Processing myocardial perfusion data

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 June 2010 (03.06.2010)

PCT

(10) International Publication Number
WO 2010/061335 A1

(51) **International Patent Classification**:
G01R 33/54 (2006.01) *G01R 33/563* (2006.01)

(21) **International Application Number**:
PCT/IB2009/055314

(22) **International Filing Date**:
24 November 2009 (24.11.2009)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
08170273.0 28 November 2008 (28.11.2008) EP

(71) **Applicant** *(for all designated States except US)*: **KONINKLIJKE PHILIPS ELECTRONICS N.V.** [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(72) **Inventors; and**

(75) **Inventors/Applicants** *(for US only)*: **BREEUWER, Marcel** [NL/NL]; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL). **OLIVAN BESCOS, Javier** [ES/NL]; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL). **TERMEER, Maurice, A.** [NL/NL]; c/o High Tech Campus Building 44, NL-5656 AE Eindhoven (NL).

(74) **Agents**: **VAN VELZEN, Maaike, M.** et al.; High Tech Campus 44, NL-5600 AE Eindhoven (NL).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) **Title**: PROCESSING MYOCARDIAL PERFUSION DATA

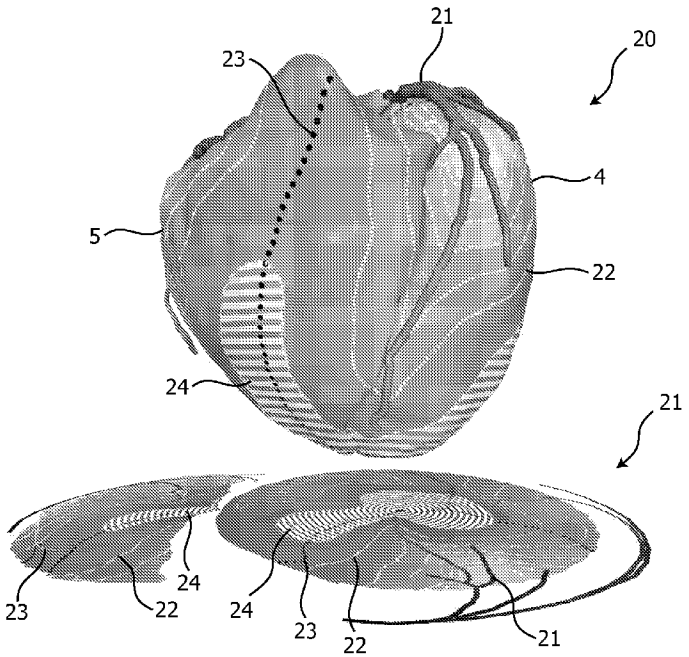

FIG. 3

(57) **Abstract**: The invention relates to a system for processing cardiac data. The system comprises a processor that is arranged to obtain patient-specific myocardial perfusion data. The processor is also arranged for modeling a surface geometry of a patient-specific myocardium division. Further, the processor is arranged for integrating the myocardium division model and the myocardial perfusion data into a single model.

WO 2010/061335 A1

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Processing myocardial perfusion data

FIELD OF THE INVENTION

The invention relates to a system for processing cardiac data.

BACKGROUND TO THE INVENTION

Three-dimensional (3D) imaging of the heart and the coronary arteries by MRI and CTA is currently entering clinical practice. With these imaging modalities coronary arteries as well as other cardiac structures such as the left- and right-ventricular myocardium can be dynamically imaged.

Over the last few years, automatic segmentation of the complete heart including the coronary arteries has been extensively investigated. This has resulted in CT/MR whole-heart segmentation algorithms, see e.g. the article "Automatic whole heart segmentation in CT images: Method and validation" by O. Ecabert et al., Proc. of SPIE 2007, Vol. 6512, pages 65120G-1 - 65120G-12, and in algorithms for tracking the centerlines of the coronary arteries, see e.g. the article "3D MR coronary axis determination using a minimum cost path approach" by O. Wink et al., Magn. Reson. Med. 47, 2002, pages 1169– 1175. Based on these automatic segmentations, surface renderings can be made of the heart and the surrounding vessels.

Myocardial perfusion can be measured with ECG-triggered Gadolinium-enhanced 1st-pass MR perfusion imaging, see e.g. the article "Noninvasive detection of myocardial ischemia from perfusion reserve based on cardiovascular magnetic resonance" by N. Al-Saadi et al., Circulation 101, 2000, pages 1379-1383., followed by quantitative perfusion analysis e.g. with the Philips ViewForum MRcardio software analysis product, see the article "Quantification of atherosclerotic heart disease with cardiac MRI" by M. Breeuwer, Medica Mundi 49(2), 2005, pages 30-38. At present, the measured perfusion is represented in so-called Bulls Eye plots. An example of such a bull's eye plot is shown in Figure 1. The resolution of MR myocardial perfusion imaging in the bull's eye plot is very limited, viz. only three to five slices for the complete ventricle.

The most frequently occurring heart disease is coronary-artery stenosis, i.e. narrowing of the coronary-artery, which usually results in myocardial ischemia, i.e. a reduced

contraction due to insufficient supply of oxygen-rich blood, and may result in myocardial infarction, i.e. starvation of myocardial tissue due to lack of oxygen.

Due to the specific layout of the bull's eye plot, it is very difficult, if not impossible, to accurately relate reduced perfusion areas in the bull's eye plot to the patient-specific 3D anatomy of the ventricle and coronary arteries that may cause a reduced perfusion. As a result, it is very complicated for clinicians to decide which coronary arteries cause the disease.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a system for processing cardiac data, wherein it is easier for clinicians to identify ventricle and coronary arteries causing a reduced perfusion.

The invention is defined by the independent claims. Advantageous embodiments are defined in the dependent claims.

According to a first aspect of the invention, a system for processing cardiac data is provided, the system comprising a processor that is arranged to obtain patient-specific myocardial perfusion data; model a surface geometry of a patient-specific myocardium division; and integrate the myocardium division model and the myocardial perfusion data into a single model.

By integrating the myocardium division model and the myocardial perfusion data into a single model, myocardial perfusion data can easily be interrelated to the surface geometry of the patient's myocardium. As a result, clinicians can more easily identify myocardium areas having reduced perfusion. In particular, underperfused myocardial areas can thus be identified. The system according to the invention can be used for supporting the diagnosis of coronary-artery disease and/or for monitoring the effect of treatment such as ballooning, stenting and/or by-pass surgery.

In an implementation, the single model comprises a 2D and/or a 3D representation, e.g. a bull's eye plot and/or a 3D surface rendering of the myocardium, thereby providing an integrated model that might be visualized in a way that is familiar to clinicians.

In an implementation, the processor is arranged for modeling a patient-specific coronary-artery anatomy, wherein the integrating step further comprises integrating the coronary-artery anatomy model in the single model. By providing a coronary-artery anatomy model and by integrating it in the single model, the myocardial perfusion data interrelated to

the surface geometry of the patient's myocardium can be also interrelated to a coronary-artery anatomy causing the blood supply. In particular, a coronary-artery structure might be identified causing underperfused myocardial areas.

In an implementation, the processor is arranged for assigning a blood supply parameter to a myocardium surface location on the basis of the myocardial perfusion data, the value of the parameter being associated with a corresponding blood supply value, so that blood supply information can be visualized in relation with the myocardium surface.

In an implementation, the parameter value is chosen in a color range, e.g. ranging from light gray to dark red, thereby avoiding visual clutter due to too many colors. Obviously, also other color ranges can be applied.

In an implementation, the parameter value is normalized with a maximum blood supply value, so that relative blood supply information is provided. In another implementation, absolute parameter values can be provided, e.g. if an accurate algorithm for evaluating blood perfusion data is applied.

In an implementation, the processor is arranged for classifying a myocardium surface location as underperfused if the corresponding blood supply value is below a selectable threshold. The resultant underperfused locations can advantageously be visualized in a particular way, e.g. by a striped pattern or in a specific color.

In an implementation, the processor is arranged for interlinking myocardium surface locations having corresponding blood supply values that substantially coincide, thereby offering the possibility that myocardium surface locations that have substantially the same blood perfusion are shown in relation with each other, e.g. by displaying an isocontour as a dashed line.

In an implementation, the processor is arranged for visualizing the single model, thereby providing integrated information in a suitable way to clinicians.

In an implementation, the processor is arranged for dividing the myocardium surface into coronary artery territories, based on a corresponding principal supplying artery. As a result, insight can be obtained into which region is supplied by which coronary artery. In visualizing the coronary artery territories, different techniques can be applied, e.g. showing territory border lines, e.g. by determining an equiperfusion contour where the supply of a primary and a secondary feeding artery is substantially equal.

In an implementation, the processor is arranged for assigning the blood supply parameter to myocardium surface locations in a specific coronary artery territory, thereby providing information as to which particular myocardium surface area a particular coronary

artery is supplying blood. When visualizing the integrated model, such a specific coronary artery territory might be depicted using the assigned blood supply parameter values, while no blood supply information relating to other coronary artery territories is shown. As a result, a focused view on the specific territory is provided.

In an implementation, the processor is arranged for assigning parameter values to artery structures, based on corresponding relative blood supply to a specified area of interest on the myocardium surface. In this approach, information is provided of coronary artery groups that are involved in supplying blood to a specified area on the myocardium surface.

In an implementation, the myocardium division relates to the left ventricle and/or the right ventricle, thereby providing blood perfusion data related to one or both ventricles.

According to a second aspect of the present invention, a method of processing cardiac data is provided, which method comprises the steps of obtaining patient-specific myocardial perfusion data, modeling a surface geometry of a patient-specific myocardium division; and integrating the myocardium division model and the myocardial perfusion data into a single model.

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 obtaining patient-specific myocardial perfusion data, modeling a surface geometry of a patient-specific myocardium division; and integrating the myocardium division model and the myocardial perfusion data into a single model.

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 view of a bull's eye plot;

Fig. 2 shows a schematic perspective view of a myocardium geometry;

Fig. 3 shows a first integrated model;

Fig. 4a shows a second integrated model;

Fig. 4b shows a third integrated model;

Fig. 5a shows a fourth integrated model;

Fig. 5b shows a fifth integrated model;

Fig. 5c shows a sixth integrated model;

Fig. 5d shows a seventh integrated model;

Fig. 6 shows an eighth integrated model;

Fig. 7a shows a ninth integrated model;

Fig. 7b shows a tenth integrated model;

Fig. 8a shows an eleventh integrated model;

Fig. 8b shows a twelfth integrated model;

Fig. 9a shows a thirteenth integrated model;

Fig. 9b shows a fourteenth integrated model;

Fig. 10 shows a flow chart of an embodiment of the method according to the invention; and

Fig. 11 shows a schematic view of an embodiment of a system according to the invention.

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) and/or X-ray, and in future possibly 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 regarding the left ventricle.

According to an aspect of the invention, a surface geometry of a patient-specific myocardium division is modeled.

A bull's eye plot is a visualization primitive that is commonly used in cardiac medicine. Its main goal is to provide a two-dimensional overview of the left ventricle 4 and optionally the right ventricle 5. The classical approach to generating a bull's eye plot is to segment the myocardium into a stack of long-axis slices and map these segments to a set of concentric rings.

However, a bull's eye plot can also be constructed as a continuous unfolding of the left ventricle along its long axis 2. Figure 2 shows a schematic perspective view of a myocardium geometry 1. The segmentation of the heart that is used in this context is an unstructured grid of vertices along the epicardium 7. Each of these vertices can be specified by three parameters: an angle φ with the short axis 3 on a plane perpendicular to the long axis 2, the distance h to the apex 8 along the long axis 2 and the distance r to the long axis 2.

Any point on the epicardium 7 can then be projected, symbolically indicated by the arrows P, onto a cylinder by interpreting φ and h as cylindrical coordinates. Since the surface will be projected on a plane 9, 10, the information provided by r is superfluous. The parameters φ and h are sufficient as polar coordinates to form a circle. The segmentation covers the entire left and right ventricles 4, 5. Since the projection of the top of both ventricles does not provide useful information and only clutters the projection, we do not project vertices that have a value of h exceeding a predefined threshold. This threshold is based on the extent of h of the septum 6, i.e. the myocardial wall shared by the left and right ventricles. As an additional constraint for the right ventricle, any triangles that would cause overlap in the projection are also not included in the bull's eye plot 9, 10.

Since the right ventricle 5 is also part of the processing, this is also depicted in the bull's eye plot. While several approaches to visualize the right ventricle in a two-dimensional manner exist, the most common approach is to represent it by a half circle. This approach is based on the idea that the right ventricle 5 is essentially a half left ventricle 4. This approach is common in clinical practice.

To realize a half-circle unfolding, firstly the same parameterization to the right ventricle 5 is applied as has been applied to the left ventricle 4. In the bull's eye plot, the right ventricle is translated along the short axis 3 to prevent overlap with the projection of the left ventricle 4. Next, the angle φ is normalized to the range $[-\frac{1}{2}\pi; \frac{1}{2}\pi]$ to form a half circle. This step also eliminates any inter-patient shape variations of the right ventricle.

Both the 3D myocardium geometry 1 and the 2D bull's eye plot form a model of the surface geometry of a patient-specific myocardium division.

According to a further aspect of the invention, a patient-specific coronary-artery anatomy is modeled.

According to another aspect of the invention, patient-specific myocardial perfusion data are provided. Such data can be generated by various myocardial perfusion measurement and/or modeling algorithms, e.g. by modeling the influence of a vessel diameter on the blood flow by representing the coronary artery tree as a network of resistors. Obviously, more advanced algorithms can be applied for generating the patient-specific myocardial perfusion data. A primary outcome of a computational model of myocardial perfusion data is the blood supply present at each point in the myocardium.

Then, the myocardium division model, the coronary-artery anatomy model and the myocardial perfusion data are integrated into a single, integrated model. In the integrated model, a coronary-artery anatomy 21 is present on the myocardium surface 4, 5.

Figure 3 shows a first integrated model 20. Here, myocardial perfusion data are visualized, e.g. by color encoding or by gray scale encoding, both in the 2D representation and in the 3D representation. In particular, a blood supply parameter is assigned to a myocardium surface location, wherein the value of the parameter is associated with a corresponding blood supply value. To avoid visual clutter due to too many colors, the blood supply parameter value is chosen in a color range, viz. ranging from a light gray to dark red color. For additional insight in the structure of the supplying regions, isocontours 22 are added as white dashed lines. These contours 22 represent linked myocardium surface locations having corresponding blood supply values that substantially coincide. Thus, the contours 22 delineate borders where the supply of blood is equal. Further, a striped pattern 24 is applied to underperfused regions, i.e., regions where the supply is below a user-specified threshold. Additionally or alternatively, a specific pattern can be applied to well perfused regions, i.e. regions where the supply is above a user-specified threshold.

Due to the simplicity of the currently available myocardium perfusion modeling approaches, the absolute values that have been obtained may not be close to reality.

In that case, no meaningful intervals can be defined that correspond to a healthy supply. Instead, a relative supply value can be shown, which is based on a maximum supply in the model under analysis. In order to perceive both large and small differences in the distribution of blood 4 throughout the myocardium, a logarithmic scaling is performed prior to applying color encoding and computing the isocontours 22. This makes the interpretation of the shape of regions with near-equal supply easier. Obviously, also other scaling can be applied, e.g. linear scaling. The striped pattern provides a way of marking underperfused areas, i.e., areas where the supply of blood is below a predefined threshold.

The striped pattern is implemented using h, i.e. the distance to the apex along the long axis part of the parameterization. All parts where the fractional part of $\delta \cdot h$ is larger than 1/2 are made opaque, the others transparent. This leads to stripes perpendicular to the long axis in the three-dimensional view, and circles or arcs in the two-dimensional projection. An advantage of this pattern is that it is rotation invariant. The orientation of the pattern is perceived equally throughout the entire mesh and the two-dimensional projection.

The coronary arteries 21 are displayed in the three-dimensional view as well as on the bull's eye plot. In the three-dimensional view, the coronary arteries 21 are displayed as a tube with a radius corresponding to the actual artery radius. In another embodiment, the shown radius of the coronary arteries is fixed. In order to prevent intersections of the coronary arteries with the myocardium, the positions of the arteries have been modified. The computational modeling uses unmodified positions. The coronary arteries are first projected onto the myocardium 4, 5 and subsequently translated a constant distance along the surface normal. This causes each coronary artery to have a constant distance to the myocardium. A color encoding is used to show the relative outflow at each point in the coronary artery tree 21.

The coronary arteries 21 are also projected onto the bull's eye plot, using the same projection technique as described with respect to the myocardium geometry. Whether a point along an artery should be projected on the projection of the left or right ventricle 4, 5 is based on which ventricle is closest. A similar color encoding showing relative outflow on the projected coronary arteries is used.

To gain an insight into which region is supplied by each coronary artery, the coronary artery territories are visualized. To this end, the coronary artery 21 is divided into three groups: left anterior descending (LAD), left circumflex (LCX) and right coronary artery (RCA). This division is common in clinical practice and is also recommended by the AHA. In the direct visualization of blood supply, the coronary territories are visualized by drawing

black dotted equi-perfusion lines 23. This is shown in Figure 3, but also in Figures 4a and 4b, showing a second and a third integrated model, respectively. Along these lines 23 the supply of the primary and secondary feeding arteries is equal. When more branches of the coronary arteries are available for processing, a further coronary territory subdivision can be made, which is becoming feasible using e.g. CTA data.

While visualizing the equi-perfusion lines 23 already gives a good basic insight into the area supplied by each coronary artery group 21a-c, these areas are not discrete. Areas throughout the myocardium, especially near the boundaries of the coronary territories, may be fed by multiple coronary arteries. As is demonstrated in Figures 4a-b, this is visualized by showing the full territory supplied by each coronary artery group in separate colors. Where these regions overlap, a striped two-color pattern 24 is applied to indicate multiple coronary artery groups supply this region. This striped pattern is implemented using the same approach as the striped pattern for visualizing underperfused regions.

The boundaries of each coronary territory are controlled by a user-specified threshold. If the supply from a coronary artery group at a certain point is above this threshold, that point is considered to be part of the coronary territory belonging to that group. Figures 4a-b show that, using this approach, the regions supplied by each coronary artery group 21a-c as well as regions supplied by multiple arteries can be clearly identified.

With computational modeling of perfusion, separate information can be provided on the supply for each coronary artery group 21a-c. This allows separate visualization of the blood supply by each group. It gives a focused view on the area supplied by a particular group.

Figures 5a-d show an example of the separate visualization of coronary artery groups by showing four bull's eye plots. Figure 5a shows a fourth integrated model wherein the supply of all three coronary artery groups 21a-c has been combined, while Figures 5b, 5c and 5d show the supply of the LAD 21a, LCX 21b and RCA 21c, respectively. The result is obtained by assigning the blood supply parameter to myocardium surface locations in a specific coronary artery territory. Due to the separation, more detailed visualization techniques can be applied than when visualizing the coronary territories in a combined fashion, as was described above. A combined visualization of the coronary territories allows assessing the relation between them, while separate visualization allows a more comprehensive analysis of a particular group.

Showing the supply from coronary arteries separately benefits from the two-dimensional projection, as this allows a quick comparison of the regions supplied by each

coronary artery group. The ease of comparison argument holds for the bull's eye plot in general. Comparisons cannot be as easily performed in the case of different viewpoints of the three-dimensional view. In the bull's eye plot the relation to the three-dimensional anatomy is however partially lost.

The previously discussed techniques visualize the region supplied by each coronary artery group. The inverse can also be performed, i.e., visualizing the coronary artery groups that a region of interest may be supplied by. This approach is demonstrated in Figure 6, showing an eighth integrated model. Here, a user indicates a specific area of interest by specifying a point on either the three-dimensional mesh or the bull's eye plot and optionally a radius to determine the size of the region. Then, a relative supply from each of the three coronary artery groups 21a-c is computed. As a result, one or a plurality of parameter values are assigned to one or a plurality of specific artery structures of the coronary-artery anatomy, based on a corresponding relative blood supply from the specific artery structure to the specified area of interest on the myocardium surface. To visualize the parameter values, arrows 30a, 30b are drawn from the point of each coronary artery group closest to the specified point. The relative supply by each group is expressed in the width of each arrow 30a, 30b.

This approach allows a quick identification of the supplying coronary arteries in a visualization where this may not be directly apparent. An example thereof could be a query as to the coronary arteries supplying an underperfused region 24 in visualizations as described above.

In order to evaluate the effectiveness of the visualization techniques previously described, an experiment has been performed. Starting out with a scan of a healthy subject, the coronary anatomy is visualized using computational modeling of the blood perfusion and using the proposed visualization techniques. Next, artificially, a stenosis has been induced in one or more of the coronary arteries, and the change in the visualization of the coronary perfusion is observed.

The approach requires a whole-heart scan of sufficient accuracy to allow a detailed segmentation of the coronary arteries with diameter measurements. CT currently provides a better resolution than MRI. Therefore, it has been decided to use CT scans for the experiment. When MRI has advanced sufficiently to allow accurate segmentation of the coronary arteries, MRI is preferable over CT. MRI allows the acquisition of additional data that show the functioning of the heart, which can lead to a more comprehensive diagnosis.

A stenosis often causes a perfusion defect in the area normally supplied by the coronary artery that contains the stenosis. When modeling a stenosis, this perfusion defect is expected to be observed in the resulting visualizations. Figures 7a and 7b show a comparison of a healthy case, Figure 7a showing a ninth integrated model, and the same case with an artificially induced stenosis blocking part of the upper LAD by approximately 70%, Figure 7b showing a tenth integrated model. In conformity with expectations, Figure 7b shows an increased underperfused region near the lower segment of the LAD, indicated by an arrow 31. The shape of the isocontours also expressed the change in supply in the affected area.

A stenosis is also expected to change the shape of the territory of the respective coronary artery. Figures 8a and 8b, showing an eleventh integrated model and a twelfth integrated model, respectively, compare the coronary artery territories of a normal case and the same case with an artificially induced stenosis in the RCA, respectively. In Figure 8b the severe reduction in size of the RCA territory can clearly be observed, especially the posterior and septal parts of the left ventricle are affected. Note that the territory of the LAD has slightly increased. A stenosis in an artery can thus have a global effect on the distribution of blood.

Further, the effect of a stenosis can also be observed in the visualization of the supplying coronary arteries of a region of interest. Figures 9a and 9b, showing a thirteenth integrated model and a fourteenth integrated model, respectively, compare the same region of interest in a healthy case and in a case with an artificially induced stenosis in the LAD. While the region is primarily supplied by the LAD in the healthy case, it is primarily supplied by the LCX and at the border of an underperfused region in the stenosed case.

The computational modeling presented herein is simple, but sufficient to demonstrate the feasibility of visualization of the results. In current clinical practice the 17-segment model from the AHA is used as a reference for the relation between the coronary arteries and the myocardium. This model is not based on patient-specific information. It has been extended by including patient-specific information and by applying a computational model to obtain a more detailed relation between the coronary arteries and the myocardium. While the model is rather simple, it gives more detailed information than is currently available in medical practice.

The computational blood perfusion data model described above computes the way blood perfuses throughout the myocardium. In current clinical practice, this is measured by nuclear medicine and ultrasound. Perfusion scans can also be made with MRI, which provide similar information. The computational approach can be comprehensively combined

with measurements from these imaging techniques to evaluate the correlation to these techniques. If the computational approach turns out to have good prognostic value, the difficult, time-consuming and expensive perfusion scans may be avoided.

The described computational approach may require an accurate segmentation of the coronary artery tree with accurate artery diameter measurements. For this reason, CT data has been used to demonstrate the techniques, as current MRI technology seems to be inadequate to image coronary arteries with the required accuracy.

Figure 10 schematically shows a flowchart of an exemplary embodiment of a method according to the invention. The method comprises the steps of obtaining (100) patient-specific myocardial perfusion data, to model (110) a surface geometry of a patient-specific myocardium division, to model (120) a patient-specific coronary-artery anatomy and to integrate (130) the myocardium division model, the coronary-artery anatomy and the myocardial perfusion data into a single model. In this respect it is noted that in another embodiment of the invention, the method does not comprise the step of modeling the patient-specific coronary-artery anatomy and integrating it in the single model.

Further, Figure 11 schematically shows a computer system 200 for processing cardiac data. The system 200 comprises a processor 210 that is arranged to obtain patient-specific myocardial perfusion data, to model a surface geometry of a patient-specific myocardium division, and to integrate the myocardium division model and the myocardial perfusion data into a single model.

It is noted that the method of processing cardiac data can be performed using dedicated hardware structures, such as FPGA and/or ASIC components. Alternatively, 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 system (200) for processing cardiac data, comprising a processor (210) that is arranged to

obtain (100) patient-specific myocardial perfusion data;

model (110) a surface geometry (1) of a patient-specific myocardium division (4), (5); and

integrate (130) the myocardium division model and the myocardial perfusion data into a single model (20).

2. A system according to claim 1, wherein the single model comprises a 2D and/or a 3D representation.

3. A system according to claim 1, wherein the processor is further arranged for modeling (120) a patient-specific coronary-artery anatomy, and wherein the integrating step further comprises integrating the coronary-artery anatomy model in the single model.

4. A system according to claim 1, wherein the processor is further arranged for assigning a blood supply parameter to a myocardium surface location on the basis of the myocardial perfusion data, the value of the parameter being associated with a corresponding blood supply value.

5. A system according to claim 4, wherein the parameter value is chosen in a color range.

6. A system according to claim 4 or 5, wherein the parameter value is relative to a reference blood supply value, in particular, wherein the parameter value is normalized with respect to a maximum blood supply value, thereby providing a relative blood supply.

7. A system according to claim 1, wherein the processor is further arranged for classifying a myocardium surface location (24) as underperfused if the corresponding blood supply value is below a selectable threshold.

8. A system according to claim 1, wherein the processor is further arranged for linking myocardium surface locations having corresponding blood supply values that substantially coincide.

9. A system according to claim 1, wherein the processor is further arranged for visualizing the single model.

10. A system according to claim 3, wherein the processor is further arranged for dividing the myocardium surface into coronary artery territories, based on a corresponding principal supplying artery (21) of the coronary-artery anatomy.

11. A system according to claim 4, wherein the processor is further arranged for dividing the myocardium surface into coronary artery territories, based on a corresponding principal supplying artery (21) of the coronary-artery anatomy, and wherein the processor is further arranged for assigning the blood supply parameter to myocardium surface locations in a specific coronary artery territory from the coronary artery territories.

12. A system according to claim 11, wherein the processor is further arranged for assigning a parameter value to a specific artery structure of the coronary-artery anatomy, based on a relative blood supply from the specific artery structure to a specified area of interest on the myocardium surface.

13. A system according to claim 1, wherein the myocardium division is the left ventricle (4) and/or the right ventricle (5).

14. A method of processing cardiac data, comprising the steps of:
obtaining (100) patient-specific myocardial perfusion data;
modeling (110) a surface geometry (1) of a patient-specific myocardium division (4), (5); and

integrating (130) the myocardium division model and the myocardial perfusion data into a single model (20).

15. A computer program product for processing cardiac data, which computer program product comprises instructions for causing a processor (210) to perform the steps of:

obtaining (100) patient-specific myocardial perfusion data;

modeling (110) a surface geometry (1) of a patient-specific myocardium division (4), (5); and

integrating (130) the myocardium division model and the myocardial perfusion data into a single model (20).

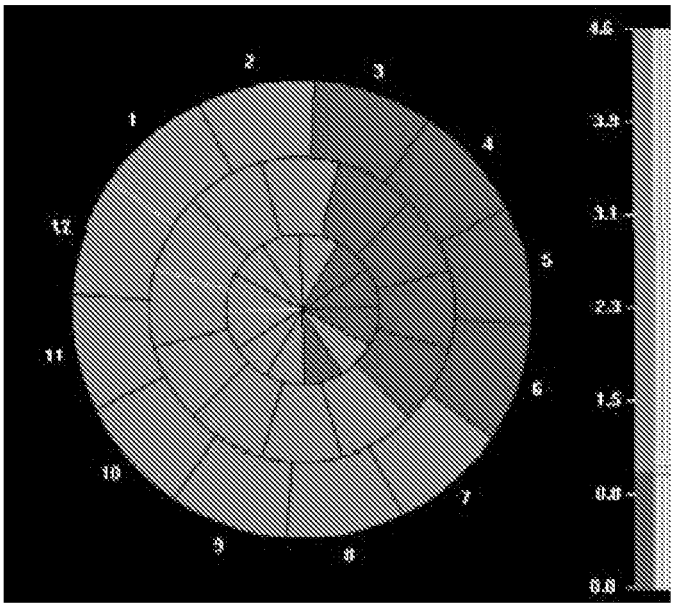

FIG. 1

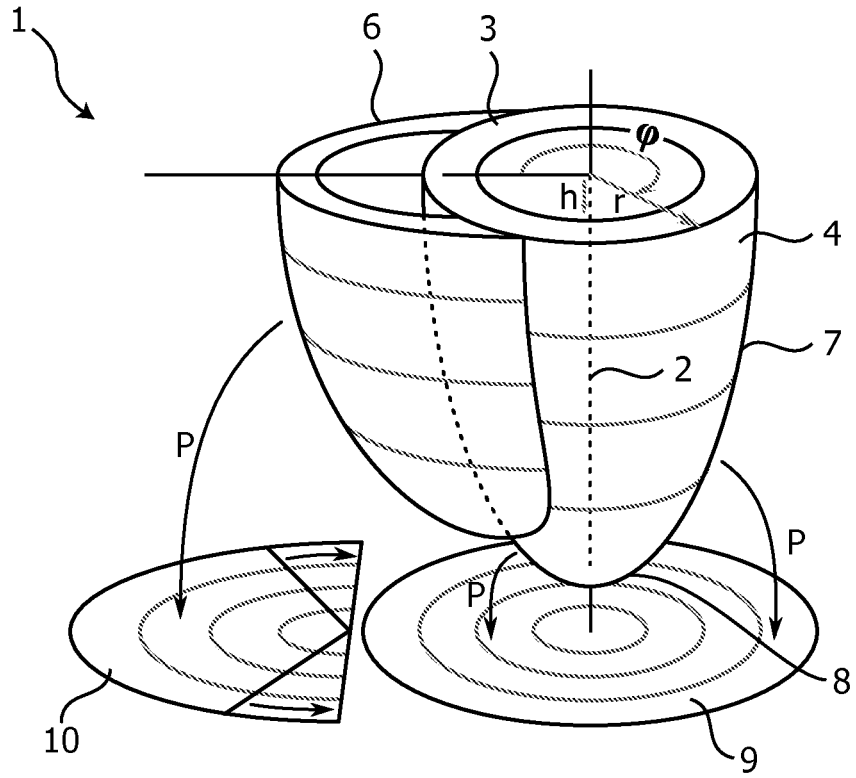

FIG. 2

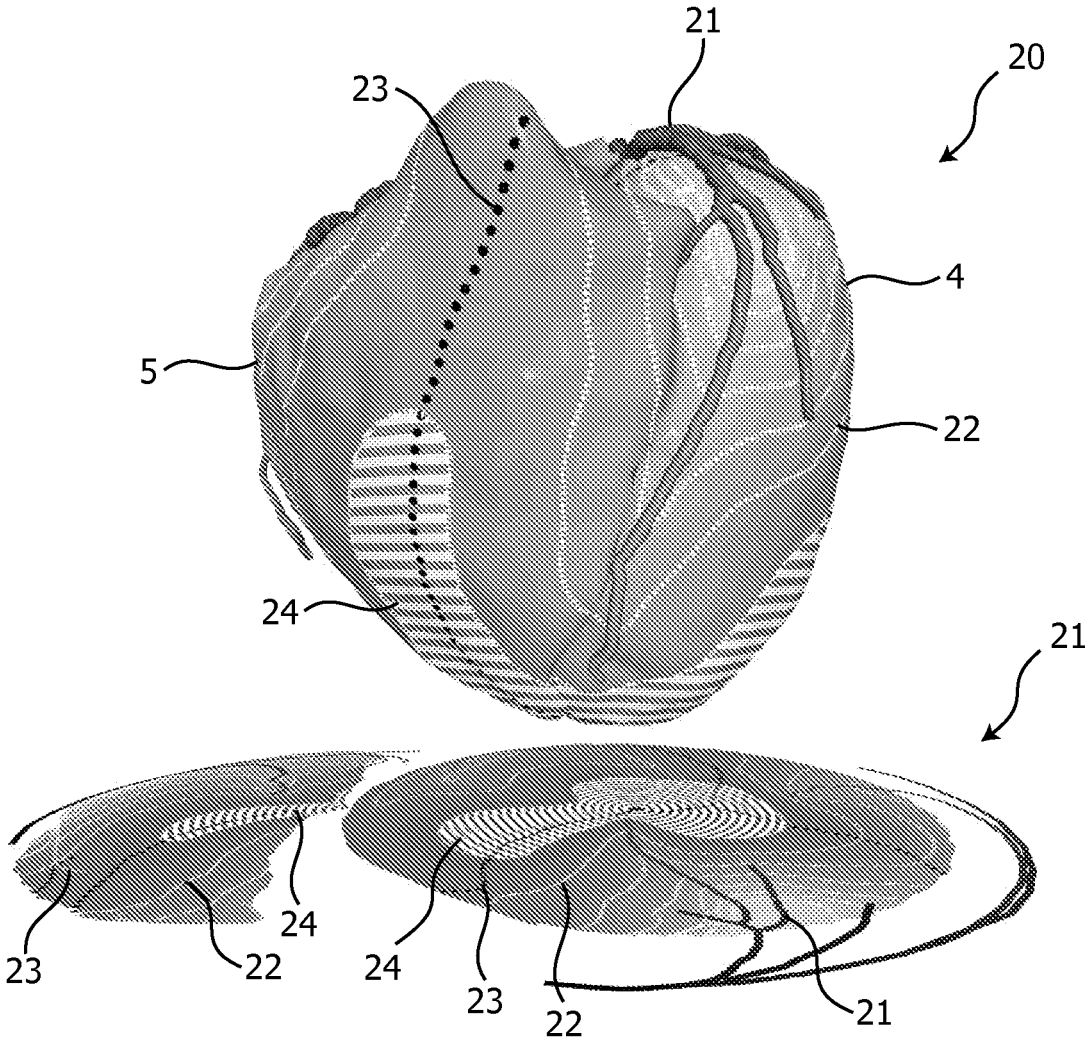

FIG. 3

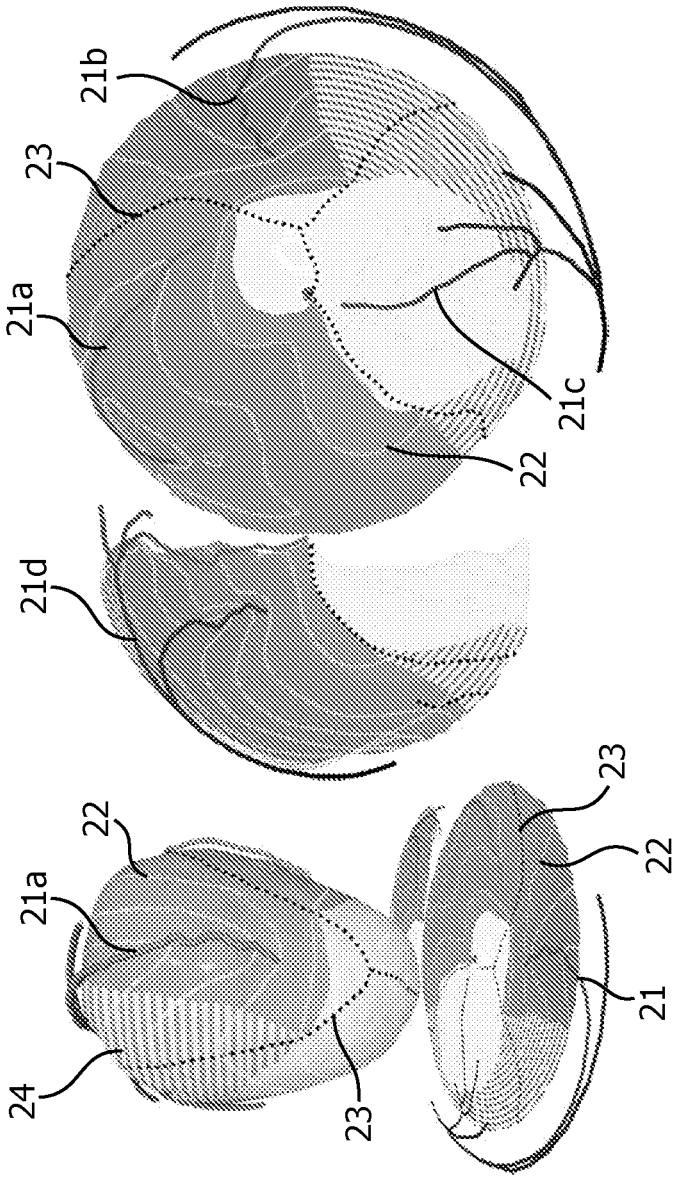

FIG. 4

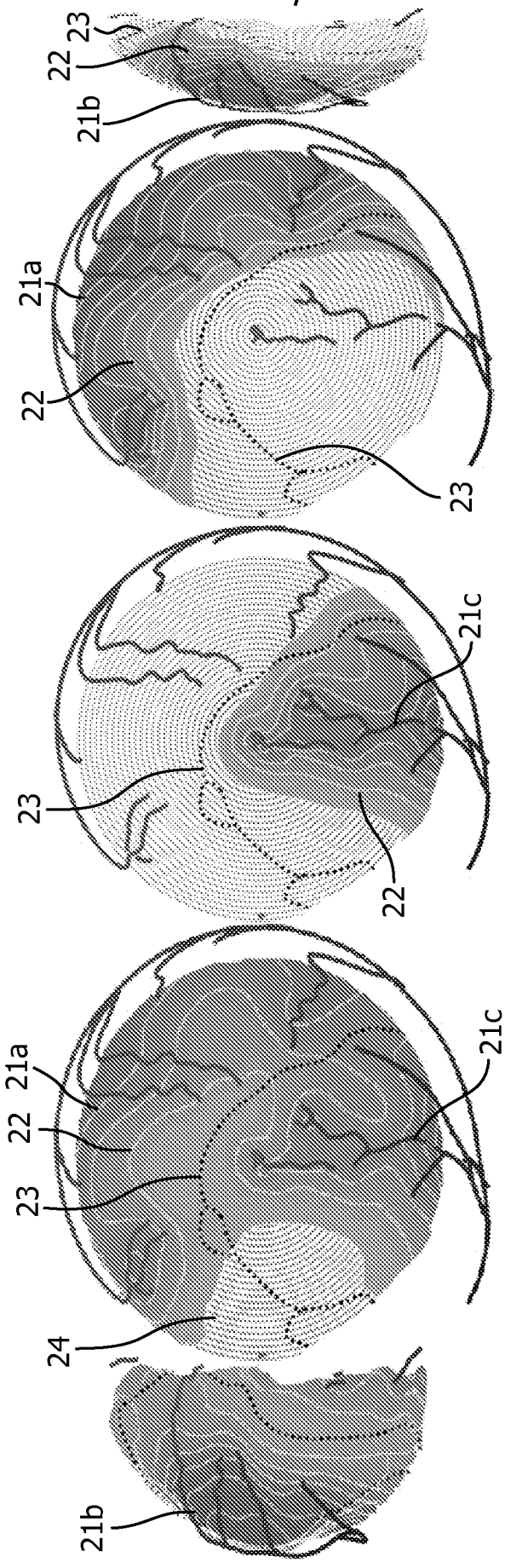

FIG. 5

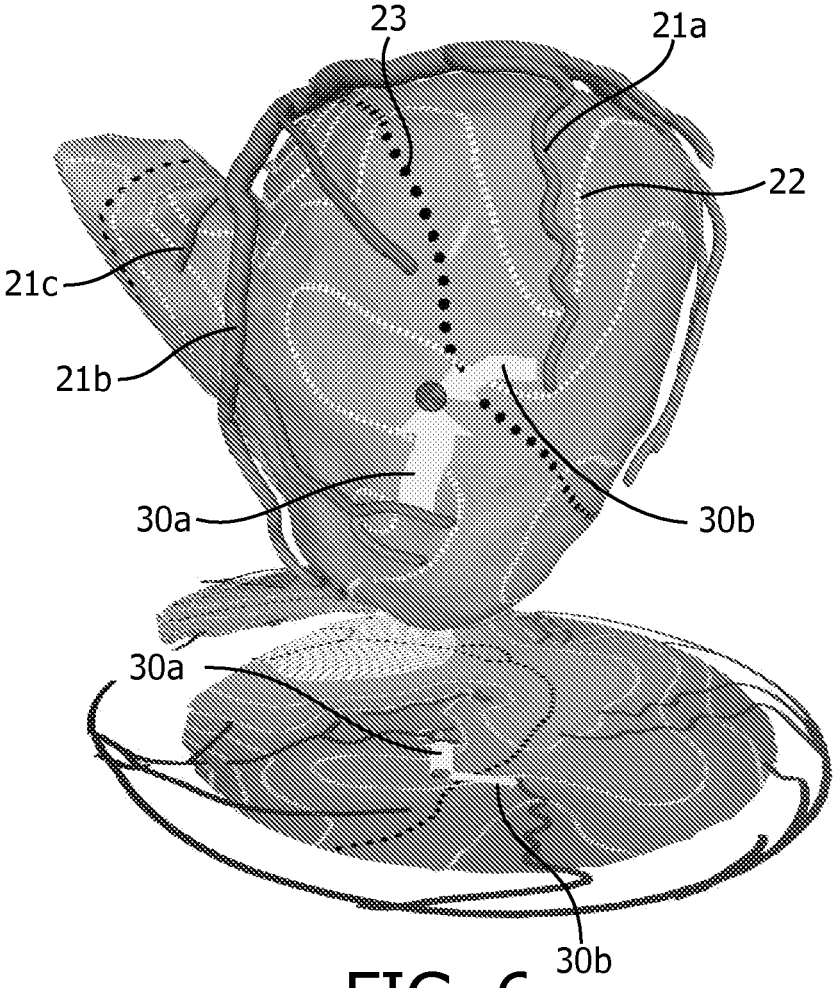

FIG. 6

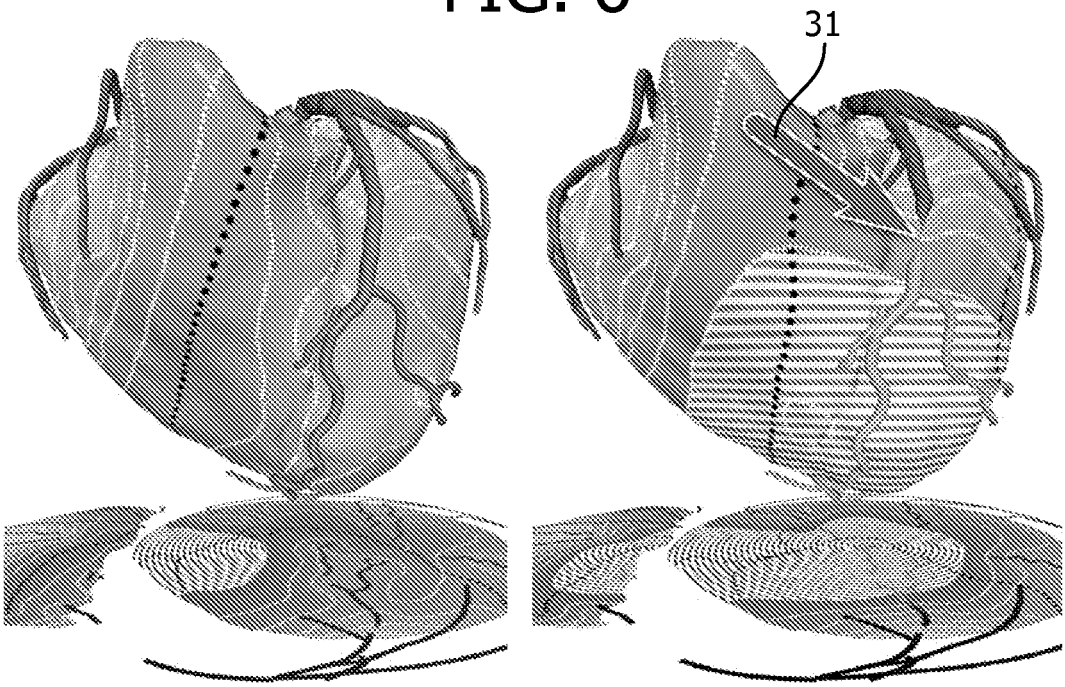

FIG. 7

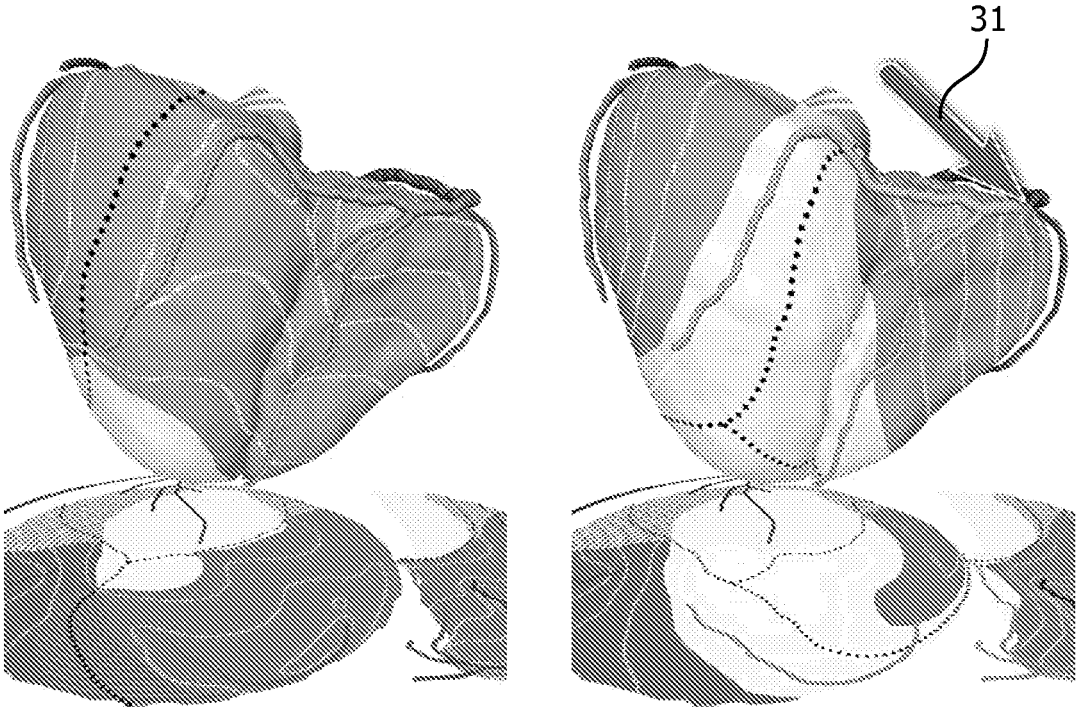

FIG. 8

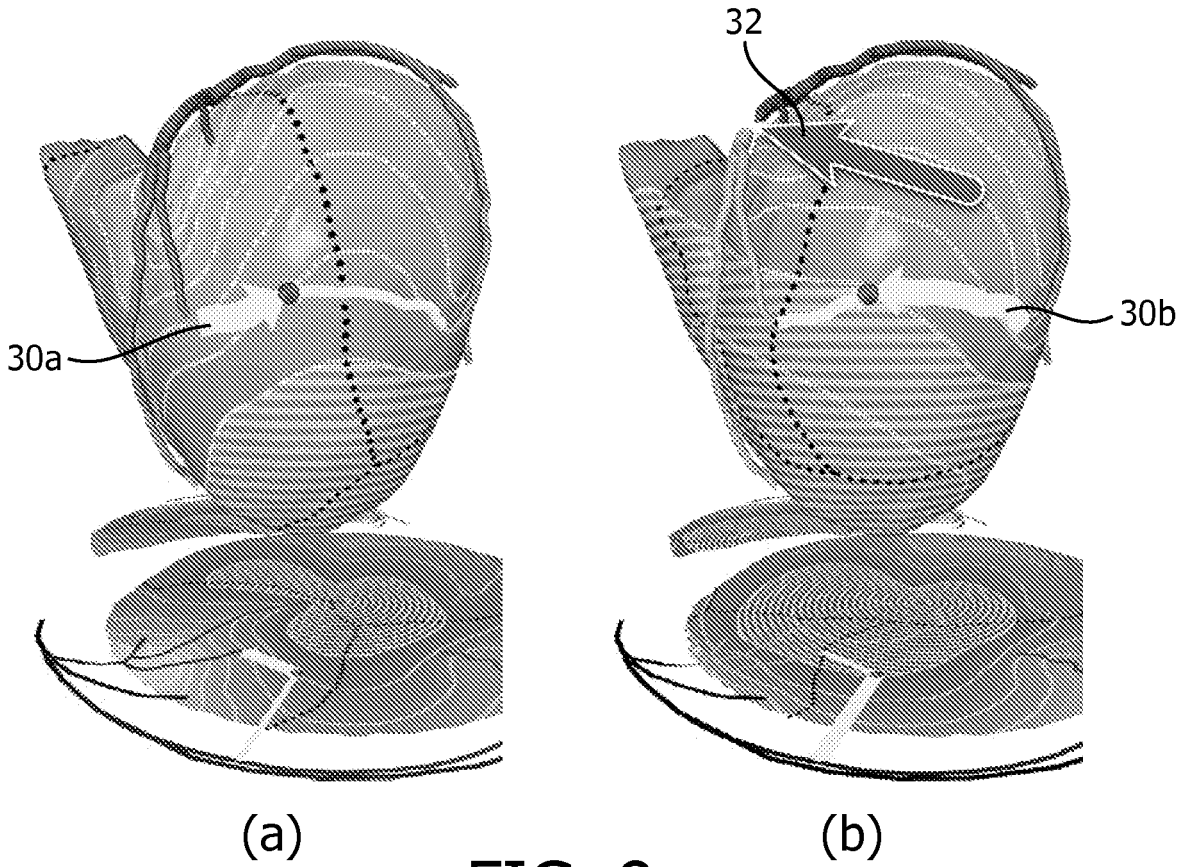

FIG. 9

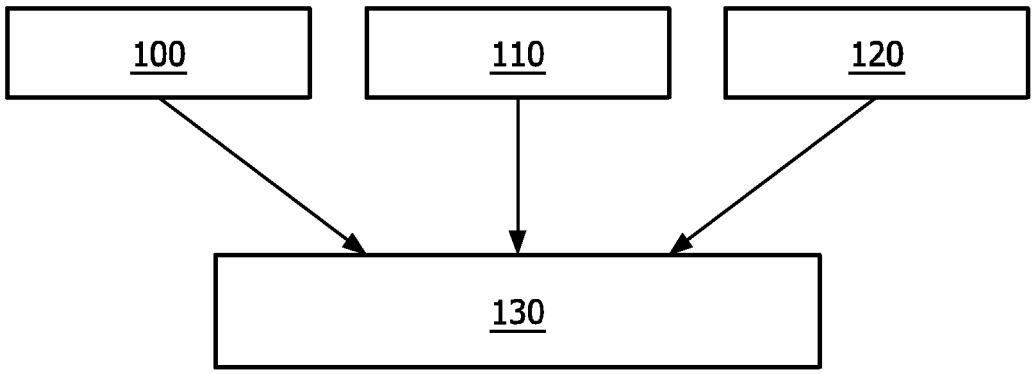

FIG. 10

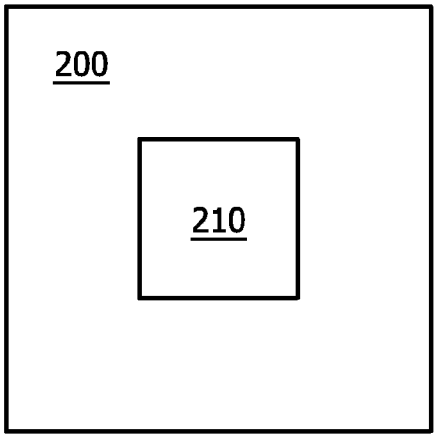

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/055314

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/54 G01R33/563

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, BIOSIS, COMPENDEX, EMBASE, INSPEC, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MAURICE TERMEER ET AL: "Visualization of Myocardial Perfusion Derived from Coronary Anatomy" IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, IEEE SERVICE CENTER, LOS ALAMITOS, CA, US, vol. 14, no. 6, 1 November 2008 (2008-11-01), pages 1595-1602, XP007906950 ISSN: 1077-2626 Sections 2-5 ----- -/--	1-15

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 March 2010	01/04/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Streif, Jörg Ulrich

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Lydia Paasche et al: "Integrierte Visualisierung kardialer MR-Daten zur Beurteilung von Funktion, Perfusion und Vitalität des Myokards" In: Alexander Horsch, Thomas M. Deserno, Heinz Handels, Hans-Peter Meinzer und Thomas Tolxdorff: "Bildverarbeitung für die Medizin 2007" 25 March 2007 (2007-03-25), Springer Verlag , Berlin Heidelberg , XP002573876 ISBN: 9783540710912 , pages 212-216 Section 3	1-15
X	TERMEER M ET AL: "CoViCAD: Comprehensive Visualization of Coronary Artery Disease" IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, IEEE SERVICE CENTER, LOS ALAMITOS, CA, US, vol. 13, no. 6, 1 November 2007 (2007-11-01), pages 1632-1639, XP011196452 ISSN: 1077-2626 Sections 4, 5	1-15
X,P	WO 2009/031081 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]; BREEUWER MARCEL [NL]; OLIVAN BESC) 12 March 2009 (2009-03-12) the whole document	1-15
A	CERQUEIRA M D ET AL: "STANDARDIZED MYOCARDIAL SEGMENTATION AND NOMENCLATURE FOR TOMOGRAPHIC IMAGING OF THE HEART A STATEMENT OF HEALTHCARE PROFESSIONALS FROM THE CARDIAC IMAGING COMMITTEE OF THE COUNCIL ON CLINICAL CARDIOLOGY OF THE AMERICAN HEART ASSOCIATION" CIRCULATION, LIPPINCOTT WILLIAMS & WILKINS, US, vol. 105, no. 4, 29 January 2002 (2002-01-29), pages 539-542, XP001164153 ISSN: 0009-7322 the whole document	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2009/055314

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009031081 A2	12-03-2009	NONE	