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(54) Title: PROCESSING CARDIAC DATA FOR PERSONALIZED AHA DIAGRAM

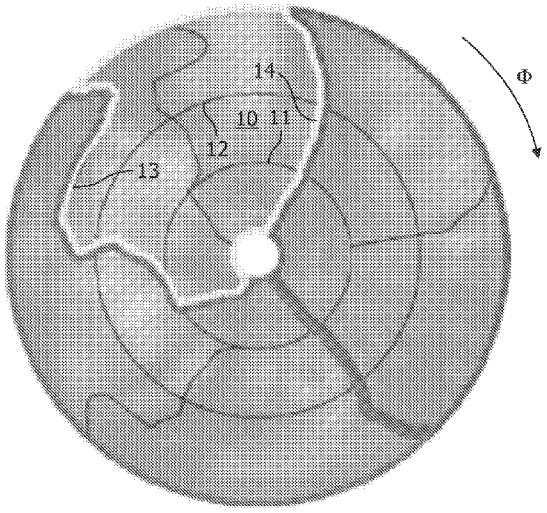


FIG. 4

(57) Abstract: The invention relates to a method of processing cardiac data. The method comprises the steps of modeling a patient-specific coronary-artery anatomy, modeling a surface geometry of the patient-specific myocardium at a heart division, projecting the coronary-artery anatomy and the myocardium surface geometry onto a plane which is transverse with respect to an axis of the heart division, dividing the projected myocardium surface geometry in arterial territories being closest to a corresponding coronary-artery, and representing cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

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Processing cardiac data for personalized AHA diagram

FIELD OF THE INVENTION

The invention relates to a method of processing cardiac data.

BACKGROUND TO THE INVENTION

In processing cardiac data, medical images of the human heart and quantitative data derived from measurements are obtained. The data can be acquired with imaging techniques such as magnetic resonance imaging (MRI), computed tomography angiography (CTA), ultrasound imaging (US) and nuclear medicine imaging (NM). The invention especially focuses on the processing of data related to visualization, analysis and reporting of the functioning of the left ventricle.

During the last decade, a variety of algorithms and software implementations have become available for assisting the diagnosis of coronary-artery disease (CAD) and for following this disease over time. CAD mostly affects the functioning of the left ventricle, which is responsible for the main blood supply to the body via the aorta. Left-ventricular analysis consists of the derivation of a large number of parameters that describe the local contraction, perfusion and viability of the left-ventricular myocardium, see e.g. the article "Quantification of atherosclerotic heart disease with cardiac MRI" by M. Breeuwer in Medica Mundi No. 49, Vol. 2, August 2005, pages 30-38. For example, from a 10-slice short-axis cine cardiac MR acquisition about 1000 wall-thickening values are usually derived (10 slices x 100 values per slice).

In the field of cardiac analysis, it is common practice to report the average value of cardiac parameters in relatively large segments, covering a substantial part of the left ventricle. Fig. 3 shows such a segmental representation of cardiac data, assuming 6 equi-angular segments per slice.

In 2002, the American Heart Association (AHA) proposed a standard for the partition of the left ventricle into segments, see the article "Standardized Myocardial Segmentation and Nomenclature for Tomographic Imaging of the Heart – A Statement for Healthcare Professionals From the Cardiac Imaging Committee of the Council on Clinical Cardiology of the American Heart Association" by M.D. Cerqueira et al. in the Circulation

2002; 105, pages 539-542. According to this standard, the left ventricle is divided into 17 segments, as is shown in Fig. 3. The rationale behind this partition is that specific groups of segments are supplied by specific coronary arteries. If a specific coronary artery is diseased, this will usually be reflected in the value of the parameters in the segments associated with this coronary artery.

However, the suggested relation between coronary arteries and AHA segments is only valid on average. Large variations in anatomy may occur between individuals, see e.g. the article "Correspondence between the 17-segment model and coronary arterial anatomy using contrast-enhanced cardiac magnetic resonance imaging" by Ortiz-Pérez et al. in JACC: Cardiovascular Imaging, Vol. 1, No. 3, 2008, page 282-293. It may thus happen that on the basis of the standard relation proposed by the AHA, incorrect conclusions are drawn about which coronary artery is responsible for abnormal segmental parameter values.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a method of processing cardiac data wherein the occurrence of an incorrect diagnosis of an artery disease can be reduced.

According to a first aspect of the invention, a method of processing cardiac data is provided, the method comprising the steps of modeling a patient-specific coronary-artery anatomy, modeling a surface geometry of the patient-specific myocardium at a heart division, projecting the coronary-artery anatomy and the myocardium surface geometry onto a plane which is transverse with respect to an axis of the heart division, dividing the projected myocardium surface geometry in arterial territories being closest to a corresponding coronary-artery, and representing cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

By interrelating a patient-specific coronary-artery anatomy to the patient-specific myocardium surface, a meaningful partition of the projected myocardium surface can be formed based on closest coronary-artery information. The term projection should not be construed to mean an orthogonal projection of the myocardium surface on the projection plane, but should be understood as a mapping of said myocardium surface on said projection plane. Further, by representing cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data, meaningful medical information for each of the of associated arterial territories can be provided. Since a patient-specific relation between the coronary-artery anatomy and arterial territories on the

myocardium is established the chance of incorrect diagnosis of coronary-artery disease is reduced.

In an implementation, the step of modeling the coronary-artery anatomy comprises identifying centerlines of the lumen of coronary arteries. As a result, a relatively simple representation of the coronary-artery anatomy is obtained.

In an implementation, the step of modeling the coronary-artery anatomy and/or the step of modeling a surface geometry of the patient-specific myocardium comprises imaging cardiac data, e.g. performing a magnetic resonance imaging (MRI), computed tomography angiography (CTA) imaging, ultrasound (US) imaging and/or nuclear medicine (NM) imaging process, so that a proper model can be determined.

In an implementation, the step of projecting the coronary-artery anatomy and the myocardium surface geometry comprises generating a bull's eye plot, thereby arriving at a generally accepted representation of cardiac data. As an example, an AHA bull's eye plot can be generated, or a continuous bull's eye plot. In principle, also other representations can be generated, e.g. a 3D visualization.

In an implementation, the step of dividing the myocardium surface geometry in the arterial territories comprises determining a distance between a location on the myocardium surface geometry and a specific coronary-artery, so that it is possible to determine whether a specific arterial territory is the closest one to a specific coronary-artery or not.

In an implementation, the distance between a location on the myocardium surface geometry and a specific coronary-artery is defined as the length of the shortest curve on the myocardial surface geometry connecting the location in the myocardium surface geometry to a point of the specific coronary-artery. As a result, a useful measure between a surface point and a coronary-artery is defined. Obviously, also other measures can be chosen, e.g. a Euclidian distance between the location in the myocardium surface and a point of the specific coronary-artery.

In an implementation, the step of dividing the projected myocardium surface geometry in arterial territories comprises identifying bordering territories separating the arterial territories. Preferably, the bordering territories, e.g. borders of arterial territories, are visualized. As a result, a personalized AHA diagram geometry can be obtained.

In an implementation, the identified bordering territories are based on closest coronary-artery information.

In an implementation, the step of dividing the projected myocardium surface in territories further comprises sub-dividing the specific arterial territory into a plurality of sub-territories. The definition of the sub-territories may be based, e.g. on the slice thickness as in the case of the AHA left ventricle segmentation.

In an implementation, the step of representing cardiac data associated with the specific arterial territory comprises determining values of said cardiac data averaged over each of the plurality of sub-territories of the specific arterial territory, so that a single value may represent the medical state of the myocardium surface part associated with a particular sub-territory.

In an implementation, the method further comprises visualizing the divided myocardium surface geometry and the associated reduced number of cardiac parameters, e.g. by presenting the information in gray values or using color pixels. The information can be communicated to medically trained personel, e.g. can be printed or displayed.

In an implementation, the heart division is the left ventricle. The method can also be applied to other heart divisions, such as the right ventricle and the atria of the heart.

According to a second aspect of the present invention, a computer system for processing cardiac data is provided, the system comprising a processor that is arranged to model a patient-specific coronary-artery anatomy, model a surface geometry of the patient-specific myocardium at a heart division, project the coronary-artery anatomy and the myocardium surface geometry onto a plane which is transverse with respect to an axis of the heart division, divide the projected myocardium surface geometry in arterial territories being closest to a corresponding coronary-artery, and represent cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

According to a third aspect of the present invention, a computer program product for processing cardiac data is provided, which computer program product comprises instructions for causing a processor to perform the steps of modeling a patient-specific coronary-artery anatomy, modeling a surface geometry of the patient-specific myocardium at a heart division, projecting the coronary-artery anatomy and the myocardium surface geometry onto a plane which is transverse with respect to an axis of the heart division, dividing the projected myocardium surface geometry in arterial territories being closest to a corresponding coronary-artery, and representing cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

It will be appreciated by those skilled in the art that two or more of the above-mentioned embodiments, implementations, and/or aspects of the invention may be combined in any way deemed useful.

Modifications and variations of the computer system and/or of the computer program product, which correspond to the described modifications and variations of the method, can be carried out by a person skilled in the art on the basis of the present description.

A person skilled in the art will appreciate that the method may be applied to multidimensional image data, e.g., to 3-dimensional (3-D) or 4-dimensional (4-D) images, acquired by various acquisition modalities such as, but not limited to, standard X-ray Imaging, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Ultrasound (US), Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), and Nuclear Medicine (NM).

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be more fully understood, embodiments thereof will now be described by way of example only, with reference to the figures in which:

Fig. 1 shows a schematic perspective view of a left ventricle;

Fig. 2 shows a projection of coronary-artery anatomy and myocardium surface geometry;

Fig. 3 shows a Bull's eye plot according to a standardized segmentation;

Fig. 4 shows a Bull's eye plot according to a personalized segmentation;

Fig. 5 schematically shows a flowchart of an exemplary implementation of the method; and

Fig. 6 schematically shows an embodiment of the computer system.

The Figures are merely for illustrating implementations and embodiments of the invention. In the Figures, the same reference numbers refer to equal or corresponding parts.

DETAILED DESCRIPTION OF EMBODIMENTS

The method of processing cardiac data according to the invention is based on heart imaging data, such as computed tomography angiography (CTA), magnetic resonance imaging (MRI), echocardiography (cardiac ultrasound) and/or nuclear medicine imaging

(NM). Analysis of the heart measurements may provide numerical values of parameters representative of contraction, perfusion and viability of the myocardium. The method according to the invention focuses especially on processing data of the left ventricle.

Fig. 1 shows a schematic perspective view of a left ventricle 1 in a polar (r, Φ, h)-coordinate system. Further, a long axis 3 substantially coinciding with a longitudinal axis of the left ventricle, and a short axis 5 substantially perpendicular to the long axis are shown. The method comprises the step of modeling a patient-specific coronary-artery anatomy. The step of modeling the coronary-artery anatomy may comprise identifying centerlines of the lumen of coronary arteries. After the identification step, which is based on measured cardiac data, the arteries can be modeled as curved lines in a 3D space using segmentation techniques. As an example, reference is made to an algorithm as published in the article "Validation of a semi-automatic coronary vessel tracker algorithm for magnetic resonance whole-heart angiography" by J. Sonnemans et al. in Proceedings SCMR 2008, abstract 210, pages 73-74. Here, whole-heart cardiac MRI, cardiac CTA or rotational angiography image data is used as input data. The anatomy can, for example, be represented by the centerline of the lumen of the coronary arteries.

The method further comprises modeling a surface geometry of the patient-specific myocardium 2 at the left ventricle 1. For example, the geometry of the surface of the left ventricular myocardium 2 can be derived from the image data that has been used for modeling the coronary anatomy, e.g. from whole-heart cardiac MRI and CTA, or from other cardiac image data, such as functional, perfusion, viability MRI, US and/or NM. In the latter case, a registration between the whole-heart image data and the data used for deriving the left-ventricular geometry may be performed. This can be done using existing registration technology, see e.g. "Medical Image Registration" by Hajnal, Hill & Hawkes, CRC Press, ISBN 0-8493-0064-9.

The method further comprises the step of projecting the coronary-artery anatomy and the myocardium surface geometry onto a plane 4 which is transverse with respect to a long axis 3 of the left ventricle 1. As a result, a two-dimensional representation, also called a bull's eye plot, is generated from the information of both the coronary-artery anatomy and the myocardium surface 2. In the two-dimensional representation, a polar (h, Φ)-coordinate system is introduced. It is noted that the projection plane 4 is positioned below the ventricle 1 but can also be placed above the ventricle 1. Alternatively, the projection plane 4 can be oriented otherwise, e.g. perpendicular to the short axis of the left ventricle 1.

In general, a 2D Bull's-Eye plot represents quantitative analysis results of e.g. myocardial function, perfusion or viability of the heart. The Bull's-Eye plot may comprise a set of concentric rings 6. Each ring can be divided into a number of segments. Inner circles represent a region near the apex, the bottom of the left ventricle, while outer circles represent the area near the top of the left ventricle. The plot is popular in medical practice as it is intuitive and gives a comparable global overview of a property being measured. Similar representations could be generated for other heart components such as the right ventricle and atria.

Fig. 2 shows the projection of the coronary-artery anatomy and the myocardium surface geometry. The coronary-artery anatomy comprises multiple arteries 7a-f. Further, in Fig. 2, the projected myocardium surface 8 comprises a number of infarcted areas, depicted as dark regions 9a, 9b.

The method further comprises the step of dividing the projected myocardium surface 8 in arterial territories being closest to a corresponding coronary-artery 7a-7f. The dividing step comprises determining a distance between a location on the myocardium surface and a specific coronary-artery. Here, the distance between a location A in the myocardium surface 8 and a specific coronary-artery 7b is defined as the length of the shortest curve of the curves c1 and c2 on the myocardial surface geometry connecting the location A in the myocardium surface 8 to a point B and C, respectively, of the specific coronary-artery 7b. As an example, in Fig. 2, the shortest curve is the curve c2 between the location A on the surface 8 and a specific point C of the specific coronary-artery 7b. The collection of locations having a distance to a specific coronary-artery that is smaller than a distance to the other coronary-arteries forms a specific arterial territory comprising locations closest to the corresponding specific coronary-artery.

The step of dividing the projected myocardium surface geometry in arterial territories may further comprise identifying bordering territories separating the arterial territories. The bordering territories may be borders, i.e. border lines defined by locations equidistant to two or more coronary arteries. They may be mapped into and shown in the projection plane along with the arteries. The dividing step may further comprise segmenting the myocardium surface geometry according to a standard segmentation, thus further dividing the arterial territories in sub-territories. As a result, the sub-territories are bordered at predetermined height values defined by the long axis 3 of the ventricle, while a border location in a circumferential direction Φ is based on the closest coronary-artery information.

Fig. 3 shows a Bull's eye plot according to a standardized segmentation of the left ventricle. Here, the plot is divided in predefined ring sections having standardized affiliations R_1-R_{17} each representing a specified region in the myocardial surface. Each ring section 10 is bordered by an inner radial border 11, an outer radial border 12 and straight borders 13, 14 in the circumferential direction Φ.

Fig. 4 shows a Bull's eye plot according to a personalized segmentation, resulting from the method as described above. The plot comprises a number of ring sections 10, i.e. sub-territories, being bordered by an inner radial border 11, an outer radial border 12 and segments of the arterial territories borders 13, 14 in the circumferential direction Φ, the latter borders 13, 14 being based on closest coronary-artery information. As a consequence, a personalized segmentation is obtained wherein a particular segment, a ring section 10, is meaningful related to a particular coronary-artery.

The method further comprises the step of representing cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data. As an example, an averaged value of cardiac data associated with each ring section 10 can be determined. Alternatively, other cardiac parameters can be deduced, e.g. first order statistical values. As an example, a median, modus, minimum and/or maximum value can be chosen as the value representing a ring section.

According to the invention, the method may comprise visualizing the reduced number of cardiac parameters and the divided myocardium surface geometry so that medically trained people can easily observe cardiac information.

Further, the method may comprise mapping the boundaries of the arterial territories to the standardized boundaries of the AHA diagram, so that the standard diagram is shown while the data associated with each arterial territory more properly is associated with a corresponding coronary-artery.

Fig. 5 schematically shows a flowchart of the method. The method comprises the steps of modeling 100 a patient-specific coronary-artery anatomy, modeling 110 a surface geometry of the patient-specific myocardium at a heart division, projecting 120 the coronary-artery anatomy and the myocardium surface geometry onto a plane which is transverse with respect to a long axis of the heart division; dividing 130 the projected myocardium surface geometry in arterial territories being closest to a corresponding coronary-artery; and representing 140 cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

Briefly formulated, the method according to the invention processes the cardiac data such that a 17-segment American Heart Association (AHA) diagram is adapted to a patient-specific coronary-artery anatomy, i.e. that segment boundaries are modified in such a way that a more proper relation is obtained between segments and supplying coronary arteries.

Further, Fig. 6 schematically shows a computer system 113 for processing cardiac data. The system 113 comprises a processor 112 that is arranged to model a patient-specific coronary-artery anatomy, model a surface geometry of the patient-specific myocardium at a heart division, project the coronary-artery anatomy and the myocardium surface geometry onto a plane which is transverse with respect to a long axis of the heart division, divide the projected myocardium surface geometry in arterial territories being closest to a corresponding coronary-artery, and represent cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

It is noted that the method for processing cardiac data can be performed using dedicated hardware structures, such as FPGA and/or ASIC components. Otherwise, the method can also at least partially be performed using a computer program product comprising instructions for causing the processor 112 to perform the above described steps of the method according to the invention.

The invention is not restricted to the embodiments described herein. It will be understood that many variants are possible.

Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention. Any reference signs in the claims shall not be construed as limiting the scope.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention and that those skilled in the art will be able to design alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word “comprising” does not exclude the presence of elements or steps not listed in a claim or in the description. The word “a” or “an” preceding an element does not exclude the presence of a plurality of such elements. The invention can be implemented by means of hardware comprising several distinct elements and by means of a programmed computer. In the system claims enumerating several units, several of these units can be embodied by one and the same

item of hardware or software. The usage of the words first, second, third, etc., does not indicate any ordering. These words are to be interpreted as names.

CLAIMS:

1. A method of processing cardiac data, comprising the steps of:
modeling (100) a patient-specific coronary-artery anatomy;
modeling (110) a surface geometry of the patient-specific myocardium (2) at a heart division (1);
projecting (120) the coronary-artery anatomy and the myocardium surface geometry onto a plane (4) which is transverse with respect to an axis (3) of the heart division;
dividing (130) the projected myocardium surface geometry in arterial territories (10) being closest to a corresponding coronary-artery (7); and
representing (140) cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

2. A method according to claim 1, wherein the step of modeling the coronary-artery anatomy comprises identifying centerlines of the lumen of coronary arteries.

3. A method according to claim 1, wherein the step of modeling a coronary-artery anatomy comprises imaging cardiac data.

4. A method according to claim 1, wherein the step of modeling a surface geometry of the patient-specific myocardium comprises imaging cardiac data.

5. A method according to claim 1, wherein the step of projecting the coronary-artery anatomy and the myocardium surface geometry comprises generating a bull's eye plot.

6. A method according to claim 1, wherein the step of dividing the myocardium surface geometry in the arterial territories comprises determining a distance between a location on the myocardium surface geometry and a specific coronary-artery.

7. A method according to claim 6, wherein the distance between a location on the myocardium surface geometry and a specific coronary-artery is defined as the length of the

shortest curve (c2) on the myocardial surface geometry connecting the location (A) in the myocardium surface geometry to a point (C) of the specific coronary-artery.

8. A method according to claim 1, wherein the step of dividing the projected myocardium surface geometry in the arterial territories comprises identifying bordering territories (13, 14) separating the arterial territories.

9. A method according to claim 8, wherein the identified bordering territories (13, 14) are based on closest coronary-artery information.

10. A method according to claim 1, further comprising sub-dividing the specific arterial territory into a plurality of sub-territories.

11. A method according to claim 10, wherein the step of representing cardiac data associated with the specific arterial territory comprises determining values of said cardiac data averaged over each of the plurality of sub-territories of the specific arterial territory.

12. A method according to claim 1, further comprising visualizing the divided myocardium surface geometry and the associated reduced number of cardiac parameters.

13. A method according to claim 1, wherein the heart division is the left ventricle.

14. A computer system for processing cardiac data, comprising a processor (12) that is arranged to

model a patient-specific coronary-artery anatomy;

model a surface geometry of the patient-specific myocardium (2) at a heart division (1);

project the coronary-artery anatomy and the myocardium surface geometry onto a plane (4) which is transverse with respect to an axis (3) of the heart division;

divide the projected myocardium surface geometry in arterial territories (10) being closest to a corresponding coronary-artery (7); and

represent cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

15. A computer program product for processing cardiac data, which computer program product comprises instructions for causing a processor (112) to perform the steps of:

modeling a patient-specific coronary-artery anatomy;

modeling a surface geometry of the patient-specific myocardium (2) at a heart division (1);

projecting the coronary-artery anatomy and the myocardium surface geometry onto a plane (4) which is transverse with respect to an axis (3) of the heart division;

dividing the projected myocardium surface geometry in arterial territories (10) being closest to a corresponding coronary-artery (7); and

representing cardiac data associated with a specific arterial territory by a reduced number of cardiac parameters derived from said cardiac data.

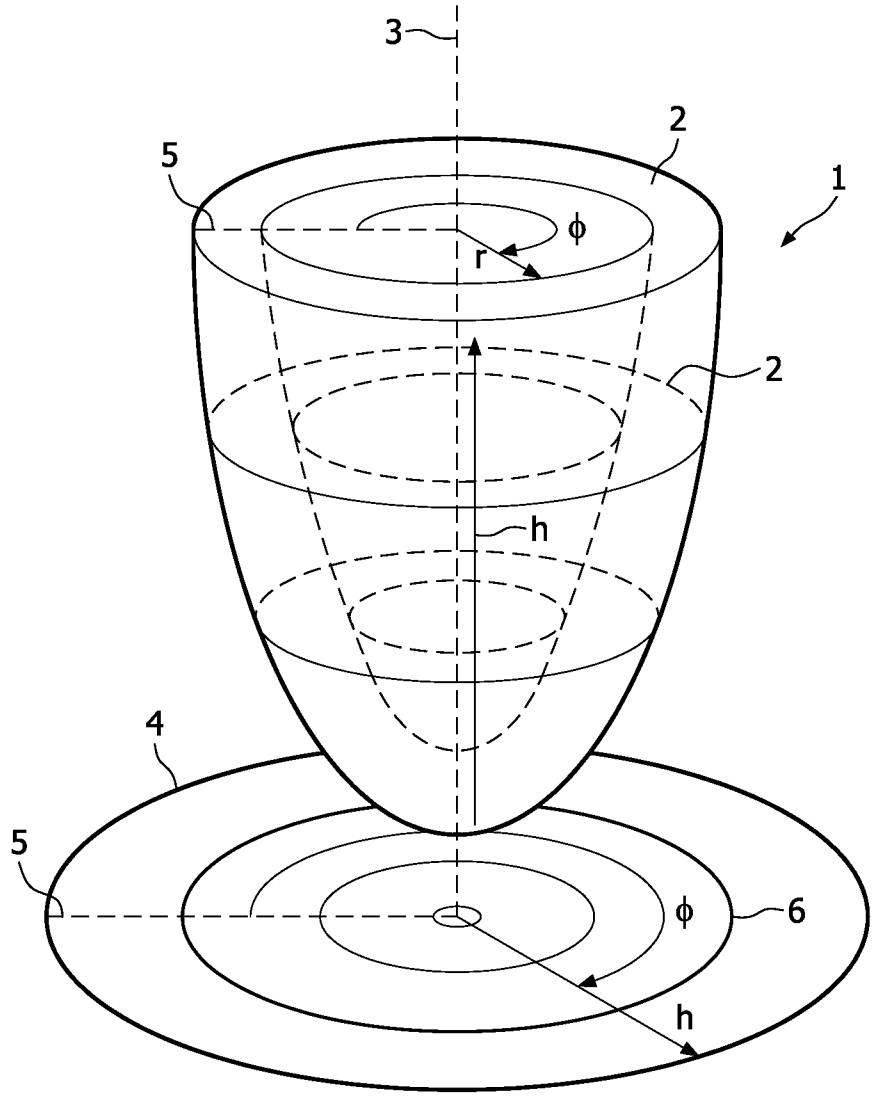


FIG. 1

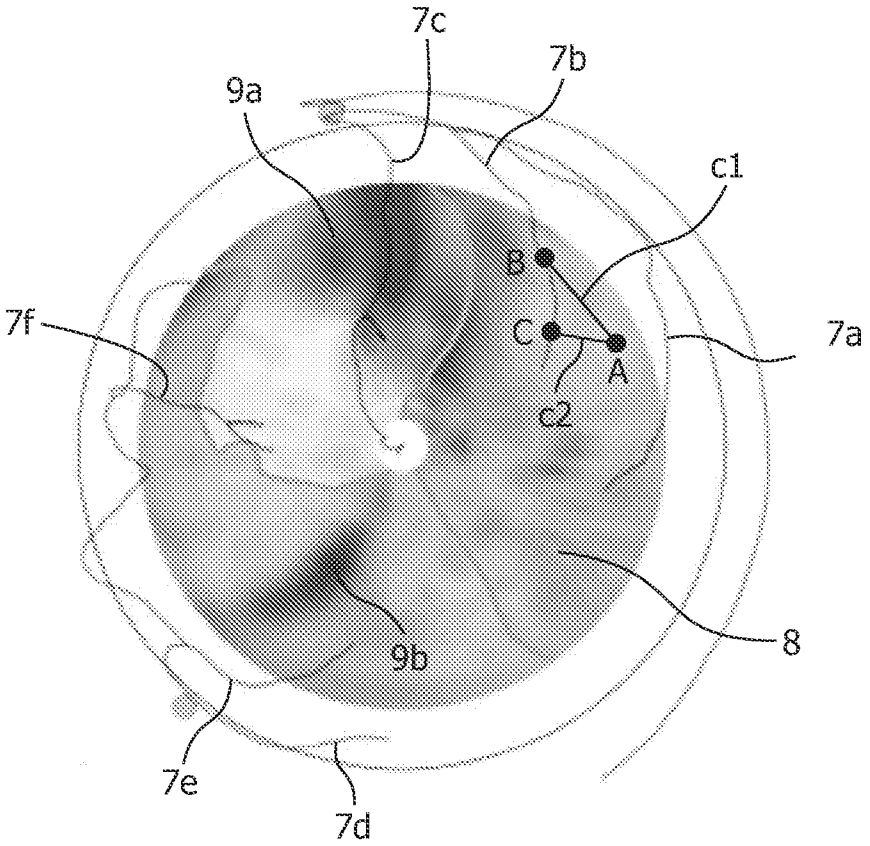


FIG. 2

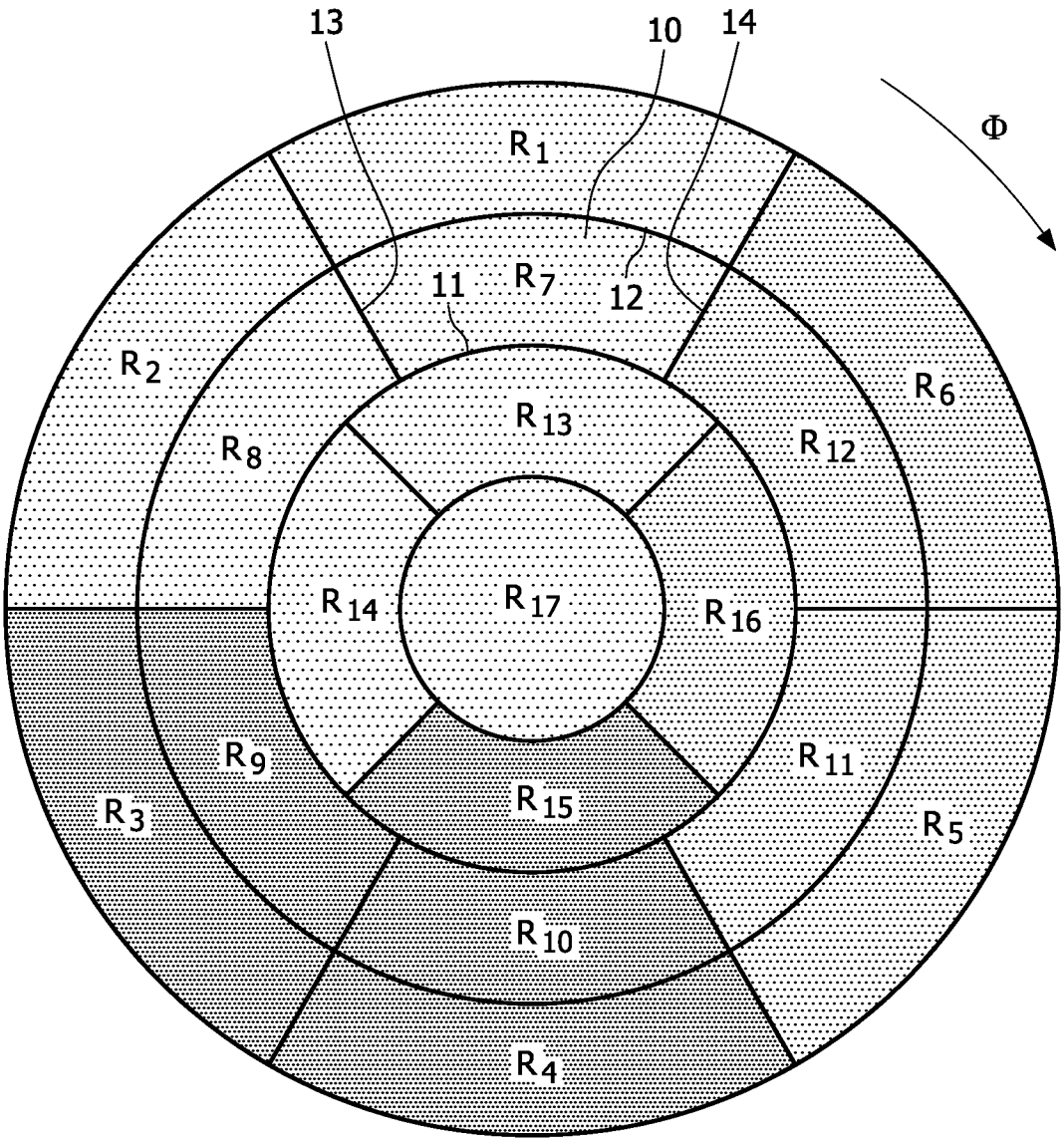

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14
Φ
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R7
12
R2
R6
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R4

FIG. 3

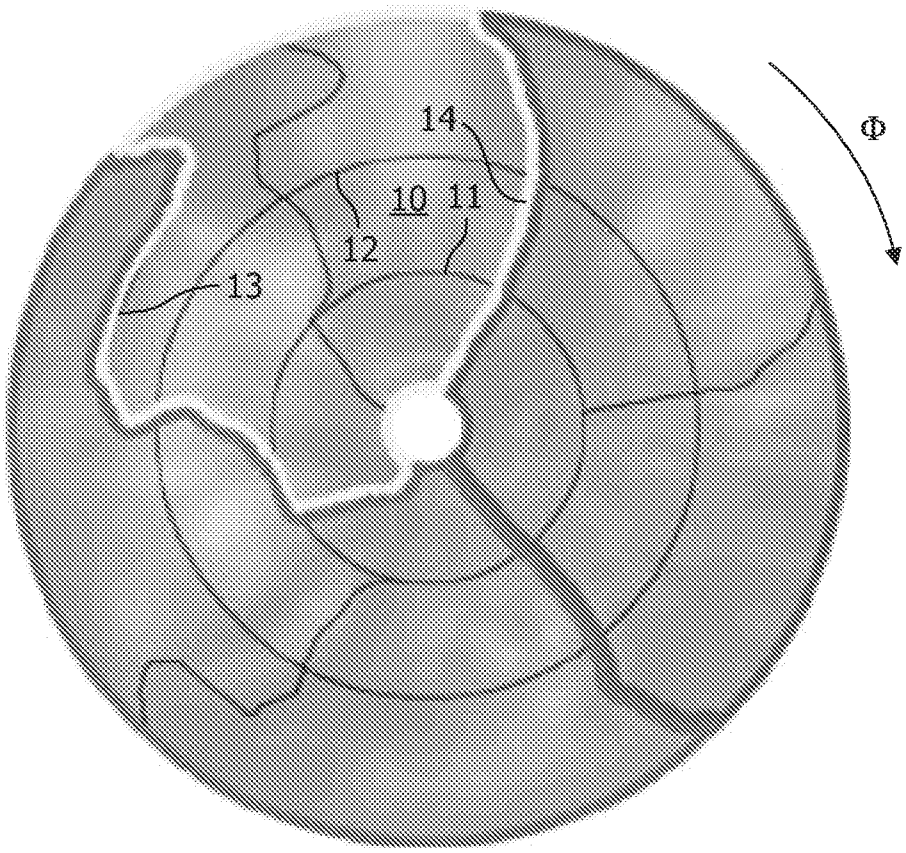


FIG. 4

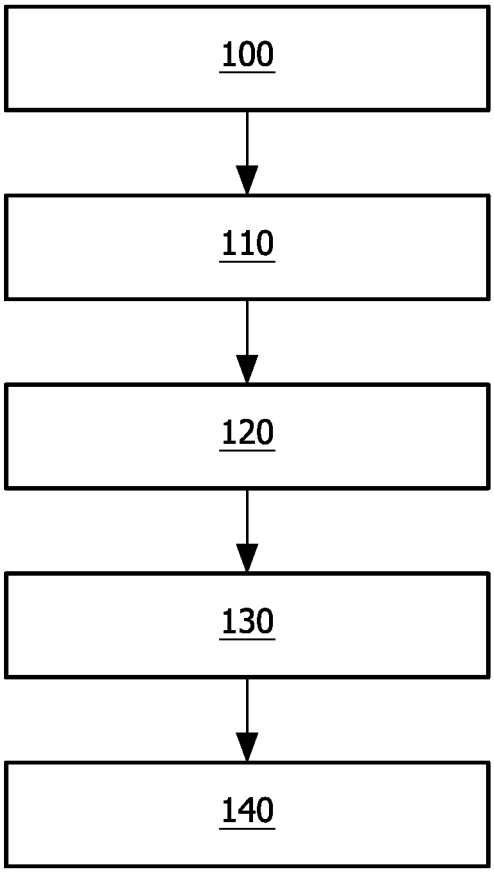


FIG. 5

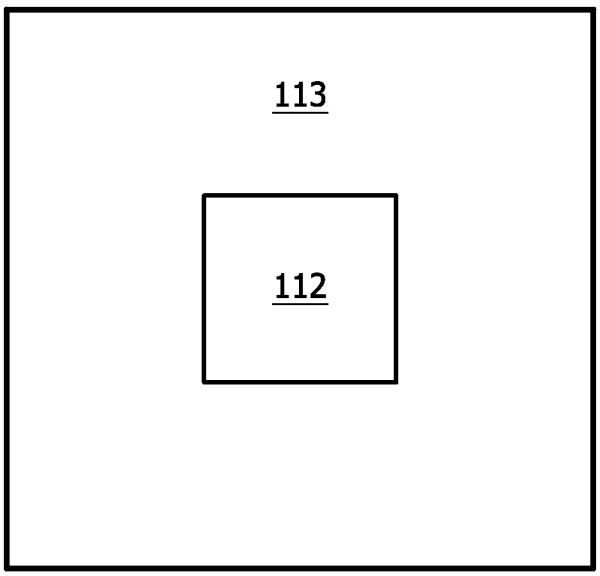


FIG. 6