



(11) **EP 1 461 630 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
10.02.2010 Bulletin 2010/06

(21) Application number: **02804980.7**

(22) Date of filing: **09.12.2002**

(51) Int Cl.:
G01R 33/48 (2006.01)

(86) International application number:
PCT/IB2002/005201

(87) International publication number:
WO 2003/052444 (26.06.2003 Gazette 2003/26)

(54) **MRI-GUIDED TEMPERATURE MAPPING OF TISSUE UNDERGOING THERMAL TREATMENT**

MRI-GELEITETE TEMPERATURABBILDUNG EINES EINER WÄRMEBEHANDLUNG
UNTERZOGENEN GEWEBES

IMAGERIE THERMIQUE GUIDEE PAR IRM DE TISSUS SOUMIS A UN TRAITEMENT THERMIQUE

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
IE IT LI LU MC NL PT SE SI SK TR**

(30) Priority: **14.12.2001 US 22758**

(43) Date of publication of application:
29.09.2004 Bulletin 2004/40

(73) Proprietor: **Insightec-Txsonics Ltd.
39120 Tirat-Carmel (IL)**

(72) Inventor: **FREUNDLICH, David
Haifa (IL)**

(74) Representative: **Dennemeyer, John James
Dennemeyer & Associates S.A.
55, rue des Bruyères
1274 Howald (LU)**

(56) References cited:
EP-A- 0 558 029 US-A- 6 128 522

- **CHUNG A H ET AL: "THERMAL DOSIMETRY OF A FOCUSED ULTRASOUND BEAM IN VIVO BY MAGNETIC RESONANCE IMAGING" MEDICAL PHYSICS, AMERICAN INSTITUTE OF PHYSICS. NEW YORK, US, vol. 26, no. 9, September 1999 (1999-09), pages 2017-2026, XP000930233 ISSN: 0094-2405**
- **HUTCHINSON E B ET AL: "INTRACAVITY ULTRASOUND PHASED ARRAYS FOR PROSTATE THERMAL THERAPIESMRI COMPATIBILITY AND IN VIVO TESTING" MEDICAL PHYSICS, AMERICAN INSTITUTE OF PHYSICS. NEW YORK, US, vol. 25, no. 12, December 1998 (1998-12), pages 2392-2399, XP000875117 ISSN: 0094-2405**
- **KENDELL K R ET AL: "MR-guided focused-ultrasound ablation system: determination of precision and accuracy in preparation for clinical trials." RADIOLOGY. UNITED STATES DEC 1998, vol. 209, no. 3, December 1998 (1998-12), pages 856-861, XP009006810 ISSN: 0033-8419**

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 1 461 630 B1

Description

BACKGROUND

1. Field of the Invention

[0001] The present invention relates generally to magnetic resonance imaging (MRI) guided thermal treatment systems, and more particularly to using MRI to obtain thermal evolution images of a tissue mass undergoing thermal treatment.

2. Background of the Invention

[0002] Certain types of body tissues, such as tumors, can be destroyed by heat. One way to apply thermal energy to internal body tissue is to focus high intensity, ultrasonic acoustic waves into the tissue using, e.g., a phased-array of piezoelectric transducers. Such treatment can reduce or even eliminate the need for invasive surgery to remove the tissue. Of critical importance to the treatment process is verifying that a sufficient thermal dose is reached during each application of ultrasonic energy (or "sonication") to kill/ablate the portion of the target tissue structure being heated. It is also important to be able to precisely track which portions of the tissue structure have been killed/ablated, in order to minimize the total number of sonications needed in a particular treatment session.

[0003] Towards this end, MRI systems are used to assist in aiming ultrasonic wave energy at a target tissue structure in a body, and to monitor the temperature change of the tissue region being heated during the thermal treatment process to ensure that a sufficient thermal dose is reached to fully ablate the tissue being heated.

[0004] One method of measuring temperature change using MRI techniques exploits the temperature dependence of the proton resonant frequency (PRF) in water. The temperature dependence of the PRF is primarily due to temperature-induced rupture, stretching, or bending of the hydrogen bonds in water. The temperature dependence of pure water is 0.0107 ppm/°C, and the temperature dependence of other water-based tissues is close to this value. Because of a non-homogenous magnetic field within the MRI machine, absolute PRF measurements are not possible. Instead, changes in PRF are measured by first taking a MR image before the delivery of heat, and subtracting this baseline value from subsequent measurements. The temperature-induced changes in PRF are then estimated by measuring, changes in phase of the MR signal, or frequency shift, in certain MR imaging sequences.

[0005] Notably, the duration of each sonication must be limited, e.g., to approximately ten seconds, in order to avoid the unwanted (and painful) build up of heat in healthy tissue surrounding the target tissue structure being heated. Thus, there is limited time for acquiring temporal MR images for monitoring the temperature increase

during a sonication in order to verify a sufficient kill temperature has been reached. Because it can take at least one and as much as three seconds to acquire a single MR thermal sensitive image, this means there is little room for using a multi slice MR imaging techniques to cover the whole heated volume.

[0006] Chung A. H. et al, "Thermal dosimetry of a focused ultrasound beam in vivo by magnetic resonance imaging", Med. Phys. 26(9), September 1999, p. 2017-2026, discloses a PRF shift technique for generating temperature images for a series of time intervals during an ultrasonic heating.

[0007] In particular, the article discloses a system for monitoring changes in temperature of a tissue mass being heated by energy converging in a focal zone encompassing a portion of the tissue mass, the focal zone being generally elongate and symmetrical about the focal axis, the system being configured to acquire a first plurality of magnetic resonance images of the tissue mass in a first image plane aligned substantially perpendicular to the focal axis; and define a cross-section of the focal zone in the first image plane from the first plurality of images. Further, a second plurality of images is generated in a second image plane which intersects the first image plane. The second image plane is substantially parallel to the focal axis.

SUMMARY OF THE INVENTION

[0008] The invention is directed to systems using magnetic resonance imaging for monitoring the temperature of a tissue mass undergoing thermal treatment by energy converging in a generally elongate focal zone symmetrical about a focal axis, and comprising the features according to the subject matter defined in the claims 1 to 7.

[0009] Other aspects and features of the invention will become apparent in view of the disclosed and described embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Preferred embodiments and implementations of the invention are now shown and described in conjunction with the following drawings, in which:

FIG. 1 is a simplified schematic illustration of a MRI-guided focussed ultrasound thermal treatment system emitting a converging ultrasound beam to a focal zone in a target tissue mass located in a patient; FIG. 2 is a cross-sectional view of the focal zone taken in a first imaging plane parallel to a focal axis of the ultrasound beam; FIG. 3 is a cross-sectional view of the focal zone taken in a second imaging plane perpendicular to the focal axis of the ultrasound beam; FIG. 4 is a graph illustrating the temporal temperature change of the tissue the focal zone taken in a given image plane;

FIG. 5 is a diagram illustrating differences in the temperature change detected by MR imaging of the focal zone, depending on where the MR imaging plane is aligned; and

FIG. 6 is a flow chart illustrating an exemplary process by which a system according to the invention monitors the thermal evolution of the target tissue structure, ensuring proper alignment of the MR imaging plane with the focal zone.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0011] FIG. 1 is a simplified schematic illustration of an exemplary MRI-guided focussed ultrasound thermal treatment system 100. The system 100 includes a phased array transducer 102 driven by a controller 106 for emitting a beam of focussed ultrasound energy 112 converging in a focal zone 104 located in a target tissue mass 105 in a patient 116. The geometry of the focal zone 104 within the target tissue structure 105 is a function of the shape of the transducer 102 and phasing of the individual transducer elements, which dictate the interaction of the converging ultrasonic waves. In the illustrated embodiment, the transducer is a concave, spherical cap, such the focal zone 104 will have a generally elongate shape, symmetrical about a focal axis, as shown in FIGS. 2 and 3.

[0012] Thermal conduction in the tissue mass 105 and cooling blood flow may also play a role in the actual thermal energy distribution in the tissue mass 105. Also, for a given output power of the energy beam 112 and volume of the focal zone 104, a longer sonication results in higher tissue temperature within the focal zone 104, and greater heat transfer through conduction to tissue adjacent the focal zone 104. Importantly, to avoid near field heating of non-target tissue, as well as secondary hot spots, there are practical limits to both the duration of the sonication and the energy level of the ultrasound beam 112. Thus, the actual tissue volume being heated may vary somewhat from the initial boundaries of the ultrasound beam focal zone 104. For purposes of simplification in describing the invention herein, it is presumed herein that the boundary of the focal zone 104 is defined as the tissue volume that receives significant thermal energy, whether directly from the ultrasound energy, or indirectly from thermal conduction.

[0013] A MRI system 114 is used to acquire images taken along a two-dimensional image plane (or slice) 115 passing through a portion of the focal zone 104. The acquired images are processed by a processor 108 to monitor the change in temperature of this portion of the tissue mass 105. The tissue temperature changes measured from images acquired in one or more imaging planes 115 are used to derive a three-dimensional thermal evolution of the entire focal zone 104. The thermal evolution is used to verify that a sufficient tissue "kill" thermal dose is reached in the focal zone 104, as well as to track which

portions of the tissue 105 have been killed. This information, in turn, is used by the ultrasound controller 106 for positioning the ultrasound energy beam 112 and focal zone 104 for successive sonications of the tissue mass 105. Thus, it is critical that the thermal evolution of the three-dimensional focal zone 104 be accurate.

[0014] More particular aspects, features, embodiments, and preferred systems and methods for operating an MRI-guided focussed ultrasound system, such as system 100, are disclosed in U.S. Patent No. 6,419,648 and US 2002/0180438 A1.

[0015] FIGS. 2 and 3 depict cross-sectional images of the focal zone 104 taken in orthogonal imaging planes. Notably, the focal zone 104 is substantially elongate in shape and symmetrical along a focal axis 120 of the ultrasound transducer 102. The cross-sectional view of the focal zone 104 shown in FIG. 2 is taken in an image plane parallel to, and in this instance including the focal axis 120, referred to herein as a "vertical" image plane. The cross-sectional view of the focal zone 104 shown in FIG. 3 is taken in an image plane perpendicular to the focal axis 120, (along line B-B in FIG. 2), referred to herein as a "horizontal" image plane. Notably, images taken in a horizontal image plane are easier to locate such that they will intersect the heated zone along the focal axis 120, whereas images taken in a vertical image plane may or may not intersect the heated zone along the focal axis 120.

[0016] FIG. 4 is a graph of the temperature change of the tissue in the focal zone taken in a selected image plane over the course of a sonication. In particular, the graph depicts changes in tissue temperature (at one pixel) in the image plane corresponding to differences in a characteristic of the tissue measured in successive MR images T_1 - T_{13} taken in the particular image plane. In one embodiment, the measured characteristic is a phase of an electromagnetic signal emitted from the tissue, wherein the corresponding temperature change is estimated based on a phase shift in the signal between successive images.

[0017] At time T_1 , which is preferably just before initiation of the sonication, the MRI system 114 acquires a first image, which is used to establish a baseline of the measured tissue characteristic, presumably reflecting body temperature of the patient 116. The application of ultrasonic energy then commences and a second image is acquired at time T_2 . From this second image, the thermal evolution, i.e., change in tissue temperature, from time T_1 to T_2 in the respective image plane can be estimated from the change in the measured tissue characteristic. Successive temporal images are taken as the tissue is being heated. The actual number of images that can be acquired while the tissue is being heated may vary between embodiments and depend, e.g., on the imaging modality of the MRI system.

[0018] The process of acquiring images in the respective image plane continues at least to the end of the sonication period, i.e., until the application of ultrasonic en-

ergy ceases. In the graph of FIG. 4, the application of ultrasonic energy continues to time T_7 , at which point accumulated heat in tissue reaches a peak temperature 132. The processor 108 uses the images acquired at times T_1 - T_{13} to ensure that the heat transferred to the tissue 105 in the focal zone 104 exceeds a predetermined "kill threshold" thermal dose.

[0019] In order to derive an accurate three-dimensional temperature evolution of the focal zone 104, it would seem necessary to be able to track the temperature map changes in both horizontal and vertical image planes, including a sufficient number of planes covering the entire focal zone. However, this is not possible, since the acquired images are taken along thin "slices" of the tissue and require a relatively long time to acquire with respect to the limited sonication time. This is particularly problematic with images taken in a vertical image plane of the focal zone 104. As seen in FIGS. 2 and 3, the thermal energy is most concentrated, and thus a higher temperature is reached, in an elongate-shaped center 122 of the focal zone 104. Thus, it is readily apparent that images acquired in a vertical imaging plane taken along line C-C in FIG. 2 will not accurately depict the true thermal evolution map of the focal zone. In particular, unless images acquired in a vertical image plane either include the focal axis 120, a true thermal evolution map will not be obtained.

[0020] To better illustrate the foregoing points, FIG. 5 shows the thermal evolution 142 (temperature change v. time) of a point in an image slice taken along vertical image plane C-C of FIG. 2, versus the thermal evolution 144 of a point in an image slice taken in a vertical image plane taken along line A-A including the focal axis 120. Thus, in order for processor 108 to generate a more accurate estimate of the thermal evolution of the focal zone 104, the thermal images acquired by the MRI system 114 during the sonication should be taken in a vertical plane located as close to the focal axis 120 as possible. If the images are taken in a vertical plane too distant from the focal axis 120, the processor 108 will under estimate the thermal evolution of focal zone 104, as would be the case with the thermal evolution 142 illustrated in FIG. 5. As noted above, because the temporal period of successive image acquisitions is between 1 to 3 seconds, and the application of ultrasonic energy in a given sonication is for a relatively short period, e.g., 10 seconds, there is not adequate opportunity to adjust the alignment of the vertical imaging plane during a sonication.

[0021] The processor 108 is configured to acquire a plurality of images of the tissue mass 105 in a horizontal image plane (i.e., aligned substantially perpendicular to the focal axis), which is relatively easy to locate somewhere along the focal zone given the generally elongate shape of the focal zone 104.

[0022] In one embodiment, the plurality of horizontal images include a baseline image taken just prior to the sonication, and a further image taken after the heating has commenced, such that a temperature change will

appear between the two images. From the temperature change, the boundary of a cross-section of the focal zone 104 in the horizontal image plane can be determined by the processor 108. At the same time the plurality of horizontal images are being acquired, a plurality of images in a vertical imaging plane are also acquired, i.e., in an interleaved mode, wherein the vertical imaging plane is established to be at the midpoint of the defined focal zone cross-section. Because the focal zone 104 is generally symmetrical about the focal axis 120, the midpoint of the defined cross-section will be approximately aligns with the focal axis 120, such that the vertical plane will either encompass the focal axis 120, or otherwise be sufficiently close to the focal axis to provide an accurate reflection of the thermal evolution of the focal zone 104. In particular, the acquired horizontal thermal images will show whether the vertical thermal images are actually close enough to the midline of the focal zone. If not, the operator is able to adjust the vertical imaging plane so that, at the next application of energy, the vertical imaging plane will be at the midpoint of the focal zone.

[0023] A process 600 using a system according to the invention for acquiring images sufficient to generate an accurate thermal evolution of tissue in a focal zone being heated by focussed energy is illustrated in FIG. 6. The system may employ a software or firmware controlled processor for controlling the acquisition of MR images, and analyzing the acquired images, e.g., processor 108 in system 100.

[0024] First, in step 602, a plurality of temperature images are acquired in a horizontal imaging plane, a first temperature image of the plurality preferably being a baseline image acquired prior to initiation of the sonication. In one embodiment, the horizontal temperature images include only two images in order to minimize the time and system resources needed for their acquisition.

[0025] In step 604, the focal axis of symmetry in the vertical plane is located using the temperature change measurements derived from the horizontal temperature images. Step 604 includes determining the boundaries (edges) of the focal zone lying in the first horizontal imaging plane.

[0026] In step 606, once the boundary of the focal zone is located in the horizontal imaging plane, an approximate center point of the focal zone in the respective plane is located. Because the focal zone is generally symmetrical about a longitudinal (vertical) axis of symmetry, the center point determined in this manner will also lie on the axis of symmetry for any horizontal imaging plane intersecting the focal zone.

[0027] In step 608, a vertical imaging plane is determined based on the location of center point (or "midpoint") of the focal zone in the horizontal imaging plane. In particular, the vertical imaging plane is selected to be orthogonal to the horizontal imaging plane and containing the midpoint. In step 610, which is undertaken contemporaneous with step 602, i.e., in an interleaved mode, a plurality of temperature images are acquired in the ver-

tical imaging plane. In a preferred embodiment, the vertical temperature images are continually acquired until the heating period is ended.

[0028] In step 612, a three-dimensional thermal evolution of the portion of the tissue mass in the focal zone is derived based on the horizontal and vertical temperature images. In a preferred embodiment, the thermal evolution is derived by first defining a cross-section of the focal zone in the vertical image plane from the vertical temperature images. Because of the elongate geometry of the focal zone, the cross-section of the focal zone in the vertical image plane will have a length substantially axially aligned with the focal axis of symmetry. The cross-section of the focal zone in the horizontal plane is then extrapolated along the length of the cross-section of the focal zone in the vertical plane to arrive at an estimated focal zone geometry. By determining differences in a characteristic of the tissue mass measured in successive images of the vertical temperature images, changes in temperature of the tissue mass between respective images can also be determined.

[0029] The thermal evolution of the three-dimensional focal zone geometry is estimated based on extrapolating the temperature changes in the vertical plane across the horizontal focal zone cross section. In one embodiment, the measured tissue characteristic is a phase of an electromagnetic signal emitted from the tissue mass, wherein the corresponding temperature change is derived from a phase shift in the signal between successive images.

[0030] In step 614, the derived thermal evolution is then used to verify that the thermal dose at the tissue mass in the focal zone exceeded a threshold tissue kill thermal dose. The first and second plurality of images acquired in steps 602 and 610 can also be used to verify that the ultrasonic energy was applied at the correct location within target mass 104.

[0031] It may be preferable to acquire subsequent images taken in the same or differing horizontal imaging plane(s) in order to verify that the geometry of the cross-section of the focal zone remains uniform, both with respect to any changes in the boundary during the sonication, and with respect to the uniformity of the focal zone boundaries along the entire length of the vertical image plane. Towards this end, in step 616, the system acquires one or more additional images of the tissue mass in the focal zone in a second horizontal image plane (i.e., orthogonal to the vertical imaging plane), between acquiring temporal images of the second plurality of images in the vertical plane. A cross-section of the focal zone in the second horizontal imaging plane is then defined in step 618. In step 620, it is then verified that the vertical imaging plane bisects the second horizontal imaging plane at approximately a midpoint of the defined focal zone cross-section in the second horizontal imaging plane.

[0032] The actual pattern and ratio of images acquired in the vertical imaging plane to images acquired in one or more horizontal imaging planes can vary widely de-

pending on the embodiment. Although, preferably the ratio always includes more images in the vertical plane than in the horizontal plane(s) so that there is sufficient images taken along the longitudinal axis of the focal zone to generate an accurate estimate of the thermal evolution. The system processor may be programmed to acquire, e.g., one image in a horizontal imaging plane for every image acquired in the vertical imaging plane after the sonication has commenced. This can be especially useful if the shape of focal zone is slightly irregular.

[0033] While embodiments and implementations of the invention have been shown and described, it should be apparent that many more embodiments and implementations are within the scope of the invention. For example, while the described embodiments are directed to MR imaging of an elongate focal zone of converging ultrasound energy symmetrical about a focal axis, the same inventive concepts may also apply to temperature monitoring of a different heating modality, e.g., converging focussed light waves, or converging radio frequency electromagnetic energy.

Claims

1. A system for monitoring changes in temperature of a tissue mass being heated by energy converging in a focal zone (104) encompassing at least a portion of the tissue mass, the focal zone being generally elongate and symmetrical about a focal axis (120), the system being configured to:

acquire a first plurality of magnetic resonance images of the tissue mass in a first image plane aligned substantially perpendicular to the focal axis, differences in a characteristic of the tissue mass measured in successive images of said first plurality of magnetic resonance images reflecting changes in temperature of the tissue mass;

define a cross-section of the focal zone in the first image plane from the first plurality of images;

determine an approximate center point of the cross-section of the focal zone;

determine a second image plane aligned substantially parallel to the focal axis (120) and intersecting the first image plane at the approximate center point; and

acquire a second plurality of images of the tissue mass in said second image plane.

2. The system of claim 1, wherein the heating energy is applied for a defined heating period, and wherein an image of the second plurality of images is acquired proximate an end of the heating period.

3. The system of claim 1, further configured to derive

a three-dimensional thermal evolution of the tissue mass in the focal zone (104) based on the first and second pluralities of images.

4. The system of claim 3, wherein the thermal evolution is derived by defining a cross-section of the focal zone (104) in the second image plane from the second plurality of images, the cross-section of the focal zone in the second image plane having a length, extrapolating the cross-section of the focal zone in the first image plane along the length of the cross-section of the focal zone in the second image plane, and determining differences in a characteristic of the tissue mass in the focal zone measured in successive images of the second plurality of images, the differences in the measured characteristic corresponding at least in part to changes in temperature of the tissue mass between respective images. 5
5. The system of claim 1, further configured to verify that the temperature of the tissue mass in the focal zone (104) exceeded a threshold temperature or thermal dose based on the derived thermal evolution. 10
6. The system of claim 4, further configured to acquire one or more additional images of the tissue mass in the focal zone (104) in a third image plane aligned substantially perpendicular to the focal axis (120) between acquiring images of the second plurality of images, define a cross-section of the focal zone in the third image plane, and verify that the second imaging plane bisects the third image plane at approximately a midpoint of the defined focal zone cross-section in the third image plane. 15
7. A system according to one of the preceding claims, wherein the first plurality of images includes a baseline image taken prior to the application of ultrasound energy to the tissue mass. 20

Patentansprüche

1. System zur Überwachung von Temperaturänderungen einer Gewebemasse, die durch Energie erhitzt wird, die in einem Fokalebereich (104) zusammenläuft, der mindestens einen Abschnitt der Gewebemasse einbezieht, wobei der Fokalebereich im Allgemeinen länglich und um eine Brennnachse (120) herum symmetrisch ist, wobei das System für folgende Schritte konfiguriert ist: 45

Erfassen einer ersten Vielzahl von Magnetresonanzbildern der Gewebemasse in einer ersten Bildebene, die im Wesentlichen senkrecht zur Brennnachse ausgerichtet ist, wobei Unterschiede in einer Charakteristik der Gewebemasse, 50

die in aufeinander folgenden Bildern der ersten Vielzahl von Magnetresonanzbildern gemessen wird, Temperaturänderungen der Gewebemasse widerspiegeln;

Definieren eines Querschnitts des Fokalebereichs in der ersten Bildebene aus der ersten Bilderviellzahl;

Bestimmen eines angenäherten Mittelpunkts des Querschnitts des Fokalebereichs;

Bestimmen einer zweiten Bildebene, die im Wesentlichen parallel zu der Brennnachse (120) ausgerichtet ist und sich mit der ersten Bildebene in dem angenäherten Mittelpunkt schneidet; und

Erfassen einer zweiten Vielzahl von Bildern der Gewebemasse in der zweiten Bildebene.

2. System nach Anspruch 1, wobei die Heizenergie während einer definierten Heizperiode angewendet wird, und wobei ein Bild der zweiten Bilderviellzahl gegen Ende der Heizperiode aufgenommen wird.
3. System nach Anspruch 1, ferner konfiguriert, um eine dreidimensionale thermische Entwicklung der Gewebemasse in dem Fokalebereich (104) abzuleiten, basierend auf der ersten und zweiten Vielzahl von Bildern. 25
4. System nach Anspruch 3, wobei die thermische Entwicklung abgeleitet wird durch das Definieren eines Querschnitts des Fokalebereichs (104) in der zweiten Bildebene aus der zweiten Vielzahl von Bildern, wobei der Querschnitt des Fokalebereichs in der zweiten Bildebene eine Länge aufweist, das Extrapolieren des Querschnitts des Fokalebereichs in der ersten Bildebene entlang der Länge des Querschnitts des Fokalebereichs in der zweiten Bildebene und das Bestimmen von Unterschieden in einer Charakteristik der Gewebemasse in dem Fokalebereich, die in aufeinander folgenden Bildern der zweiten Vielzahl von Bildern gemessen wird, wobei die Unterschiede der gemessenen Charakteristik mindestens teilweise Temperaturänderungen der Gewebemasse zwischen jeweiligen Bildern entsprechen. 30

5. System nach Anspruch 1, ferner konfiguriert um zu überprüfen, dass die Temperatur der Gewebemasse in dem Fokalebereich (104) eine Schwellentemperatur oder eine Wärmedosis überschritten hat, basierend auf der abgeleiteten thermischen Entwicklung. 35

6. System nach Anspruch 4, ferner konfiguriert, um eines oder mehrere zusätzliche Bilder der Gewebemasse in dem Fokalebereich (104) in einer dritten Bildebene zu erfassen, die im Wesentlichen zu der Brennnachse (120) senkrecht ausgerichtet ist, zwischen dem Erfassen von Bildern der zweiten Bilderviellzahl, Definieren eines Querschnitts des Fokal- 40

berelchs in der dritten Bildebene und Überprüfen, dass die zweite bilderzeugende Ebene die dritte Bildebene ungefähr in einem Mittelpunkt des definierten Querschnitts des Fokalbereichs in der dritten Bildebene halbiert.

7. System nach einem der vorhergehenden Ansprüche, wobei die erste Bildervielzahl ein Bezugsbild umfasst, das vor dem Anwenden von Ultraschallenergie auf die Gewebemasse aufgenommen wurde.

Revendications

1. Système de surveillance de changements de température d'une masse tissulaire chauffée par de l'énergie convergeant dans une zone focale (104) englobant au moins une partie de la masse tissulaire, la zone focale étant en général allongée et symétrique autour d'un axe focal (120), le système étant configuré pour ;

acquérir une première pluralité d'images par résonance magnétique de la masse tissulaire dans un premier plan image aligné de façon substantiellement perpendiculaire à l'axe focal, des différences d'une caractéristique de la masse tissulaire mesurée sur des images successives de ladite première pluralité d'images par résonance magnétique reflétant des changements de température de la masse tissulaire ; définir une section transversale de la zone focale dans le premier plan image à partir de la première pluralité d'images ; déterminer un point central approximatif de la section transversale de la zone focale ; déterminer un deuxième plan image aligné substantiellement en parallèle à l'axe focal (120) et coupant le premier plan image au point central approximatif ; et acquérir une deuxième pluralité d'images de la masse tissulaire dans ledit deuxième plan image.

2. Système selon la revendication 1, dans lequel l'énergie de chauffage est appliquée pendant une période de chauffage définie, et dans lequel une image de la deuxième pluralité d'images est acquise près de la fin de la période de chauffage.

3. système selon la revendication 1, configuré en outre pour dériver une évolution thermique tridimensionnelle de la masse tissulaire dans la zone focale (104) basée sur les première et deuxième pluralités d'images.

4. Système selon la revendication 3, dans lequel l'évolution thermique est dérivée en définissant une sec-

tion transversale de la zone focale (104) dans le deuxième plan image à partir de la deuxième pluralité d'images, la section transversale de la zone focale dans le deuxième plan image ayant une certaine longueur, en extrapolant la section transversale de la zone focale dans le premier plan image suivant la longueur de la section transversale de la zone focale dans le deuxième plan image, et en déterminant des différences d'une caractéristique de la masse tissulaire dans la zone focale mesurée sur des images successives de la deuxième pluralité d'images, les différences dans la caractéristique mesurée correspondant au moins en partie à des changements de température de la masse tissulaire entre des images respectives.

5. Système selon la revendication 1, configuré en outre pour vérifier que la température de la masse tissulaire dans la zone focale (104) a dépassé une température de seuil ou une dose thermique sur la base de l'évaluation thermique dérivée.

6. Système selon la revendication 4, configuré en outre pour acquérir une ou plusieurs images supplémentaires de la masse tissulaire dans la zone focale (104) dans un troisième plan image aligné de façon substantiellement perpendiculaire à l'axe focal (120) entre l'acquisition d'images de la deuxième pluralité d'images, définir une section transversale de la zone focale dans le troisième plan image, et vérifier que le deuxième plan de formation d'image coupe le troisième plan image en deux, approximativement en un point milieu de la section transversale de zone focale définie dans le troisième plan image.

7. Système selon l'une quelconque des revendications précédentes, dans lequel la première pluralité d'images comprend une image de référence prise avant l'application de l'énergie ultrasonore à la masse tissulaire,

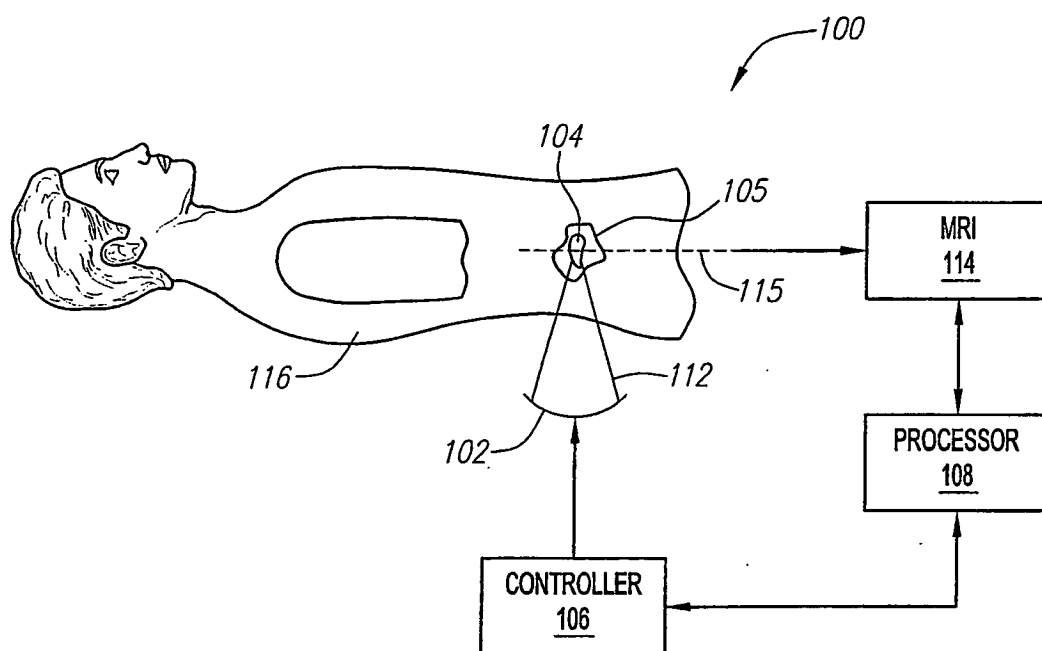


FIG. 1

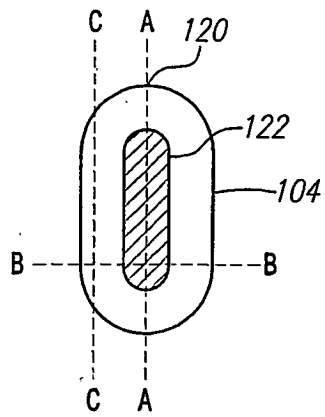


FIG. 2

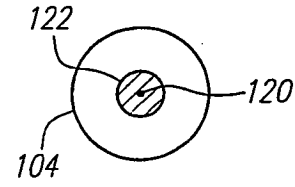


FIG. 3

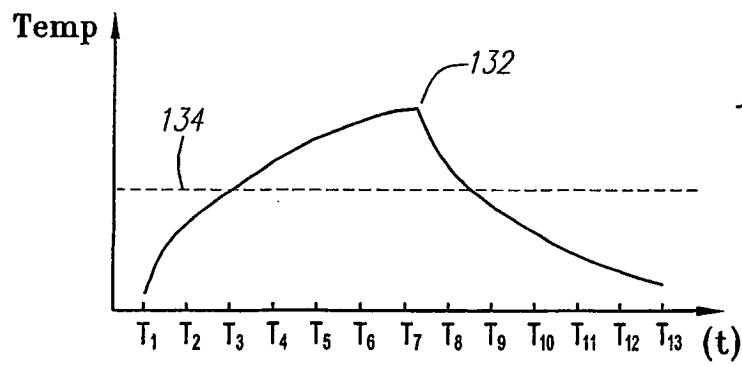


FIG. 4

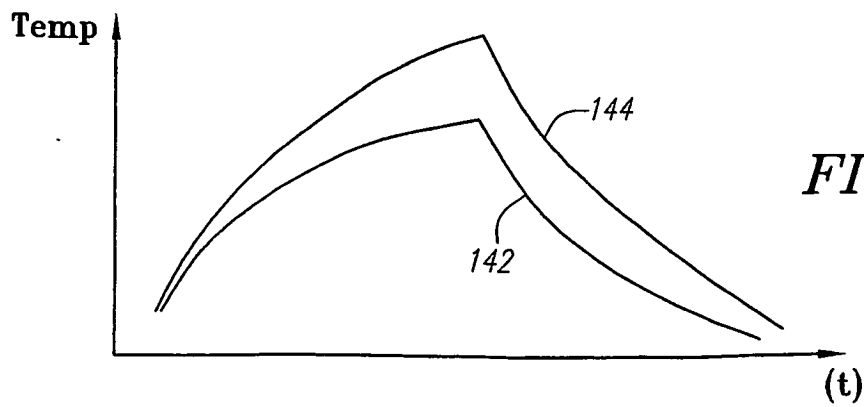
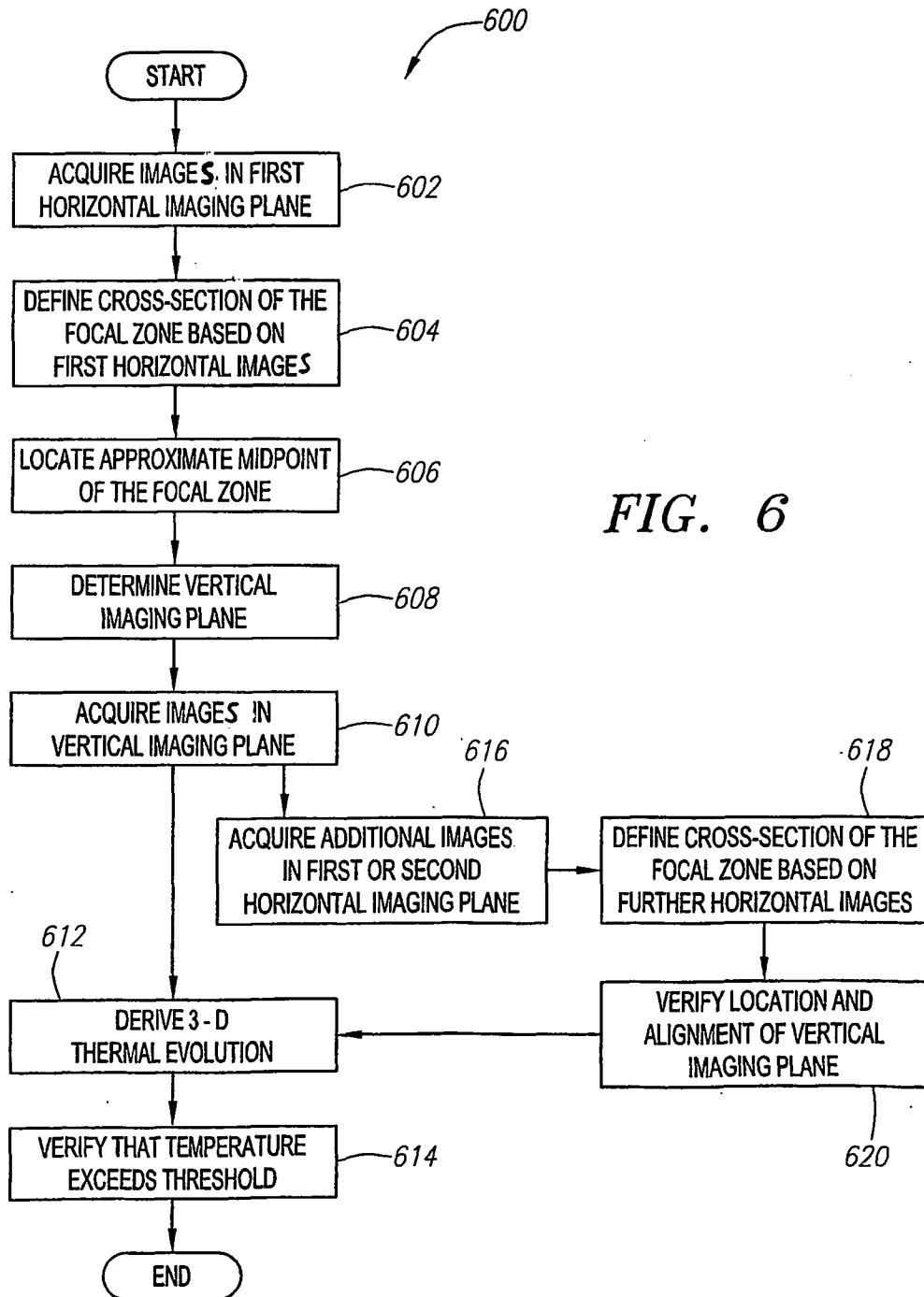


FIG. 5



REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 6419648 B [0014]
- US 20020180438 A1 [0014]

Non-patent literature cited in the description

- **Chung A. H. et al.** Thermal dosimetry of a focused ultrasound beam in vivo by magnetic resonance imaging. *Med. Phys.*, September 1999, vol. 26 (9), 2017-2026 [0006]

专利名称(译)	MRI引导的组织进行热处理的温度图		
公开(公告)号	EP1461630B1	公开(公告)日	2010-02-10
申请号	EP2002804980	申请日	2002-12-09
[标]申请(专利权)人(译)	InSightec的TXSONICS		
申请(专利权)人(译)	InSightec的-TXSONICS LTD.		
当前申请(专利权)人(译)	InSightec的有限公司.		
[标]发明人	FREUNDLICH DAVID		
发明人	FREUNDLICH, DAVID		
IPC分类号	G01R33/48 G01R33/28 A61B5/00 A61B5/055 A61B17/00 A61B18/00 A61B19/00 A61F7/00 A61N7/02		
CPC分类号	A61B5/01 A61B5/055 A61B2017/00084 A61B2090/374 A61N7/02 G01R33/4804		
优先权	10/022758 2001-12-14 US		
其他公开文献	EP1461630A1		
外部链接	Espacenet		

摘要(译)

一种系统采用磁共振成像来监测由聚焦区域中会聚的组织块的温度，该聚焦区域通常是细长的并且关于焦轴对称。在基本垂直于焦轴对准的第一图像平面中获取组织块的第一多个图像。然后，从第一多个图像中定义第一图像平面中的聚焦区的横截面。在基本平行于焦轴对准的第二图像平面中获取组织块的第二多个图像，第二图像平面在限定的焦点区域横截面的大约中点处将第一图像平面二等分。

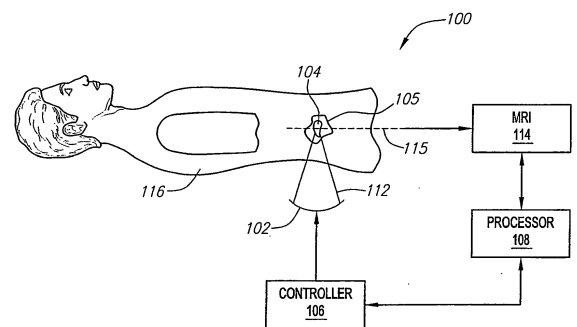


FIG. 1