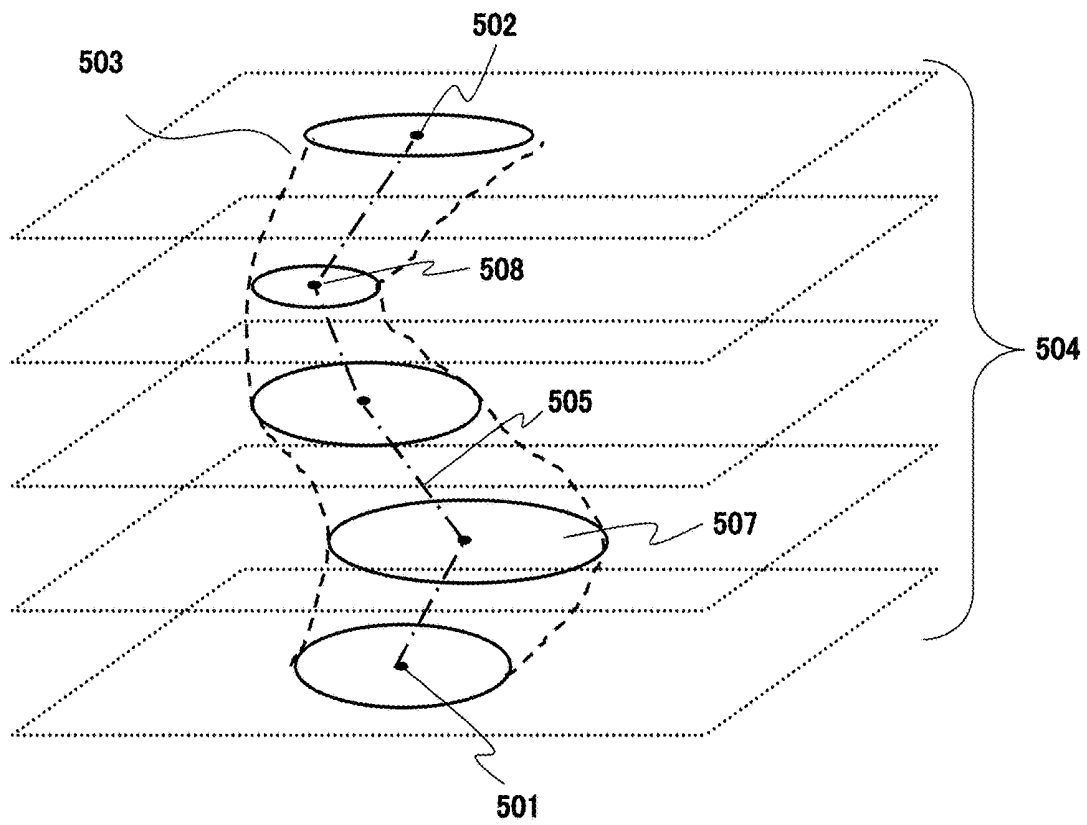
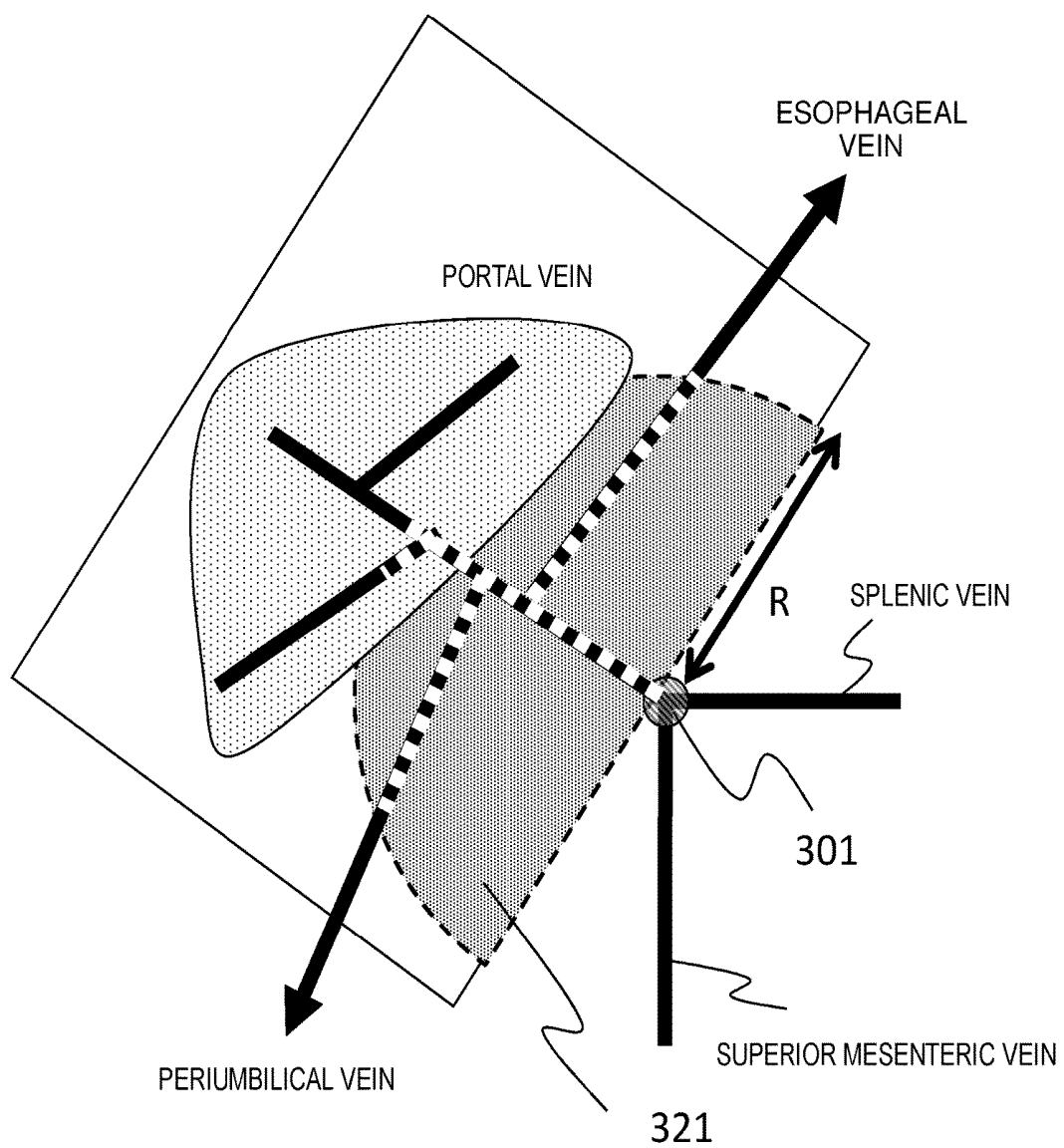


FIG.17



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FIG. 18

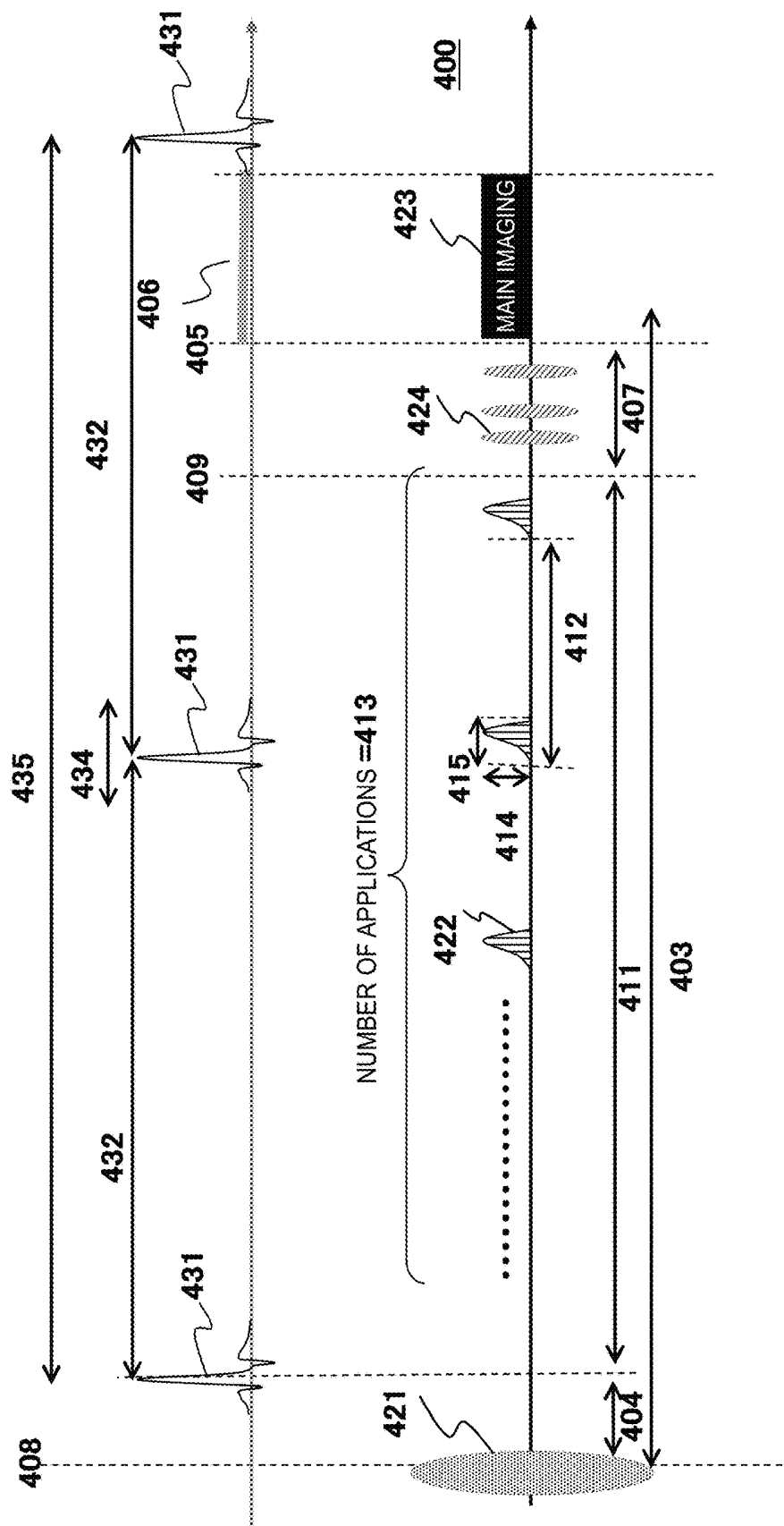
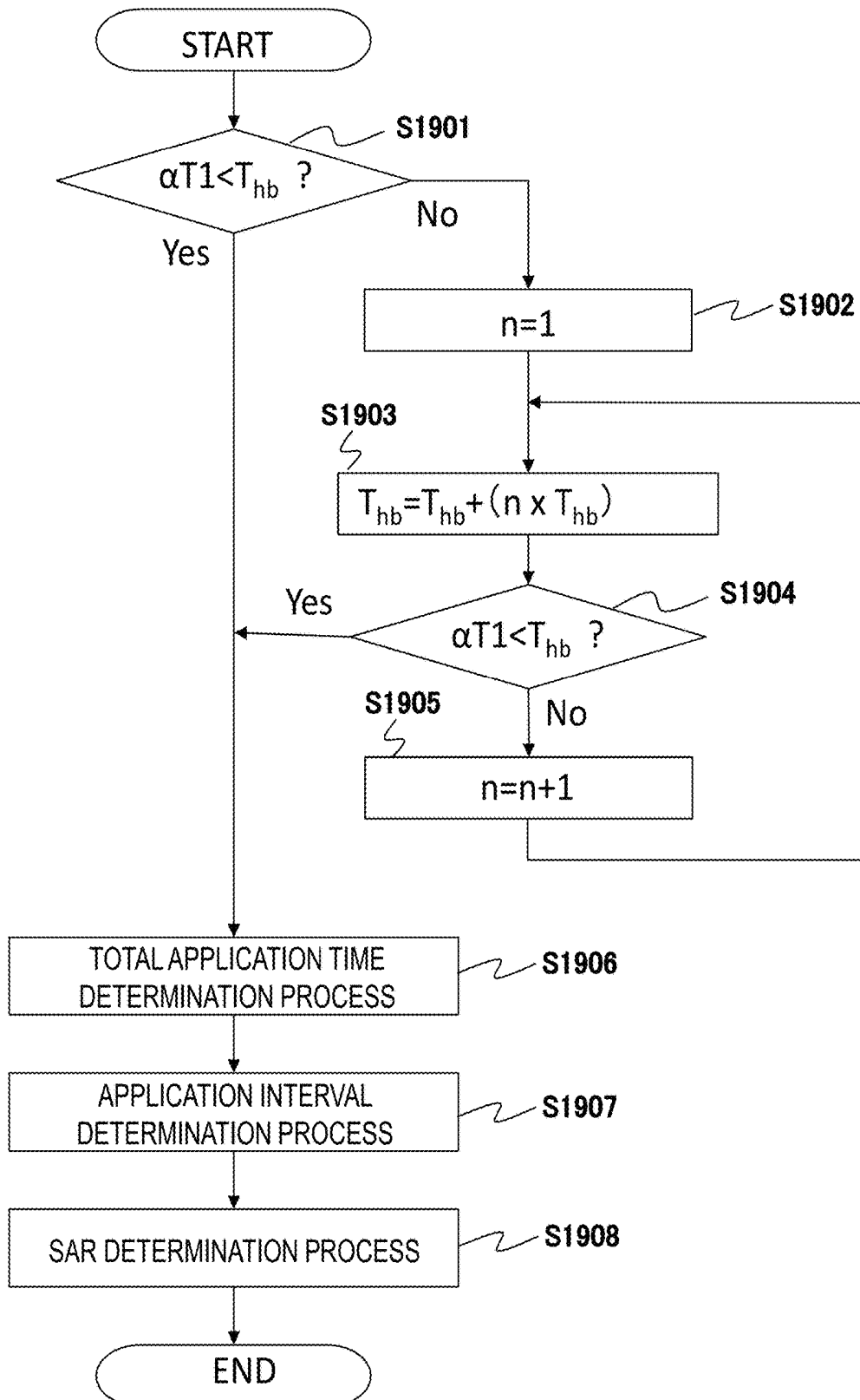


FIG. 19



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MAGNETIC RESONANCE IMAGING APPARATUS AND MAGNETIC RESONANCE IMAGING METHOD

TECHNICAL FIELD

The present invention relates to the Magnetic Resonance Imaging (hereinafter, referred to as MRI) technique and, in particular, to a technique for obtaining hemodynamic information in combination of an IR (Inversion Recovery) pulse and a two-dimensional selective RF pulse (hereinafter, referred to as a 2DRF pulse).

BACKGROUND ART

When liver cirrhosis progresses and an artery aneurysm is formed by blood in the portal vein flowing into the esophageal vein or the like, which increase the risk of esophageal varix rupture or the like. Therefore, it is necessary to visualize the portal system.

In order to visualize blood with an MRI apparatus, there is a method using an IR pulse. For example, entire magnetization is inverted using a first IR pulse that does not perform slice selection, and then a second slice selective IR pulse that performs slice selection is applied so that the regional blood flowing into an imaging surface is recovered from the magnetization. Then, imaging is performed after timings (TI) where the magnetization of the background tissue in the imaging surface becomes Null (for example, refer to Non-patent Literature 1).

Hence, the background tissue is suppressed, and additionally, and the blood flowed into the imaging surface between TIs can be visualized at a high signal.

Also, there is a method for applying a slice selective IR pulse to an imaging surface and imaging after a timing (TI) at which the magnetization of the background tissue becomes Null using the same IR pulse (for example, refer to Non-patent Literature 2).

Hence, the background tissue is suppressed, and additionally, blood flowed into an imaging surface between TIs is visualized at a high signal.

Also, the TOF imaging (Selective TOF MRA) in which a 2D RF pulse is applied as a pre-saturation pulse (Beam Sat pulse) to check a dominant region of a certain blood vessel is also known as the other blood vessel visualization method (for example, refer to Non-patent Literature 3).

CITATION LIST

Non-Patent Literature

- NPTL 1: Hitoshi Kanazawa and Mitsue Miyazaki, et al., "Time-Spatial Labeling Inversion Tag (t-SLIP) using a Selective IR-Tag ON/OFF Pulse in 2D and 3D half-Fourier FSE as Arterial Spin Labeling" Proc. Intl. Soc. Mag. Reson. Med. 10 (2002)
- NPTL 2: Isao Kanamori, Akitoshi Fujino, and Masami Niwa, "MRI of practice" (2011) p. 321-324
- NPTL 3: Takashi Nishihara, et al., "Selective TOF MRA using Beam Saturation pulse", Proc. ISMRM 2012, 2497

SUMMARY OF INVENTION

Technical Problem

The blood vessel visualization method using an IR pulse disclosed in Non-patent Literature 1 or 2 needs to apply an

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IR pulse to a large region in order to perform labeling for all blood flowing into the region. For example, if an IR pulse is applied to a narrow range in a regionally selective manner in order to visualize a dominant region of a certain blood vessel, and this results in an insufficient amount of blood to be labeled, which reduces the blood vessel visualization ability. Therefore, the details of the blood path and the flow velocity cannot be checked sufficiently. Also, although a blood flow path can be visualized in Selective TOF MRA disclosed in Non-patent Literature 3, it is difficult to visualize blood in the portal system where the blood flow velocity is slow compared to the head and the blood flow direction is complicated.

For example, although only blood in a certain region can be suppressed by combining the blood vessel visualization method using an IR pulse with a slice-selective type of pre-saturation pulse, only a certain blood vessel with a complicated structure such as a portal vein cannot be suppressed selectively. On the other hand, only a certain blood vessel can be suppressed selectively by applying the Beam Sat pulse disclosed in Non-patent Literature 3 to the blood vessel visualization method using an IR pulse. However, because the region to be suppressed is narrow, blood that is not suppressed by the Beam Sat pulse flows into the imaging region, only partial blood is suppressed, and the downstream blood cannot be suppressed. It is particularly unsuitable for TOF to visualize blood vessels of the portal system where the blood flow velocity is slow and the blood flow direction is complicated.

The present invention was made in light of the above problems and has a purpose to provide a technique in MRI for efficiently suppressing downstream blood in a certain region in a blood vessel such as a portal vein with a slow blood flow velocity.

Solution to Problem

The present invention combines a blood vessel visualization method using an IR pulse with a method in which a Beam Sat pulse is applied to a certain blood vessel as a pre-saturation pulse. At this time, in order to visualize hemodynamics of a desired blood vessel, a plurality of Beam Sat pulses are applied so that signals of blood flowing into a desired imaging region from the said blood vessel are equally suppressed between the IR pulse application and the start of main imaging. Application conditions of the plurality of the Beam Sat pulses achieving the above are determined based on a blood flow velocity in a desired blood vessel and the said blood TI.

Advantageous Effects of Invention

According to the present invention, downstream blood in a certain region can be suppressed efficiently in a blood vessel such as a portal vein with a slow blood flow velocity.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1(a) is a block diagram of the MRI apparatus of the first embodiment, and FIG. 1(b) is a functional block diagram of the control unit.

FIG. 2(a) is an explanatory diagram for explaining a slice selective excitation sequence, and FIG. 2(b) is an explanatory diagram for explaining a 2D RF sequence.

FIG. 3 is an explanatory diagram for explaining a blood flow to be suppressed in the first embodiment.

FIG. 4 is an explanatory diagram for explaining an example of the pulse sequence of the first embodiment.

FIGS. 5(a) to 5(d) are explanatory diagrams for explaining a relationship between a Beam Sat pulse, a suppressed blood flow, and T1.

FIG. 6 is a flow chart of the imaging process of the first embodiment.

FIG. 7 is a flow chart of the application condition determination process of the first embodiment.

FIG. 8 is an explanatory diagram for explaining an example of the pulse sequence of the second embodiment.

FIG. 9 is a functional block diagram of the control unit of the second embodiment.

FIG. 10 is a flow chart of the imaging process of the second embodiment.

FIG. 11 is an explanatory diagram for explaining the breathing instruction display of the second embodiment.

FIG. 12 is a flow chart of the imaging process of the third embodiment.

FIG. 13 is an explanatory diagram for explaining an example of the pulse sequence of the fourth embodiment.

FIG. 14(a) is a functional block diagram of the control unit of the fifth embodiment, and FIG. 14(b) is a functional block diagram of the control unit in a variation of the fifth embodiment.

FIG. 15 is an explanatory diagram for explaining the flow velocity calculation principle of the fifth embodiment.

FIG. 16 is an explanatory diagram for explaining the measurement method of a non-suppression region using the flow velocity calculation section of the fifth embodiment.

FIG. 17 is an explanatory diagram for explaining a display example of the suppression range of the fifth embodiment.

FIG. 18 is an explanatory diagram for explaining a pulse sequence of electrocardiographic synchronization in a variation of the fifth embodiment.

FIG. 19 is a flow chart of the application condition determination process during electrocardiographic synchronization in a variation of the fifth embodiment

DESCRIPTION OF EMBODIMENTS

First Embodiment

Hereinafter, the first embodiment applying the present invention will be described. In all the diagrams for explaining the embodiments of the present invention, the same symbols are provided basically for the same functions, and the repeated explanations will be omitted.

First, the configuration of the MRI apparatus of the present embodiment will be described. FIG. 1(a) is a block diagram of the MRI apparatus 100 of the present embodiment. The MRI apparatus 100 of the present embodiment is an apparatus that obtains a tomographic image of the object 101 using the NMR phenomenon. As shown in FIG. 1(a), the static magnetic field generating magnet 102, the gradient magnetic field coil 103, the gradient magnetic field power sources 106, the transmission RF coil (transmission coil) 104, the RF transmission unit 107, the reception RF coil (reception coil) 105, the signal detection unit 108, the signal processing unit 109, the sequencer 110, the control unit 120, the display unit 121, the operation unit 122, the storage unit 123, and the bed 111 that places the object 101 and carries the object 101 out of/in the inside of the static magnetic field generating magnet 102 are included.

The static magnetic field generating magnet 102 functions as a static magnetic field generating unit generating a static magnetic field. The static magnetic field generating magnet

102 generates a homogeneous static magnetic field respectively in a direction orthogonal to the body axis of the object 101 in case of the vertical magnetic field system or in the body axis in case of the horizontal magnetic field system, and a static magnetic field generation source of the permanent magnet system, the normal conduction system, or the superconducting system is disposed near the object 101.

The gradient magnetic field coil 103 and the gradient magnetic field power sources 106 function as a gradient magnetic field application unit applying a gradient magnetic field to the object 101 disposed in a static magnetic field. The gradient magnetic field coil 103 is coils wound in the three axis directions X, Y, and Z that are the real space coordinate system (static coordinate system) of the MRI apparatus. The respective gradient magnetic field coils are connected to the gradient magnetic field power sources 106 that drive them and to which an electric current is supplied. Specifically, the gradient magnetic field power sources 106 of the respective gradient magnetic field coils are respectively driven according to the command from the sequencer 110 to be described later and supply an electric current to the respective gradient magnetic field coils. Hence, the gradient magnetic fields Gx, Gy, and Gz are generated in the three axis directions X, Y, and Z.

For example, when imaging a two-dimensional slice plane, a slice gradient magnetic field pulse (Gs) is applied in a direction orthogonal to a slice plane (cross section to be imaged), which sets the slice plane for the object 101. A phase-encoding gradient magnetic field pulse (Gp) and a frequency encoding (readout) gradient magnetic field pulse (Gf) are applied in the other two directions that are orthogonal to the slice plane and are orthogonal to each other, and then positional information in the respective directions are encoded for an echo signal.

The transmission coil 104 and the RF transmission unit 107 function as a high-frequency magnetic field transmission unit transmitting a high-frequency pulse (RF pulse) that excites magnetization of the object 101 at a predetermined flip angle. The transmission coil 104 is a coil to irradiate an RF pulse to the object 101 and is connected to the RF transmission unit 107, and an RF pulse current is supplied from the RF transmission unit 107. By irradiating an RF pulse to the object 101 from the transmission coil 104, the NMR phenomenon is induced to nuclear spins of atoms composing biological tissues of the object 101.

Specifically, the RF transmission unit 107 is driven according to the command from the sequencer 110 to be described later, performs amplitude modulation for a high-frequency pulse, and the high-frequency pulse is amplified and supplied to the transmission coil 104 disposed in the vicinity of the object 101. The supplied high-frequency pulse is irradiated to the object 101 from the transmission coil 104.

The reception coil 105 and the signal detection unit 108 function as a signal reception unit receiving an echo signal generated by the object 101. The reception coil 105 is a coil to receive an NMR signal (echo signal) emitted by the NMR phenomenon of nuclear spins composing biological tissues of the object 101, is connected to the signal detection unit 108, and transmits a received echo signal to the signal detection unit 108. The signal detection unit 108 performs a detection process for the echo signal received by the reception coil 105.

Specifically, a responding echo signal of the object 101 induced by an RF pulse irradiated from the transmission coil 104 is sent to the signal detection unit 108 after being received in the reception coil 105 disposed in the vicinity of

the object **101**. The signal detection unit **108** amplifies a received echo signal according to the command from the sequencer **110** to be described later, divides the echo signal into orthogonal two-system signals by quadrature phase detection, samples each signal in a predetermined number (for example, 128, 256, 512, or the like), performs A/D conversion for each sampled signal into a digital amount, and then sends it to the signal processing unit **109** to be described later. Thus, an echo signal is obtained as time-series digital data (hereinafter, referred to as echo data) comprised of the predetermined number of sampling data.

The signal processing unit **109** performs various signal processes for echo data and sends the processed echo data to the control unit **120**.

The sequencer **110** transmits various commands for data collection required for reconstructing a tomographic image of the object **101** mainly to the gradient magnetic field power sources **106**, the RF transmission unit **107**, and the signal detection unit **108** and controls them. Specifically, the sequencer **110** operates by control of the control unit **120** to be described later, controls the gradient magnetic field power sources **106**, the RF transmission unit **107**, and the signal detection unit **108** according to the imaging sequence, applies an RF pulse and a gradient magnetic field pulse to the object **101**, repeats detection of an echo signal from the object **101**, and then collects echo data required for reconstructing an image in an imaging region of the object **101**.

The control unit **120** controls the sequencer **110**, processes various data, displays process results, performs control such as storage, and includes a CPU and a memory inside. In the present embodiment, an image is reconstructed from an echo signal received by the above signal reception unit, and commands to control operations of a gradient magnetic field application unit, high-frequency magnetic field transmission unit, and signal reception unit are provided to the sequencer **110** according to the imaging sequence. Additionally, the imaging sequence is generated by imaging parameters set by a user and a pulse sequence specified by a user.

The control unit **120** of the present embodiment specifically controls the sequencer **110** to execute echo data collection and stores the collected echo data in a region equivalent to k-space of a memory based on encoding information applied to the echo data. An echo data group stored in the region equivalent to k-space of a memory is also referred to as k-space data. Then, a signal process for the k-space data and a process such as image reconstruction by the Fourier transform are executed, and the result image of the object **101** is displayed on the display unit **121** to be described later and is recorded in the storage unit **123**.

The display unit **121** and the operation unit **122** are interfaces to communicate various control information of the MRI apparatus **100**, information required for arithmetic processing, and the arithmetic processing results with a user. The MRI apparatus **100** of the present embodiment receives an input from a user through the display unit **121** and the operation unit **122**. The operation unit **122** is disposed in the vicinity of the display unit **121** and controls various processes of the MRI apparatus **100** interactively through the operation unit **122** by an operator checking the display unit **121**. For example, the display unit **121** displays a reconstructed image of the object **101**. Also, the operation unit **122** is provided with at least one of input devices such as a trackball, a mouse, and a keyboard.

The storage unit **123** stores information required for operations of the MRI apparatus **100**, data while being

processed, and the like. For example, the storage unit **123** is comprised of an optical disk, a magnetic disk, or the like.

Additionally, in FIG. 1(a), the transmission coil **104** and the gradient magnetic field coil **103** are installed in the static magnetic field space of the static magnetic field generating magnet **102** where the object **101** is to be inserted so that they are opposite to the object **101** in case of the vertical magnetic field system or so that they surround the object **101** in case of the horizontal magnetic field system. Also, the reception coil **105** is installed so that it is opposite to or surrounds the object **101**.

Also, for example, in case of imaging in synchronization with periodic body motion of the object **101** similarly to respiration synchronized imaging, the body motion detection device **124** that detects the periodic body motion of the object **101** may be further provided. The body motion detection device **124** is installed in a position where body motion of the object **101** to be detected can be detected. The detected body motion information is sent to the control unit **120**.

A clinically prevalent nuclide to be imaged by the MRI apparatus **100** is a hydrogen nucleus (proton) that is a main structural component of the object **101**. The MRI apparatus **100** two- or three-dimensionally images shapes or functions of the human head, abdomen, extremities, and the like by imaging information about spatial distribution of the proton density and spatial distribution of the relaxation time of an excitation state. At this time, in MRI, an RF pulse is applied together with a gradient magnetic field in order to excite only protons in a certain region.

As the certain region, FIG. 2(a) shows an example of the pulse sequence (slice selective excitation sequence) **210** in case of selectively exciting an arbitrary slice having a thickness in the one-dimensional direction. Hereinafter, RF, Gx, Gy, and Gz in the pulse sequence diagrams of the present description shows application timings of an RF pulse, a gradient magnetic field in the x-axis direction, a gradient magnetic field in the y-axis direction, and a gradient magnetic field in the z-axis direction respectively.

In the slice selective excitation sequence **210**, as shown in the present diagram, the slice selective gradient magnetic field **212** is applied in any one direction of Gx, Gy, and Gz at the same time as the RF pulse **211**. Here, the application in the Gz direction is shown as an example. Hence, a predetermined slice in which only a position in the z-axis direction is specified is excited selectively.

Also, as the certain region, FIG. 2(b) shows an example of the pulse sequence in case of selectively exciting a region two- or three-dimensionally. Here, as an example, the two-dimensional spatial selective excitation sequence (2D RF sequence) **220** that selectively excites a region two-dimensionally is shown.

As shown in the present diagram, the 2D RF sequence **220** includes the two-dimensional selective excitation pulse (hereinafter, referred to as a 2D RF pulse) **221** and the vibration gradient magnetic field pulse **222**. Here, a case where the vibration gradient magnetic field pulse **222** is applied in the Gx and Gy directions is shown as an example. By these 2D RF pulse **221** and the vibration gradient magnetic field pulse **222**, only a certain cylindrical region is excited selectively. Additionally, the 2D RF pulse **221** is a pencil beam type of excitation RF pulse that excites a cylindrical region.

Generally, when a crusher gradient magnetic field pulse is applied after an RF pulse, a signal of a region to which the RF pulse was applied is suppressed. In the 2D RF sequence **220** of the present embodiment, the crusher gradient mag-

netic field pulse **223** is applied to the respective gradient magnetic field application axes after applying the vibration gradient magnetic field pulse **222**.

Blood magnetization in a certain blood vessel is suppressed by combining the 2D RF pulse **221** with the vibration gradient magnetic field pulse **222** and the crusher gradient magnetic field pulse **223** to apply as a pre-saturation pulse and performing TOF imaging, which can check a dominant region of the blood vessel. Hereinafter, in the present description, a set of the 2D RF pulse **221**, the vibration gradient magnetic field pulse **222**, and the crusher gradient magnetic field pulse **223** to be applied as a pre-saturation pulse is referred to as a Beam Sat pulse.

In the present embodiment, a blood vessel visualizing method using an IR pulse is combined with a method of applying a Beam Sat pulse to a certain blood vessel as a pre-saturation pulse. At this time, in order to visualize hemodynamics of a desired blood vessel, a plurality of Beam Sat pulses are applied so that signals of blood flowing from the said desired blood vessel to a desired imaging region are equally suppressed between the IR pulse application and the main imaging start. Application conditions of the plurality of Beam Sat pulses to achieve this are determined based on a blood flow velocity in a desired blood vessel and the said blood T1.

In the present embodiment, a case where an imaging target is the portal vein of the liver as shown in FIG. 3 will be described as an example. As shown in the present diagram, blood flows into the portal vein of the imaging region from the superior mesenteric vein, the splenic vein, and the like. Also, all the blood flowing into the liver region from these veins does not necessarily flow into the portal vein and flows also to the esophageal vein, the periumbilical vein, and the like. In the present embodiment, for example, a plurality of Beam Sat pulses are applied to a predetermined region on the superior mesenteric vein in the period between the IR pulse application and the main imaging start in order to surely suppress only blood flowing from the superior mesenteric vein to the portal vein, which can observe the hemodynamics.

In order to achieve this, the control unit **120** of the present embodiment, as shown in FIG. 1(b), collects echo signals from an imaging region according to the imaging sequence and includes the imaging section **130** that reconstructs an image from the said echo signals and the imaging sequence generation section **140** that applies imaging conditions to a predetermined pulse sequence to generate the imaging sequence.

The imaging section **130** controls each portion of the MRI apparatus **100** according to the imaging sequence generated by the imaging sequence generation section **140** or the predetermined imaging sequence and executes imaging.

Specifically, the imaging section **130** provides commands to the sequencer **110** according to the imaging sequence to obtain an echo signal. Then, the Fourier transform is provided for the obtained echo signal in order to reconstruct an image. The present embodiment performs blood vessel imaging and positioning image acquisition imaging.

The pulse sequence **400** used in the present embodiment is comprised of the IR (Inversion Recovery) pulse **421** and a plurality of the Beam Sat pulses (two-dimensional selective high-frequency pulses) **422** as shown in FIG. 4. In the present embodiment, the IR pulse **421** is synchronized with the respiratory motion (the respiratory waveform **401**) and applied, and the plurality of the Beam Sat pulses **422** are applied during the TI period **403** between the IR pulse **421** and the main imaging **423**.

Also, the imaging sequence generation section **140** is provided with the reception part **141** that receives imaging conditions including application conditions of the plurality of the Beam Sat pulses (two-dimensional selective high-frequency pulses) **422** from a user and the application condition determination part **142** that determines the application conditions (applied application conditions) used in an imaging sequence from the application conditions (set application conditions) of the plurality of the Beam Sat pulses (two-dimensional selective high-frequency pulses) **422** set as the imaging conditions. At this time, the application condition determination part **142** determines the applied application conditions so as to suppress the echo signal from blood in a desired blood vessel.

Additionally, in the present description, application conditions to be determined by the application condition determination part **142** include the total application time **411** and the application interval **412** of the plurality of the Beam Sat pulses (two-dimensional selective high-frequency pulses) **422** as well as the amplitude **414** and the pulse width **415** of each Beam Sat pulse (two-dimensional selective high-frequency pulse) **422**.

The reception part **141** displays a screen that is to be a user interface on the display unit **121** and receives application conditions of a plurality of the Beam Sat pulses **422** through the said screen. At this time, an example of the screen to be displayed as a user interface will be described using FIGS. 3 and 4.

A display example of an application position reception screen will be described using FIG. 3. The positioning image **350** obtained by the imaging section **130** is displayed on the application position reception screen. A user specifies a blood vessel to be suppressed on the positioning image **350** and sets the application position **301** of the Beam Sat pulse **422**. Additionally, a region to be suppressed may be displayed clearly by a method such as hatching the region (periphery) **302** to be suppressed by the Beam Sat pulse **422**. The reception part **141** receives the application position **301** of the Beam Sat pulse **422** on the positioning image **350** in the application position reception screen.

The Beam Sat pulse setting screen display example **360** will be described using FIG. 4. In the present embodiment, respiration synchronized imaging is performed. Therefore, the respiratory waveform **401**, the IR pulse **421**, the application timing **402**, the start timing **405** of the main imaging **423**, and the execution period **406** in the pulse sequence **400** are displayed on the Beam Sat pulse setting screen display example **360**.

In case of applying the pre-pulse **424** other than the Beam Sat pulse **422** before the main imaging **423**, the application period **407** is also displayed.

A user sets the total application time **411** of the Beam Sat pulses **422**, the application interval **412**, the amplitude **414**, and the pulse width **415** through this screen. The reception part **141** receives the settings by the user as the set application conditions.

Also, in the diagram, **413** is the number of applications by the Beam Sat pulse **422**, **408** is the application start timing of the Beam Sat pulse **422**, and **409** is the application end timing. Also, **403** is the time from applying the IR pulse **421** to starting the main imaging **423**. In case of not applying the Beam Sat pulse **422**, the blood flowing into an imaging region meanwhile is visualized at a high signal. Also, **404** is the time from applying the IR pulse **421** to starting application of the Beam Sat pulse **422**. The blood flowing meanwhile is visualized at a high signal because it is not suppressed by the Beam Sat pulse **422**.

Additionally, application conditions related to a plurality of the Beam Sat pulses **422** that is set by a user are not limited to the total application time **411** and the application interval **412**. Two of the total application time **411**, the application interval **412**, and the number of application times **413** should be set.

Additionally, the initial values of application conditions of the Beam Sat pulse **422** are stored in the storage unit **123**, and it may be configured so that the initial values are displayed and adjusted by a user. For example, the adjustment may be configured so as to perform by inputting values directly or may be configured so as to display a slide bar etc. and receive the operation.

Additionally, the initial values to be stored may be associated with, for example, an imaging site, a blood vessel to be suppressed, and the like.

The application condition determination part **142** of the present embodiment determines whether or not to apply set application conditions of a Beam Sat pulse received by the reception part **141** and decides the application conditions to be eventually used for imaging. Specifically, the application condition determination part **142** suppresses blood in a desired range as well as determines the total application time **411** so as not to exceed a predetermined period determined by a T1 recovery time (hereinafter, referred to as T1 simply) of blood to be suppressed by a Beam Sat pulse, determines the application interval **412** so as to suppress blood flowing into an imaging region continuously (desirably in a continuous manner without interruption), and determines the amplitude **414** so as not to exceed a limitation by SAR (Specific Absorption Rate) as well as determines the pulse width **415** according to the determined amplitude **414** while maintaining an application area of the Beam Sat pulse (two-dimensional selective high-frequency pulse).

Additionally, when the number of application times **413** is set, the total application time **411** and the application interval **412** are obtained using the number of application times **413** and the other set application conditions, and then the above application condition determination process is performed.

In order to achieve this, the application condition determination part **142** of the present embodiment performs the three determination process: (i) the total application time determination process for determining whether or not the total application time **411** has a length in which blood in a desired range can be suppressed and is sufficiently shorter compared to the recovery time T1 of longitudinal magnetization components of blood; (ii) the application interval determination process for determining whether or not the application interval **412** is an interval that can be suppressed continuously without interruption; and (iii) the SAR determination process for determining whether or not the application conditions satisfy the SAR regulations that is an absorption amount of an RF pulse per unit time and unit mass.

First, the total application time determination process will be described. When setting the total application time **411** as T_{all} [sec], a suppressible blood vessel length L [cm] is determined by a total application time as T_{all} and a blood flow velocity V [cm/sec]. In a range where the T1 recovery can be ignored, the relationship of these is expressed in the following formula (1).

$$L = V \times T_{all} \quad (1)$$

As shown in FIG. 5(a), the Beam Sat pulse **422** is applied in the application position **301**, and the suppressed blood proceeds by L during a total application time T_{all} as shown in FIG. 5(b). Therefore, in case of a short total application

time T_{all} , a suppressible blood vessel length L becomes too short to obtain a sufficient suppression effect. Therefore, the application condition determination part **142** of the present embodiment compares a total application time T_{all} input by an operator with a predetermined first threshold value and sets the total application time T_{all} as the said first threshold value in case of equal to or less than the first threshold value. The first threshold value is determined in advance so as to be suppressible by a desired distance L.

Also, in a case where T1 of blood is longer compared to a total application time T_{all} ($T_{all} < T1$), the suppressed blood reaches a distance L as is. However, in a case where the T1 recovery cannot be ignored, that is, in a case where a total application time T_{all} is considerably longer compared to T1, the T1 recovery is performed until blood suppressed in the Beam Sat pulse application position **301** reaches the periphery **302** as shown in FIGS. 5(c) and 5(d). Therefore, the region **303** that is insufficiently suppressed is generated. Therefore, the application condition determination part **142** of the present embodiment compares a total application time T_{all} input by an operator with a predetermined second threshold value and sets the total application time T_{all} as the said second threshold value in case of more than the second threshold value. The second threshold value is determined in advance in a range where the total application time T_{all} is not affected by the T1 recovery.

In the present embodiment, a blood flow velocity V and a T1 value of an anatomical imaging site are kept in advance. Additionally, a value measured by the Phase Contrast method or the like in advance may be used for the blood flow velocity V. Then, the application condition determination part **142** acquires a T1 value of the said site from imaging site information input as an imaging condition by an operator and calculates the above first and second threshold values using the T1 value to determine whether or not to apply a total application time T_{all} input by the operator. The first threshold value is expressed as $\beta T1$ for which the T1 value is multiplied by a coefficient β . Also, the second threshold value is expressed as $\alpha T1$ for which the T1 value is multiplied by a coefficient α . Here, these coefficients are $0 < \beta < \alpha$ and $\beta \leq 1$. Therefore, the application condition determination part **142** determines whether or not the total application time T_{all} is in a range where it is larger than $\beta T1$ and equal to or less than $\alpha T1$.

Additionally, it may be configured so as to output a message for attracting attention to a user in a case where the total application time T_{all} is out of the above range. Further, in this case, the total application time **411** is not automatically set to $\beta T1$ or $\alpha T1$ again as described above, but a suggestion that a total application time T_{all} is extended or shortened is presented to a user, and it may be configured so as to set it again through the application position reception screen. Also, $\alpha T1$ may be set as a maximum value of T1 that can be input.

Next, the application interval determination process will be described. In a blood vessel range to be suppressed by one application of the Beam Sat pulse **422**, the time required for blood in the highest flow to reach the lowest flow (moving time) is determined by an application width (suppression width) φ [cm] of the Beam Sat pulse **422** and a blood flow velocity V. Therefore, as shown in the following formula (2), in a case where the application interval **412** T_{inv} is longer than a moving time for which a suppression width φ of the Beam Sat pulse **422** was divided by a blood flow velocity, blood that is not suppressed by the Beam Sat pulse **422** is

generated. If such blood flows into an imaging region, a suppression rate is reduced. Additionally, φ is the diameter of the Beam Sat pulse 422.

$$T_{inv} > \varphi/V \quad (2)$$

The application condition determination part 142 of the present embodiment determines the application interval 412 set by a user as the application interval 412 used for imaging in a case where the application interval T_{inv} set by the user does not satisfy the formula (2). On the other hand, in a case where the application interval T_{inv} is long, the calculated moving time is set as the application interval 412 used for imaging.

Next, the SAR determination process will be described. When an RF pulse is continuously irradiated, an SAR problem is generated. If an SAR of the Beam Sat pulse 422 according to the application condition set by a user exceeds a regulated value, the application condition of the Beam Sat pulse 422 needs to be changed to reduce the SAR.

The SAR is an absorption amount of an RF pulse per unit time and unit mass and can be reduced by extending the application interval 412 of the Beam Sat pulse 422. Also, the SAR is determined by the amplitude 414 and the pulse width 415 of the RF pulse and can be reduced by suppressing the amplitude 414 of the Beam Sat pulse.

In the present embodiment, because the application interval 412 affects a suppression rate as described above, it is desirable not to change the application interval 412 after determining using the above method. Therefore, the application interval is fixed, and the amplitude 414, which reduces an SAR. That is, the application condition determination part 142 of the present embodiment reduces the amplitude 414 of the Beam Sat pulse 422 so that an SAR calculated under the application conditions set by a user is within a regulated range in case of exceeding the regulated value. At the same time, the pulse width 415 is extended so as to keep an application area [$pT \cdot sec$] of the Beam Sat pulse 422 constant.

An SAR is proportional to the square of the amplitude 414 and the pulse width 415. Therefore, for example, when the amplitude 414 is reduced to $1/k$ of the original, the pulse width 415 is extended to k^2 times of the original.

Additionally, when an RF pulse amplitude is small, more advanced control is required for the hardware.

According to the hardware, the lowest RF pulse amplitude that can be controlled is determined in advance. In a case where the minimum value of the controllable RF pulse amplitude is stored in the storage unit 123 to reduce the amplitude 414, the calculated amplitude 414 is compared with the minimum value, and in a case where the calculated amplitude 414 is less than the minimum value, it may be configured so as to notify a user of the case.

Next, the imaging process flow by the control unit 120 of the present embodiment will be described. FIG. 6 is a process flow of the imaging process of the present embodiment. The imaging process of the present embodiment starts after a command from a user. Hereinafter, a case of respiration synchronized imaging will be described as an example.

The imaging section 130 obtains a positioning image (Step S0601, not shown in the diagram). A pulse sequence and imaging parameters when imaging the positioning image are set in advance. In the present embodiment, for example, the hemodynamics of the portal vein of the liver is observed. Therefore, for example, a positioning image in which the entire liver was imaged is obtained here.

Next, the reception part 141 generates an application position reception screen for determining the position 301 where the Beam Sat pulse 422 is applied and an imaging condition reception screen including an application condition setting window for setting application conditions, and then displays them on the display unit 121. Then, the application position 301 and the application conditions are received through these screens (Step S0602). The application conditions are any two of the total application time 411, the application interval 412, and the number of application times 413 of Beam Sat pulses as well as the amplitude 414 and the pulse width 415 as described above.

The application condition determination part 142 performs the above respective determination processes and performs an application condition determination process for determining application conditions (Step S0603).

The imaging sequence generation section 140 reflects the determined application conditions to generate an imaging sequence (Step S0604). Then, the imaging section 130 executes imaging (Step S0605) according to the generated imaging sequence and ends the process.

Next, the application condition determination process flow of the present embodiment will be described. FIG. 7 shows a process flow of the application condition determination process.

The application condition determination part 142 first performs a total application time determination process. Here, whether or not a total application time T_{all} is within a range determined by $\beta T1$ and $\alpha T1$ (Step S0701). Then, when it is within the range, the set total application time is determined as a total application time used for imaging (Step S0702). On the other hand, when it is out of the range, a message is displayed to a user (Step S0703), and then the reception part 141 receives an adjustment input (Step S0704). Then, the procedure goes back to Step S0701 to perform the determination again.

Additionally, when a total application time is out of the range, the total application time used for imaging may be automatically determined as $\beta T1$ or $\alpha T1$ as described above.

Next, the application condition determination part 142 performs an application interval determination process. Here, whether or not an application interval T_{inv} is that can suppress blood without interruption is determined (Step S0705).

When the application interval can suppress blood, the set application interval T_{inv} is determined as an application interval used for imaging (Step S0706). On the other hand, when the application interval cannot suppress blood, the application condition determination part 142 calculates an application width φ/a blood flow velocity V (Step S0707) and then determines it as an application interval used for imaging (Step S0706).

Next, the application condition determination part 142 performs an SAR determination process. Here, whether or not an SAR value (SAR_{cal}) by application conditions determined so far satisfies a regulated value of SAR (SAR_{res}) is determined (Step S0708). When the regulated value is satisfied, the set amplitude and pulse width are determined as those used for imaging (Step S0709). On the other hand, when the regulated value is not satisfied, it is adjusted so as to reduce the amplitude and expand the pulse width by the reduced amount (Step S0710), and the results are determined as the amplitude and the pulse width used for imaging (Step S0709).

Additionally, in the above application condition determination process, either of the total application time determi-

nation process or the application interval determination process may be performed first

Also, each function of the control unit 120 is achieved, for example, by loading a program previously stored in the storage unit 123 to the memory by the CPU and executing the program.

As described above, the MRI apparatus 100 of the present embodiment is provided with the imaging sequence generation section 140 that applies imaging conditions to a predetermined pulse sequence to generate an imaging sequence and the imaging section 130 that collects echo signals from an imaging region according to the imaging sequence to reconstruct an image from the said echo signals, the pulse sequence includes an IR (Inversion Recovery) pulse and a plurality of the two-dimensional selective high-frequency pulses 422, the imaging conditions include application conditions of the two-dimensional selective high-frequency pulses, the imaging sequence generation section 140 includes the application condition determination part 142 that determines a suitability of the set application conditions and determines application conditions used for the imaging sequence (applied application conditions) according to the determination result, and the application condition determination part 142 determines the applied application conditions so as to suppress the echo signals from blood in a desired blood vessel within SAR (Specific Absorption Rate) limitation.

The application conditions are the total application time 411 and the application interval 412 of the plurality of the two-dimensional selective high-frequency pulses 422 as well as the amplitude 414 and the pulse width 415 of the respective two-dimensional selective high-frequency pulses 422, and then the application condition determination part 142 suppresses blood in a desired range as well as determines the said total application time 411 so as not to exceed a predetermined period determined by a T1 recovery time of the blood, determines the application interval 412 so as to suppress blood flowing into the imaging region continuously without interruption, and determines the amplitude 414 so as not to exceed the limitation by SAR as well as determines the pulse width 415 according to the determined amplitude 414 while maintaining an application area of the two-dimensional selective high-frequency pulse 422.

Thus, according to the present embodiment, when combining the blood vessel visualization method using an IR pulse with a Beam Sat pulse, application conditions of a plurality of Beam Sat pulses are determined so as to equally suppress a signal of blood flowing into a desired imaging region from a desired blood vessel before imaging. Therefore, regardless of a flow velocity of a blood vessel to be imaged, blood in the section lower than an application position of a Beam Sat pulse can be suppressed efficiently, which can surely suppress blood flowing into a desired imaging region from a desired blood vessel to visualize the blood.

Second Embodiment

The second embodiment of the present invention will be described. The present embodiment considers body motion displacement of a blood vessel to be imaged. Hereinafter, an example of a case where body motion to be synchronized is assumed to be respiratory motion will be described in the present embodiment.

For example, when imaging is performed by synchronizing with respiratory motion of the object 101, there is a case where the respiratory cycle (respiratory waveform) 401

becomes as long as 401' as shown in FIG. 8. When a blood vessel to be suppressed is displaced according to respiratory motion, there is a case of generating suppression failure in which an irradiation position of the Beam Sat pulse 422 deviates from a blood vessel to be irradiated during the total application time 411. There is also a case where an unintended blood vessel and tissue are suppressed, which can cause examination failure. In order to avoid the failure, echo signals obtained in main imaging are sorted according to the application start timing 408 of the respiratory waveform 401 and the Beam Sat pulse 422 in the present embodiment.

The MRI apparatus of the present embodiment basically has a similar configuration to the MRI apparatus 100 of the first embodiment. However, in the present embodiment, the body motion displacement of a blood vessel to be imaged is considered to sort echo signals as described above. Therefore, as shown in FIG. 9, further provided are the body motion detection section 150 that detects a displacement amount by periodic body motion of an object after the peak and the adoption/rejection determination section 160 that determines the adoption or rejection of the echo signals collected by the imaging section 130 according to the relationship between the displacement amount and an application start timing of a Beam Sat pulse (two-dimensional selective high-frequency pulse) specified by the application conditions determined by the application condition determination part 142 (applied application conditions). Hereinafter, the configuration different from the first embodiment will be mainly described in the present embodiment.

The body motion detection section 150 of the present embodiment calculates a displacement amount h of a blood vessel to be applied at the Beam Sat pulse application start timing 408 determined by the total application time 411 under application conditions determined by the application condition determination part 142. The displacement amount is calculated based on body motion information from the body motion detection device 124. Additionally, the displacement amount h is, for example, a difference between H' and H of FIG. 8. Here, H is a breathing level of the normal respiratory cycle 401 at the Beam Sat pulse application start timing 408, and H' is a breathing level of the respiratory cycle 401' at the Beam Sat pulse application start timing 408.

The adoption/rejection determination section 160 determines whether or not to use echo signals measured by the imaging section 130 for reconstructing an image. In the present embodiment, the adoption or rejection is determined according to a displacement amount h at the application start timing 408 of the Beam Sat pulse detected by the body motion detection section 150. For example, as shown in FIG. 8, when the displacement amount h detected by the body motion detection section 150 is more than a predetermined threshold value h_0 , a rejection flag that instructs echo signal cancellation is set. Then, when the displacement amount h is equal to or less than a predetermined threshold value h_0 , the rejection flag is not set, and echo signals obtained in main imaging are adopted.

The imaging section 130 of the present embodiment reconstructs the image only from echo signals determined to be adopted by the adoption/rejection determination section 160. That is, the echo signals are measured as usual according to the main imaging sequence. Then, whether or not there is a rejection flag is determined, and an image is reconstructed from the obtained echo signals only when the rejection flag is not set. When the rejection flag is set, the said echo signals are cancelled and collected again. Addi-

tionally, the imaging section **130** releases the rejection flag setting after determining whether or not there is a rejection flag.

Next, the flow of the imaging process by the control unit **120** of the present embodiment will be described. Here, the process after generating an imaging sequence by the imaging sequence generation section **140** is described.

Hereinafter, an example of a case of respiration synchronized imaging will be described. FIG. **10** is a process flow of the imaging process of the present embodiment. Here, only the process in Step **S0604** of the first embodiment is shown. Imaging starts after receiving a start command from a user or after finishing an imaging sequence.

The body motion detection section **150** starts detecting body motion, and the imaging section **130** starts imaging according to the imaging sequence (Step **S1001**). At this time, the imaging section **130** applies the IR pulse **421** while synchronizing with a respiratory waveform detected by the body motion detection section **150**.

The body motion detection section **150** detects a displacement amount h at the Beam Sat pulse application start timing **408** determined by the application condition determination part **142** (Step **S1002**).

The adoption/rejection determination section **160** compares a detected displacement amount h with a threshold value h_0 (Step **S1003**). Then, when the displacement amount h is larger than the threshold value h_0 , a rejection flag is set (Step **S1004**). On the other hand, when the displacement amount h is equal to or less than the threshold value h_0 , the rejection flag is not set.

The imaging section **130** obtains an echo signal (Step **S1005**) and then determines whether or not a rejection flag is set before reconstructing an image (Step **S1006**), and when it is set, the said echo signal is cancelled (Step **S1007**), and then the process goes back to Step **S1001** without reconstructing an image. On the other hand, when the rejection flag is not set, an image is reconstructed (Step **S1008**), and then the process ends.

As described above, the MRI apparatus of the present embodiment is provided with the body motion detection section **150** that detects a displacement amount by periodic body motion of the object **101** after the peak and the adoption/rejection determination section **160** that determines the adoption or rejection of the echo signals collected by the imaging section **130** according to the relationship between the displacement amount h and the application start timing **408** of the two-dimensional selective high-frequency pulse **422** specified by the application conditions determined by the application condition determination part **142** in addition to the imaging section **130** and the imaging sequence generation section **140**, the imaging sequence is a body motion synchronization sequence, and the imaging section **130** reconstructs the image only from echo signals determined to be adopted by the adoption/rejection determination section **160**.

At this time, the adoption/rejection determination section **160** determines the echo signals obtained in the said imaging sequence to be adopted when the displacement amount h at the application start timing **408** is equal to or less than a predetermined threshold value h_0 .

Thus, according to the present embodiment, when a Beam Sat pulse is combined with the blood vessel visualization method using an IR pulse similarly to the first embodiment, applications conditions of a plurality of Beam Sat pulses are determined so as to equally suppress signals of blood flowing into a desired imaging region from a desired blood

vessel before imaging. Therefore, the similar effect to the first embodiment can be obtained.

Additionally, according to the present embodiment, echo signals obtained in the main imaging are sorted depending on the breathing level of a Beam Sat pulse application start timing. Therefore, a signal of suppression failure due to respiratory motion is not used for image reconstruction. Therefore, a desired blood flow can be suppressed with a high accuracy and imaged.

Additionally, a breathing instruction device is provided in the present embodiment, and it may be configured so that the breathing instruction device instructs the object **101** about a breath timing. The instruction is performed by, for example, specifying a timing of exhalation and inhalation so that a displacement amount at the Beam Sat pulse application start timing **408** is equal to or less than a threshold value. The instruction is performed using a voice, a monitor, stimulation by a stimulation device, or the like.

When instructing using a monitor, an example screen to be displayed to a user is shown in FIG. **11**. As shown in the present diagram, a summary of the application timings (**411** and **412**) of Beam Sat pulses determined by the application condition determination part **142** and the execution period **406** of the main imaging **423** is displayed along with the respiratory waveform **401**, and the user is prompted to breath so that a displacement timing does not exceed the Beam Sat pulse application start timing **408**. Here, as a summary, the application timing **402** of the IR pulse **421**, the application start timing **408** of the Beam Sat pulse **422**, the application end timing **409**, the main imaging start timing **405**, and the main imaging execution period **406** are shown for example.

Third Embodiment

The third embodiment of the present invention will be described. The present embodiment considers body motion displacement of a blood vessel to be imaged similarly to the second embodiment. In the present embodiment, the displacement of a blood vessel to be imaged is considered, application conditions of the Beam Sat pulse **422** are changed, and then cancellation of echo signals accordingly obtained is determined.

The MRI apparatus of the present embodiment basically has a similar configuration to the second embodiment. However, the processes of the body motion detection section **150**, the adoption/rejection determination section **160**, and the imaging section **130** are different in the present embodiment because displacement is considered to determine application conditions. Hereinafter, the processes different from the second embodiment will be mainly described in the present embodiment.

The body motion detection section **150** of the present embodiment monitors respiratory motion and notifies the application condition determination part **142** of a displacement amount at a predetermined time interval.

The imaging section **130** starts applying the Beam Sat pulse **422** at a later timing of the application start timing (setting timing) **408** of the Beam Sat pulse **422** specified by the application condition determination part **142** and a time equal to or less than a threshold value predetermined by a displacement amount (displacement timing). That is, when the setting timing **408** is earlier than the displacement timing, the application of the Beam Sat pulse **422** starts from the displacement timing instead of the setting timing **408**.

The adoption/rejection determination section **160** compares a displacement timing with the setting timing **408** and

determines echo signals obtained in the said imaging sequence (main imaging immediately after this) to be adopted when the setting timing 408 is the displacement timing or later and when the setting timing 408 is earlier than the displacement timing and a period from the displacement timing to the application end timing 409 of the two-dimensional selective high-frequency pulse specified by application conditions determined by the application condition determination part 142 is longer than a predetermined period. In the other cases, cancellation is determined, and then a cancellation flag is set.

Additionally, the adoption/rejection determination section 160 calculates a length L of a blood vessel to be suppressed during a total application time specified a time T_{all2} from a displacement timing to the application end timing 409 using the formula (1) when the setting timing 408 is earlier than the displacement timing. Then, whether or not the length is long enough to suppress a desired range is determined, and in case of enough length, echo signals obtained in the said imaging sequence (main imaging immediately after this) are determined to be adopted.

Additionally, the determination is performed by comparing a calculated time T_{all2} with a threshold value $\beta T1$ set in the first embodiment. In a case where $\beta T1 < T_{all2}$ is satisfied, the adoption is determined.

Next, the flow of the imaging process by the control unit 120 of the present embodiment will be described. Here, the process after an imaging sequence is generated by the imaging sequence generation section 140 is described.

Hereinafter, a case of respiration synchronized imaging will be described as an example. FIG. 12 is a processing flow of the imaging process of the present embodiment. Here, only the process in Step S0604 of the first embodiment is shown. Imaging starts after receiving a start command from a user or after finishing an imaging sequence.

The body motion detection section 150 starts detecting body motion, and the imaging section 130 starts imaging according to the imaging sequence (Step S1201). At this time, the imaging section 130 applies the IR pulse 421 according to the respiratory waveform detected by the body motion detection section 150.

Then, the imaging section 130 receives a displacement amount h at a predetermined time interval from the body motion detection section 150 (Step S1202). Waiting for the received displacement amount h becomes equal to or less than a threshold value h_0 after the amount exceeds the maximum value (Step S1203) is performed. The time when receiving the displacement amount h that became equal to or less than the threshold value h_0 is set as a displacement timing, and it is compared to a setting timing (Step S1204).

When a displacement timing (displacement T) is a setting timing (setting T) or later, Beam Sat pulse application starts immediately (Step S1205). At this time, the adoption/rejection determination section 160 specifies a total application time from this displacement timing and determines whether or not desired blood can be suppressed sufficiently by the total application time ($\beta T1 < T_{all2}$) (Step S1206).

Then, if impossible, a rejection flag is set (Step S1207). On the other hand, if possible, a rejection flag is not set.

On the other hand, when a displacement timing is before a setting timing, the imaging section 130 starts application of the Beam Sat pulse 422 at the setting timing (Step S1209).

The imaging section 130 starts main imaging after applying a Beam Sat pulse and the other predetermined pre-pulse and obtains an echo signal (Step S1210). Then, whether or not a rejection flag is set is determined (Step S1211), and if the rejection flag is set, the said echo signal is cancelled

(Step S1212), and then the process goes back to Step S1202 without reconstructing an image. On the other hand, if the rejection flag is not set, an image is reconstructed (Step S1213), and then the process ends.

Additionally, when it is determined that a length of the total application time 411 is insufficient in Step S1206, it may be configured so that a signal is not cancelled but Beam Sat pulse application itself is cancelled for the one cycle.

As described above, the MRI apparatus of the present embodiment is provided with the above imaging section 130, the imaging sequence generation section 140, the body motion detection section 150, and the adoption/rejection determination section 160 compares a displacement timing at which the displacement amount h becomes a predetermined threshold value H with the application start timing 408 and determines echo signals obtained in the said imaging sequence to be adopted when the application start timing 408 is after the displacement timing and when the application start timing 408 is earlier than the displacement timing and a period from the displacement timing to the application end timing 409 of the two-dimensional selective high-frequency pulse 422 specified by application conditions determined by the application condition determination part 142 is longer than a predetermined period, and then the imaging section 130 starts application of the two-dimensional selective high-frequency pulse 422 instead of the application start timing 408 from the displacement timing when the application start timing 408 is earlier than the displacement timing.

Thus, according to the present embodiment, when combining the blood vessel visualizing method using an IR pulse with a Beam Sat pulse similarly to the first embodiment, applications conditions of a plurality of Beam Sat pulses are determined so as to equally suppress signals of blood flowing into a desired imaging region from a desired blood vessel before imaging. Therefore, the similar effect to the first embodiment can be obtained.

Additionally, according to the present embodiment, echo signals obtained in main imaging are sorted depending on the breathing level of a Beam Sat pulse application start timing. Therefore, a signal of suppression failure due to respiratory motion is not used for image reconstruction. Therefore, a desired blood flow can be suppressed with a high accuracy and imaged.

Additionally, a breathing instruction device is provided even in the present embodiment similarly to the second embodiment, and it may be configured so that a breathing timing is instructed to the object 101 by the breathing instruction device.

Fourth Embodiment

Next, the fourth embodiment of the present invention will be described. Although the number of spots to be suppressed by the Beam Sat pulse 422 is one, that is, one blood vessel is suppressed in the first embodiment, multiple spots are suppressed in the present embodiment.

The MRI apparatus of the present embodiment basically has a similar configuration to the MRI apparatus 100 of the first embodiment. However, in the present embodiment, the different are the processes of the imaging sequence generation section 140 and the application condition determination part 142. Hereinafter, the configuration different from the first embodiment will be mainly described in the present embodiment.

The present embodiment, when applying a Beam Sat pulse to multiple spots (multiple blood vessels), blood

vessels to which the pulse is applied are changed cyclically to obtain an equivalent suppression effect for the respective applied blood vessels.

That is, a Beam Sat pulse is cyclically applied to a plurality of blood vessels in the present embodiment, and the application condition determination part **142** determines the application interval so that blood flowing from each blood vessel is suppressed respectively in a continuous manner without interruption and considers the two-dimensional selective high-frequency pulse to be applied to all the blood vessels in order to determine the amplitude and the pulse width so as not to exceed a limitation by the SAR.

The detailed description will be made using FIGS. **13(a)** and **13(b)**. In the present embodiment, the number of application spots is shown as M. However, a case of applying Beam Sat pulses to the four spots is shown as an example in FIG. **13(a)**.

For example, when the application interval **412** is sufficiently large compared to the pulse width **415**, an application condition is determined so that M pieces of the Beam Sat pulses **422** are applied during the application interval **412** as shown in FIG. **13(a)**. Additionally, in FIG. **13(a)**, the four Beam Sat pulses of **422a**, **422b**, **422c**, and **422d** are applied.

That is, because Beam Sat pulses are applied at the application interval **412** in M spots of application positions to a blood vessel, the Beam Sat pulses are applied at a time interval of 1/M of the application interval **412** on a pulse sequence.

In this case, the total application time **411** is similar to the first embodiment. Also, the application interval **412** of each application position becomes similar to the first embodiment. However, an application interval does not depend on the application position when determining whether or not to satisfy the SAR limitation, the interval becomes M times of the application interval **412** in the first embodiment.

Therefore, in this case, the application condition determination part **142** performs the total application time determination process and the application interval determination process similarly to the first embodiment. On the other hand, in the SAR determination process, the number of applications per unit time is multiplied M times to determine an SAR.

Additionally, in a case of exceeding a regulated value in the SAR determination process, the amplitude **414** of the respective Beam Sat pulses **422** (**422a**, **422b**, **422c**, and **422d**) is reduced to extend the pulse width **415** similarly to the first embodiment.

Also, when the application interval **412** is not sufficiently large compared to the pulse width **415**, the Beam Sat pulses **422** (**422a**, **422b**, **422c**, and **422d**) in the example of FIG. **13(b)** are cyclically applied to M spots at the respective application intervals **412** as shown in FIG. **13(b)**.

As shown in the present diagram, the Beam Sat pulses **422** are applied in each application position at an interval of M times of the application interval **412**. However, the Beam Sat pulses **422** are applied at the application interval **412** on a pulse sequence.

In this case, the total application time **411** is similar to the first embodiment. Also, the application interval **412** that affects an SAR is similar to the first embodiment. On the other hand, an application interval in each application position becomes M times of the application interval **412**.

Therefore, the application condition determination part **142** performs the total application time determination process and the SAR determination process similarly to the first embodiment. On the other hand, in the application interval

determination process, the application interval **412** is multiplied M times to determine an interval using the above formula (2).

As described above, the MRI apparatus **100** of the present embodiment is provided with the above imaging section **130** and imaging sequence generation section **140**, the two-dimensional selective high-frequency pulse **422** is cyclically applied to a plurality of blood vessels, and the application condition determination part determines the application interval **412** so that blood flowing from each blood vessel is suppressed respectively in a continuous manner without interruption and considers the two-dimensional selective high-frequency pulse **422** to be applied to all the blood vessels in order to determine the amplitude **414** and the pulse width **415** so as not to exceed a limitation by the SAR.

Thus, according to the present embodiment, when a Beam Sat pulse is combined with the blood vessel visualization method using an IR pulse similarly to the first embodiment, applications conditions of a plurality of Beam Sat pulses are determined so as to equally suppress signals of blood flowing into a desired imaging region from a desired blood vessel before imaging. Therefore, the similar effect to the first embodiment can be obtained.

Fifth Embodiment

The fifth embodiment of the present invention will be described. In the present embodiment, blood flow velocity information is further acquired.

The MRI apparatus of the present embodiment basically has a similar configuration to the MRI apparatus **100** of the first embodiment. However, in the present embodiment, blood flow velocity information is acquired. Therefore, as shown in FIG. **14(a)**, the control unit **120** of the present embodiment is further provided with the flow velocity calculation section **170** that calculates a flow velocity of blood in an imaging region from a reconstructed image.

Also, the imaging sequence of the present embodiment includes a predetermined spare time **407** between an application end timing of a plurality of Beam Sat pulses and a start timing of main imaging. The flow velocity calculation section **170** of the present embodiment calculates the flow velocity using the spare time **407** and a length of an unsuppressed blood flow.

Additionally, the other pre-pulse may be applied during the spare time **407**. That is, as shown in FIG. **4** of the first embodiment, a period in which a fat suppression pulse is applied as the pre-pulse **424** may be utilized. This imaging sequence is generated by the imaging sequence generation section **140**, and information of the spare time **407** to be set for the imaging sequence is notified to the flow velocity calculation section **170**.

A method for acquiring blood flow velocity information by setting the time (spare time) **407** when no Beam Sat pulse is applied immediately before main imaging will be described below.

As shown in FIG. **15**, because unsuppressed blood flows in by setting the spare time **407**, the unsuppressed region **311** appears on the FOV side (peripheral side) from a Beam Sat pulse application position. A length L_{Nrs} [CM] of the unsuppressed region (non-suppression region) **311** is expressed in the following formula (3) using a blood flow velocity V [cm/sec] and the spare time **407** T_{Nap} [sec].

$$L_{Nrs} = V \times T_{Nap} \quad (3)$$

Therefore, a blood flow velocity V can be calculated from the following formula (4) using the spare time $407 T_{Nap}$ and a length L_{Nrs} of the non-suppression region **311**.

$$V = L_{Nrs} / T_{Nap} \quad (4)$$

The flow velocity calculation section **170** uses the spare time $407 T_{Nap}$ and a length L_{Nrs} of the non-suppression region **311** to calculate a blood flow velocity of an imaging target region (suppression target region). At this time, a value received from the imaging sequence generation section **140** is used as the spare time $407 T_{Nap}$. Also, a length L_{Nrs} of the non-suppression region **311** is measured on a reconstructed image. The specific measurement method by the flow velocity calculation section **170** will be described using FIG. **16**.

Here, in a case of visualizing a blood vessel by applying the IR pulse **421**, a position and a range of a blood vessel in which suppressed blood flows are identified to calculate the length using that the suppressed blood has a higher signal than the background substance.

Setting a pixel of the Beam Sat pulse application position **301** as the starting point **501**, region growing is performed for an imaging target site side from the application position **301** to check a pixel value of each pixel (signal value). Setting a pixel in the farthest position from the starting point **501** as the end point **502** in pixels whose pixel values (signal values) are equal to or less than a predetermined threshold value, the blood vessel **503** that was visualized on the periphery side from the application position **301**.

Next, by identifying the intersection plane **507** of the blood vessel **503** and n pieces of the flat planes **504** on which the straight line from the starting point **501** to the end point **502** is a normal line, the gravity center **508** of the said intersection plane **507** is calculated. The same process is performed in all the n pieces of the flat planes **504** to calculate the gravity centers **508** of the respective intersection planes **507**. Lastly, all the distances **505** between the gravity centers of the intersection planes **507** that are adjacent each other are added to set as the length **311**.

Additionally, the intervals between n pieces of flat planes are, for example, the same as a slice thickness of main imaging.

Also, a length L_{Nrs} of the non-suppression region **311** may be measured by an operator on an obtained image.

The flow velocity calculation section **170** calculates a blood flow velocity after imaging by the imaging section **130**. Each process flow by the imaging section **130** and the imaging sequence generation section **140** is similar to the first embodiment other than the difference of the above generated imaging sequence.

As described above, the MRI apparatus **100** of the present embodiment is provided with the flow velocity calculation section **170** that calculates a flow velocity of the blood from the image in addition to the above imaging section **130** and imaging sequence generation section **140**, the imaging sequence includes a predetermined spare time 407 between the application end timing 409 of the plurality of the two-dimensional selective high-frequency pulses and the start timing 405 of main imaging, and the flow velocity calculation section **170** calculates the flow velocity using the spare time 407 and a length of an unsuppressed blood flow.

Thus, according to the present embodiment, when a Beam Sat pulse is combined with the blood vessel visualization method using an IR pulse similarly to the first embodiment, applications conditions of a plurality of Beam Sat pulses are determined so as to equally suppress signals of blood flowing into a desired imaging region from a desired blood

vessel before imaging. Therefore, the similar effect to the first embodiment can be obtained.

Furthermore, according to the present embodiment, blood flow velocity information of a blood vessel to be imaged can also be acquired.

Additionally, although a blood flow velocity is calculated in the present embodiment, it may be configured so as to estimate a range to be suppressed when the blood flow velocity is already known by the previous measurement. In this case, as shown in FIG. **14(b)**, the control unit **120** is further provided with the suppression range calculation section **180** that calculates a suppression range from a blood flow velocity instead of the flow velocity calculation section **170**, and the suppression range calculation section **180** calculates a suppression range from a blood flow velocity and a TI recovery time of the said blood.

Additionally, when R is a radius of the suppression range, the radius R is calculated in the following formula (5).

$$R = V \times \alpha T_I \quad (5)$$

The suppression range calculation section **180** displays a calculated suppression range on an image obtained by the imaging section **130**. FIG. **17** shows a display example. Here, the shown example is a case where the application position **301** of the Beam Sat pulse **422** is set as an intersection of the splenic vein and the superior mesenteric vein. The suppression range calculation section **180** displays the half circle on the downstream side than an application position in the radius R circle where the Beam Sat pulse application position **301** is centered as the suppression range **321** on the obtained image.

Additionally, a blood flow velocity is measured using, for example, the PC method.

Additionally, in the above respective embodiments, although an example of a case of imaging while the body motion is synchronized with respiration whose cycle is relatively long is described, the cyclic body motion to be synchronized is not limited to the respiration. For example, the body motion may be heartbeats.

As shown in FIG. **18**, the electrocardiographic waveform **431** has a short cycle compared to the respiratory waveform **401**. Therefore, in a case of applying the IR pulse **421**, applying a plurality of the Beam Sat pulses **422** that can suppress a desired blood vessel, and performing main imaging within the one cardiac cycle **432**, there is a high possibility that the total application time **411** of the Beam Sat pulses **422** cannot be sufficiently taken, which results in insufficient suppression. Therefore, when executing the pulse sequence **400** by heartbeat synchronization, a plurality of the cardiac cycles **432** are designed to be executed as the synchronization cycle **435**, which obtains a sufficient suppression effect.

Additionally, the imaging process flow in this case is similar to the imaging process of the first embodiment. On the other hand, the application condition determination process flow by the application condition determination part **142** is different. Hereinafter, the application condition determination process flow in case of electrocardiographic synchronization will be described following the process flow of FIG. **19**.

First, the synchronization cycle determination process is performed. Here, the maximum cardiac cycle number within αT_I is obtained. A cycle by the obtained cardiac cycle number is set as the synchronization cycle **435**, and imaging is executed in synchronization with the synchronization cycle **435**.

First, a length T_{hb} of the cardiac cycles **432** and $\alpha T1$ are compared (Step **S1901**). When $\alpha T1$ is shorter than the length T_{hb} of the cardiac cycle **432**, the process proceeds to the total application time determination process as is.

On the other hand, when $\alpha T1$ is equal to or longer than the length T_{hb} of the cardiac cycle **432** ($\alpha T1 \geq T_{hb}$), the number of cardiac cycles **432** is increased until $\alpha T1$ is shorter than the length of the cardiac cycle **432**. Specifically, the counter n is set to 1 (Step **S1902**), and then a value in which T_{hb} is added to $n \times T_{hb}$ is set as a new T_{hb} (Step **S1903**) to compare with $\alpha T1$ (Step **S1904**). Then, n is increased by one increment until $\alpha T1 < T_{hb}$ is satisfied (Step **S1905**), and Steps **S1903** and **S1904** are repeated. When $\alpha T1 < T_{hb}$ is satisfied eventually, a cardiac cycle number at that time is set as the synchronization cycle **435**.

After the synchronization cycle **435** is determined, the application condition determination part **142** performs the total application time determination process using the similar method to the first embodiment (Step **S1906**), performs the application interval determination process using the similar method to the first embodiment (Step **S1907**), and then performs the SAR determination process (Step **S1908**) in order to application conditions.

Additionally, when the Beam Sat pulse application position **301** is near the heart, there is a possibility that a Beam Sat pulse is applied to a deviated position from a desired blood vessel due to the heartbeat. In order to prevent this, an application timing of each Beam Sat pulse is set so that the Beam Sat pulse application is not performed during the timing **434** affected by the heartbeat.

The timing **434** may be configured so that a period from a P wave to a T wave of the electrocardiographic waveform is detected and determined by the application condition determination part **142**. Also, the reception part **141** may be configured so as to display the UI shown in FIG. **18** and receive settings by a user.

By adding the above processes, a stable suppression effect can be obtained even in electrocardiographic synchronization. This method can be applied also to a case where a respiratory cycle is considerably short.

DESCRIPTION OF REFERENCE NUMERALS

100: MRI apparatus
101: object
102: static magnetic field generating magnet
103: gradient magnetic field coil
104: transmission coil
105: reception coil
106: gradient magnetic field power source
107: RF transmission unit
108: signal detection unit
109: signal processing unit
110: sequencer
111: bed
120: control unit
121: display unit
122: operation unit
123: storage unit
124: body motion detection device
130: imaging section
140: imaging sequence generation section
141: reception part
142: application condition determination part
150: body motion detection section
160: adoption/rejection determination section
170: flow velocity calculation section

180: suppression range calculation section
210: slice selective excitation sequence
211: RF pulse
212: slice selective gradient magnetic field
220: 2D RF sequence
221: 2D RF pulse
222: vibration gradient magnetic field pulse
223: crusher gradient magnetic field pulse
301: Beam Sat pulse application position
302: region to be suppressed
303: region to be suppressed insufficiently
311: non-suppression region
321: suppression range
350: positioning image
360: Beam Sat pulse setting screen display example
400: pulse sequence
401: respiratory waveform
402: IR pulse application timing
403: TI
405: main imaging start timing
406: main imaging execution period
407: spare time
408: Beam Sat pulse application start timing
409: Beam Sat pulse application end timing
411: total application time
412: application interval
413: application times
414: amplitude
415: pulse width
421: IR pulse
422: Beam Sat pulse
422a: Beam Sat pulse
422b: Beam Sat pulse
422c: Beam Sat pulse
422d: Beam Sat pulse
423: main imaging
424: pre-pulse
431: electrocardiographic waveform
432: cardiac cycle
434: timing affected by the heartbeat
432: cycle
435: synchronization cycle
501: starting point
502: end point
503: blood vessel
504: flat plane
505: distance
507: intersection plane
508: gravity center

The invention claimed is:

1. A magnetic resonance imaging apparatus including:
 an imaging sequence generation section configured to apply imaging conditions to a predetermined pulse sequence to generate an imaging sequence; and
 an imaging section configured to collect echo signals from an imaging region according to the imaging sequence to reconstruct an image from the echo signals,
 wherein the predetermined pulse sequence includes an IR (Inversion Recovery) pulse and a plurality of two-dimensional selective high-frequency pulses,
 wherein the imaging conditions include application conditions of the plurality of two-dimensional selective high-frequency pulses,
 wherein the imaging sequence generation section includes an application condition determination part that deter-

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mines whether or not set application conditions suppress blood signals that are the echo signals from blood in a targeted blood vessel,
 wherein in response to the echo signals are suppressed, the set application conditions are determined as applied application conditions that are the application conditions to be applied to the imaging sequence, and
 wherein in response to the echo signals are not suppressed, the set application conditions changed to suppress the blood signals are determined as the applied application conditions.

2. The magnetic resonance imaging apparatus according to claim 1, wherein the application conditions include a total application time and an application interval of the plurality of two-dimensional selective high-frequency pulses as well as an amplitude and a pulse width of each of the plurality of two-dimensional selective high-frequency pulses.

3. The magnetic resonance imaging apparatus according to claim 2, wherein the application condition determination part determines:

- the total application time so that the total application time does not exceed a predetermined period determined by a T1 recovery time of blood while suppressing the echo signals from the blood in the targeted blood vessel;
- the application interval so that the blood flowing into the imaging region is continuously suppressed;
- the amplitude so as not to exceed a limitation by SAR (Specific Absorption Rate); and
- the pulse width according to the determined amplitude while maintaining an application area of a two-dimensional selective high-frequency pulse.

4. The magnetic resonance imaging apparatus according to claim 2, further including:

- a body motion detection section that detects a displacement amount by periodic body motion of an object after the peak; and
- an adoption/rejection determination section that determines the adoption or rejection of the echo signals collected by the imaging section according to the relationship between the displace amount and an application start timing of a two-dimensional selective high-frequency pulse specified by the applied application conditions,

wherein the imaging sequence is a body motion synchronization sequence, and

wherein the imaging section reconstructs the image only from the echo signals determined to be adopted by the adoption/rejection determination section.

5. The magnetic resonance imaging apparatus according to claim 4,

- wherein the adoption/rejection determination section determines the echo signals obtained in the imaging sequence to be adopted when the displace amount at the application start timing is equal to or less than a predetermined threshold value.

6. The magnetic resonance imaging apparatus according to claim 4,

- wherein the adoption/rejection determination section compares a displacement timing at which the displacement amount becomes a predetermined threshold value with the application start timing and determines echo signals obtained in the imaging sequence to be adopted when the application start timing is after the displacement timing and when the application start timing is earlier than the displacement timing and a period from the displacement timing to the application end timing of the two-dimensional selective high-frequency pulse

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specified by application conditions determined by the application condition determination part is longer than a predetermined period, and

the imaging section starts application of the two-dimensional selective high-frequency pulse instead of the application start timing from the displacement timing when the application start timing is earlier than the displacement timing.

7. The magnetic resonance imaging apparatus according to claim 4,

- wherein the periodic body motion is respiratory motion, and
- wherein the magnetic resonance imaging apparatus further comprises a breathing instruction device that instructs an object about a breath timing.

8. The magnetic resonance imaging apparatus according to claim 3,

- wherein the two-dimensional selective high-frequency pulse is cyclically applied to a plurality of blood vessels, and
- wherein the application condition determination part determines the application interval so that blood flowing from each blood vessel is suppressed respectively in a continuous manner without interruption and considers the two-dimensional selective high-frequency pulse to be applied to all the blood vessels in order to determine the amplitude and the pulse width so as not to exceed a limitation by the SAR.

9. The magnetic resonance imaging apparatus according to claim 1, further comprising:

- a flow velocity calculation section that calculates a flow velocity of the blood from the image,
- wherein the imaging sequence includes a predetermined spare time between an application end timing of the plurality of two-dimensional selective high-frequency pulses and a start timing of main imaging, and
- wherein the flow velocity calculation section calculates the flow velocity using the spare time and a length of an unsuppressed blood flow.

10. The magnetic resonance imaging apparatus according to claim 1, further comprising:

- a suppression range calculation section that calculates a suppression range from a flow velocity of the blood,
- wherein the suppression range calculation section calculates the suppression range using the flow velocity and a T1 recovery time of the blood.

11. The magnetic resonance imaging apparatus according to claim 3,

- wherein the imaging sequence is a heartbeat synchronization sequence in which a plurality of heartbeats is set as one unit.

12. The magnetic resonance imaging apparatus according to claim 3,

- wherein the application condition determination part determines a predetermined period to be the total application time when the total application time of the set application conditions is longer than the predetermined period determined by the T1 recovery time, determines the minimum value of a period in which blood in the targeted blood vessel can be suppressed to be the total application time when the total application time of the set application conditions is equal to or less than the suppressible period, determines a moving time to be the application interval when the set application interval is larger than the moving time obtained by dividing a suppression width of the two-dimensional selective high-frequency pulse by a flow velocity, and

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determines the amplitude so that the number of the plurality of two-dimensional selective high-frequency pulses to be applied per unit time determined by the set application conditions is within the limitation range when exceeding the SAR limitation.

13. A magnetic resonance imaging method, comprising:
 applying imaging conditions including applied application conditions to a predetermined pulse sequence to generate an imaging sequence;
 collecting echo signals from an imaging region according to the imaging sequence to reconstruct an image from the echo signals;
 determining whether or not set application conditions suppress blood signals that are the echo signals from blood in a targeted blood vessel;
 in response to the echo signals are suppressed, determining the set application conditions as applied application conditions that are the application conditions to be applied to an imaging sequence; and

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in response to the echo signals are not suppressed, determining the set application conditions changed to suppress the blood signals as the applied application conditions;

- 5 wherein the predetermined pulse sequence includes an IR (Inversion Recovery) pulse and a plurality of two-dimensional selective high-frequency pulses.
 14. The magnetic resonance imaging method according to claim 13,
 10 wherein the application conditions includes a total application time and an application interval of the plurality of the two-dimensional selective high-frequency pulses as well as an amplitude and a pulse width of each of the plurality of two-dimensional selective high-frequency pulses, and
 15 wherein the amplitude is determined so as not to exceed a limitation by SAR (Specific Absorption Rate) and the pulse width is determined according to the determined amplitude while maintaining an application area of a two-dimensional selective high-frequency pulse as the applied application conditions.

* * * * *

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摘要(译)

在MRI中提供了一种技术，以有效地抑制诸如门静脉之类的流速较慢的血管中特定区域的下游血液。为此，在从施加IR脉冲到开始主摄像的期间，施加多个波束饱和脉冲，以均等地抑制从期望的血管流入期望的摄像区域的血液的信号。通过基于血管中血液的流速确定达到上述目标的多个波束饱和脉冲的施加条件，可以有效地抑制门静脉等流速较慢的血管中特定区域的下游血液。所需血管和所述血液的T₁。

