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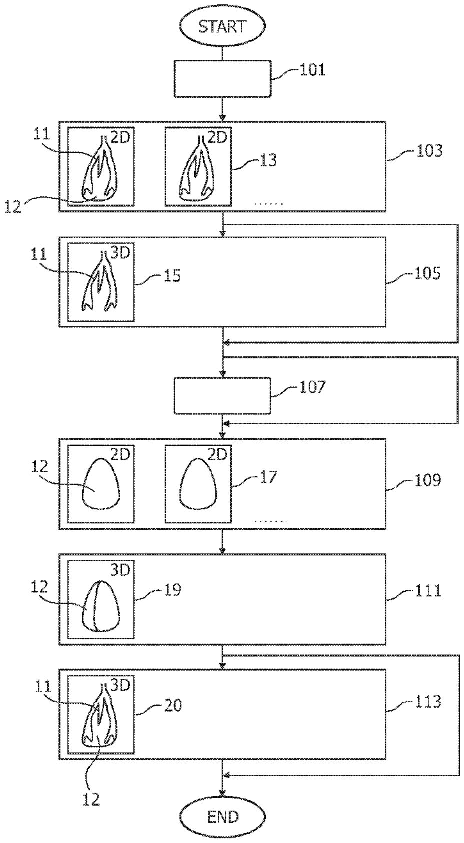

FIG. 1

(57) Abstract: A method and an apparatus for acquiring 3-dimensional images (19) of a myocardialblush of a myocardium (12) are proposed. 2-dimensional X-rayimages (13) of an acquisition region comprising the myocardium (12) and coronary arteries (11) are acquired (103) under different projection angles and optionally in different states of heart motion using a C-armsystem. Optionallya motion vector field inside of a reconstruction volume comprising myocardium (12) is estimated (107). A 3-dimensional image (19) of the myocardium in one state of the motion is reconstructed (111) from 2-dimensional X-rayimages (13). Optionally the estimated motion vector field is used for the 3-dimensional reconstruction (19) in order to compensate for the heart motion.

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METHOD FOR ACQUIRING 3-DIMENSIONAL IMAGES OF A MYOCARDIUM, PARTICULARLY OF A MYOCARDIAL BLUSH

Field of the invention

The present invention relates to a method for acquiring 3-dimensional images of a myocardium, particularly for acquiring 3-dimensional images of a myocardial blush. Furthermore, the present invention relates to an apparatus adapted to perform such method, a computer program adapted to perform such method when executed on a computer and a computer readable medium comprising such program.

Technical background

Myocardial infarction is the world leading case of death for both men and women. Myocardial infarction is most commonly triggered by arteriosclerosis and occurs when the blood supply to a part of the heart is interrupted, which usually happens due to a rupture of a vulnerable plaque. The resulting ischemia or oxygen shortage causes damage and death of heart tissue.

The coronary plaque rupture may not necessarily lead to a myocardial infarction but may also lead to a coronary microembolization, wherein an embolization of arteriosclerotic material into coronary microcirculation occurs. Such a microembolization can occur either spontaneously or can be triggered by a coronary intervention.

Therefore, for medical purposes such as a proper diagnosis, treatment and/or intervention planning, assessment of the treatment and/or intervention, e. g., a coronary angioplasty, and post treatment/intervention of myocardial infarction it may be important to know measures of myocardial perfusion such as a myocardial blush grade accurately.

Therefore, for a detection and assessment of the myocardial perfusion defects as well as for all treatment/intervention phases a 3-dimensional visualization of myocardial perfusion may be very advantageous.

Today, the myocardial perfusion is mainly imaged using non-invasive examination methods like cardiac single photon emission computed tomography

(SPECT), magnetic resonance imaging (MRI) or positron emission tomography (PET). For these examination methods however sophisticated and expensive facilities are needed. Such facilities may not always be available or accessible.

Rotational angiography has proven to be an accurate and effective diagnostic tool, for example, in the treatment of static vessels. In this approach, after injecting a contrast medium into the vessels, a C-arm having an X-ray source at its one end and a 2-dimensional X-ray detector at its opposing end rotates around a region of patient's body to be imaged while several 2-dimensional X-ray projections are acquired. From the plurality of 2-dimensional X-ray images acquired under various projection angles, a 3-dimensional model of the vessel system can be derived.

C-arm X-ray systems similar to the one described above may be - in contrary to the SPECT, MRI, PET facilities - commonly available, accessible and relatively cheap.

However, when imaging moving objects like a beating heart, there may be a problem that a 3-dimensional image can only be calculated based on 2-dimensional projections which have been acquired in a same state of the heart motion, which is approximately periodic (cyclic) in nature, where the heart and its coronary vessels are substantially at a same position or in a same state of the motion. The acquisition of the 2-dimensional images or the reconstruction of the 3-dimensional image may be gated based e.g. on electrocardiogram signals. Although usually more than one hundred 2-dimensional images are acquired while rotating the C-arm e.g. 180° around the imaged area, only a few images are acquired at a same state of the motion and can therefore conventionally be used for 3-dimensional reconstruction. As a result, the reconstructed 3-dimensional image may be not accurate enough to be used for diagnostic purposes, e.g. to evaluate myocardium blush grade.

Therefore, there may be a need for a method allowing for a 3-dimensional high image quality reconstruction and visualization of the myocardial blush from a rotational coronary angiography sequence using commonly available and accessible C-arm X-ray systems. Furthermore, there may be a need for an apparatus adapted for performing such method, a computer program adapted for performing such method when executed on a computer and a computer readable medium comprising such program.

Summary of the invention

These needs may be met by the subject-matter according to the independent claims. Advantageous embodiments of the present invention are described in the dependent claims.

According to an exemplary embodiment of the present invention a method for acquiring 3-dimensional images of a myocardial blush of a myocardium is provided, the method comprising at least the following steps preferably in the following order: (1) acquiring a plurality of 2-dimensional X-ray images of an acquisition region comprising the myocardium and coronary arteries under different projection angles using a C-arm system; and (2) generating a 3-dimensional reconstruction of the myocardium from the acquired 2-dimensional X-ray images.

In other words, a 3-dimensional image of a myocardial blush is obtained using a C-arm X-ray system. For this, 2-dimensional X-ray projections under different projection angles, which may but need not necessarily correspond to the same state or phase of a heart motion, can be used for the 3-dimensional reconstruction.

Hence, it may be seen as an aim of the method according to the exemplary embodiment of the present invention to provide a 3-dimensional image of myocardium, which may move in a motion approximately periodic in nature, particularly of myocardial blush. However, the method may be applied also to an irregularly moving heart or to a heart in the rest. The derived 3-dimensional image provided by the inventive method can e.g. be displayed on a screen. A medical practitioner can then analyze the myocardium prior, during or after a treatment/intervention. The 3-dimensional reconstruction can be observed from different viewing angles or in different cuts in order e.g. to search for anomalies in the coronary microcirculation.

First, a plurality of 2-dimensional X-ray images (projections) of an acquisition region comprising the myocardium to be imaged is acquired under different projection angles. This acquisition region will comprise also coronary arteries. For this purpose e.g. a C-arm system having an X-ray source and an opposing 2-dimensional X-ray detector can be rotated around a patient's body. The rotating movement can be performed over an angle range depending e.g. on the space available for the C-arm movement during the treatment/intervention. During the rotating movement a plurality of 2-dimensional X-ray images can be obtained under different angles of projection. For example between 150 and 300 images can be obtained over the whole range of rotation. The rotating procedure takes between 5 and 10 seconds such that the patient's heart may beat several times during the rotation.

Next a 3-dimensional reconstruction of at least the myocardium is performed by suitably processing the information about the myocardium contained in the acquired 2-dimensional X-ray projections. Optionally a 3-dimensional reconstruction of both the myocardium and coronary arteries may be performed by suitably processing the information about the myocardium and coronary arteries contained in the acquired 2-dimensional X-ray projections.

According to another exemplary embodiment of the present invention the method is adapted for acquiring 3-dimensional images of a myocardial blush of a myocardium moving in a motion, wherein a motion vector field of a reconstruction volume comprising the myocardium is estimated and the 3-dimensional reconstruction of the myocardium is generated in one state of the motion using the estimated vector filed.

The state for which the 3-dimensional reconstruction is generated may be, for example, the rest state or rest phase of its periodic motion.

It should be noted that the expressions like "phase of the heart motion" or "cardiac phase" commonly refer to a particular period within the cardiac cycle, e.g., atrial systole (end of diastole), isovolumetric contraction (beginning of systole), rapid ejection, etc. In contrary to that a state of the motion is defined as a spatial anatomical configuration of the moving myocardium.

Although there exists a correspondence between the phase of the motion and the state of the motion, this correspondence is not a one-to-one correspondence. Some positional states occur only during one particular phase of the heart cycle, whereas other states may occur during two different phases of the heart cycle.

The individual method steps of this invention in all its embodiments may be applied with respect to both to the state of the motion as well as to the phase of the motion. This will be assumed implicitly and therefore, if the contrary is not mentioned explicitly, only the expression state of the motion will be used in the sequel.

Because of the motion compensation 2-dimensional X-ray projections under different projection angles, which do not necessarily correspond to the same state of the motion, can be used for the 3-dimensional reconstruction.

Because of the repeating and approximately periodic motion of the heart, several of the X-ray images are acquired at substantially the same state of the heart motion in subsequent heart cycles. In these substantially same states, the heart is substantially in the same position in the patient's body and has substantially the same volume such that the myocardium and coronary vessels are substantially in the same position.

Herein, "in a substantially same state" may be interpreted such that the difference between the current positions of, for example, the coronary arteries between two image acquisitions in the substantially same state but in subsequent motion cycles is smaller than the diameter of the coronary arteries, preferably smaller than 20% of this diameter.

The motion vector field describes the motion of each image point within the region of interest during the heart cycle. Hence, the motion vector field gives a time parameterization of the three spatial coordinates of each point of interest. The motion vector field can also be seen as the displacement of every point of interest with respect to a reference motion state during the motion of the region of interest. The estimation of the motion vector field can be performed e.g. by using a motion estimation technique like a block matching algorithm or by tracking the motion of marker points, e.g. the centerlines of the coronary arteries.

The 3-dimensional reconstruction of the myocardium is generated using the estimated motion vector field. For this a motion compensated reconstruction algorithm is performed. In general, 3-dimensional reconstruction is performed by suitably processing the information contained in X-ray projections about an object of interest. If the object was moving and the 2-dimensional projections were acquired in different motion states, the motion must be considered in the 3-dimensional reconstruction to obtain a correct reconstruction result. For the case that the motion of the object is known, e.g. in the form of a motion vector field, the object motion that occurred during the acquisition of each 2-dimensional projection can be compensated. Therefore, the 2-dimensional projection images of the different motion states of the object can all be used to reconstruct in 3 dimensions one single motion state.

The motion compensation may be applied to any known iterative or non-iterative reconstruction technique used in medical imaging. Motion-compensated 3-dimensional reconstruction algorithms have been described in the scientific literature, e.g. a motion-compensated filtered backprojection algorithm in Schäfer et al., "Motion-compensated and gated cone beam filtered back-projection for 3-D rotational X-ray angiography", IEEE Trans. Med. Imag., Vol. 25, pages 898- 906 (2006) or a motion-compensated version of the algebraic reconstruction method in C. Blondel et al., "3D tomographic reconstruction of coronary arteries using a precomputed 4D motion field", Phys. Med. Biol., Vol. 49, pages 2197-2208 (2004).

The motion-compensated 3-dimensional reconstruction enables that all previously acquired 2-dimensional X-ray images from different projection angles may be used for the 3-dimensional reconstruction, which 2-dimensional X-ray images may correspond to different states of the motion of the heart. This is of an advantage, because the number of the 2-dimensional X-ray images, which may be used for the 3-dimensional reconstruction is much higher comparing to the case when no motion compensation is performed. Without motion compensation only those 2-dimensional X-ray images corresponding to the substantially same state of the motion could have been used for the 3-dimensional reconstruction. Accordingly, the higher number of the 2-dimensional X-ray images used for the 3-dimensional reconstruction leads to a better quality of the corresponding 3-dimensional reconstruction.

According to another exemplary embodiment of the present invention free of coronary arteries 2-dimensional X-ray images are generated by erasing the coronary arteries from the 2-dimensional X-ray images and the 3-dimensional reconstruction of the myocardium is generated from the free of coronary arteries 2-dimensional X-ray images.

It proves to be advantageous to erase the coronary arteries from the 2-dimensional X-ray images in order to reduce image artifacts from coronary arteries in the following 3-dimensional reconstruction. This may be particularly important e.g. in the case when a contrast agent is introduced into the coronary arteries before the acquisition of the X-ray images, in which case the high-contrast coronary arteries would cause unwished artifacts considerably lowering the quality of the final 3-dimensional reconstruction. The coronary arteries may be erased from the 2-dimensional X-ray projections by first detecting and segmenting them, and then subtracting the coronary arteries from the projections.

According to another exemplary embodiment of the present invention at least two of the 2-dimensional X-ray images are acquired in a substantially same state of the motion under different projection angles and at least one 3-dimensional reconstruction of the coronary arteries from these 2-dimensional X-ray images acquired in the substantially same state of the motion under different projection angles is generated.

Advantageously, according to this exemplary embodiment of the present invention, not only a 3-dimensional reconstruction of the myocardium but also a 3-dimensional reconstruction of the coronary arteries is generated. This may serve to a medical practitioner as additional information, since a spatial relationship between the myocardial blush and the coronary arteries can be established. For example, diagnosis of coronary artery disease, like narrowing or occlusion of coronary arteries, can be assessed in the reconstruction of the coronary arteries, and the impact of these conditions onto the myocardial perfusion in a certain region can be evaluated.

According to another exemplary embodiment of the present invention at least two of the 2-dimensional X-ray images are acquired in substantially different states of the motion and the motion vector field of the reconstruction volume is estimated from matching of a geometry of the 3-dimensional reconstruction of the coronary arteries in one state of motion to projections of the coronary arteries in the 2-dimensional X-ray images of the acquisition region in substantially different states of the motion.

For this, for example, the 3-dimensional reconstruction of the coronary arteries in the rest state (phase) of the motion can be used. The motion vector field inside the reconstruction volume representing heart motion during a part or whole heart cycle can be estimated. This can be done by comparing the 3-dimensional reconstruction with the 2-dimensional X-ray projections of some or all motion phases, respectively. The motion of the coronary arteries is estimated such that the geometry of the coronary arteries as shown in the projection data of each motion state matches that of the 3-dimensional reconstruction, if object motion according to the motion field for the respective state is applied to the 3-dimensional reconstruction. This enables an effective and reliable estimation of the motion field, because high quality 3-dimensional reconstruction methods of coronary arteries are available for the rest state (phase) of the heart motion. The geometry of the coronary arteries in the 3-dimensional reconstruction and in the 2-dimensional projection images of all motion phases can be matched with high accuracy, such that the subsequent estimation of the motion vector field inside of the myocardium can be performed in a reliable manner.

One possible method of the determination of motion of coronary arteries can be performed by following steps: (1) A 3-dimensional reference reconstruction of the coronary arteries is performed in the cardiac rest phase by any known method, which yields a sufficiently artifact free reconstruction with a high contrast. (2) Centerlines of the 3-dimensional coronary arteries are detected in the reference reconstruction with a 3-dimensional vesselness filter. (3) For each phase of the motion: (a) A suitable set of 2-dimensional X-ray image projections is selected from a rotational sequence. (b) Centerlines are detected in the selected 2-dimensional X-ray images and squared distance maps are computed from the centerlines. (c) An unfiltered back-projection of the squared distance maps into a volume is performed. (d) The centerlines of the 3-dimensional coronary arteries of the reference reconstruction are deformed elastically to minimize the integral of the volume distance map along the 3-dimensional centerlines. (e) The above-determined elastic transformation describes the motion of the heart for the respective motion state. (f) A combination of the motion information for some or all phases of the cardiac motion gives the motion vector field over a part or the whole heart cycle, respectively.

According to another exemplary embodiment of the present invention detecting vessels with a vesselness filter is performed before erasing coronary arteries.

According to another exemplary embodiment of the present invention background flattening of the plurality of 2-dimensional X-ray images using morphological top-hat filtering is performed before detecting the vessels.

In other words the coronary arteries are removed from the 2-dimensional X-ray images by first detecting and segmenting them, and then subtracting the coronary arteries from the projections. For the detection and segmentation of the coronary arteries the projection background can first be flattened using morphological top-hat filtering. In the background flattened 2-dimensinal projections, vessels are detected using a so-called vesselness or vessels enhancement filter. The advantage in first using a background removing filter before the vessel detection and subtraction is that, ideally, only contribution of the vessels to the grey value of the projection at a pixel is subtracted, while the grey value of the background is retained after the subtraction.

In order to flatten the varying background intensity, a background image is calculated by removing foreground structures. To this end, a local sliding maximum filter is firstly applied, the dimensions of which are slightly larger than the largest expected vessel diameter. This operation removes locally dark structures, which are smaller than the size of the filter. However, edges of larger dark regions bordering on brighter regions are also eroded, i. e. moved towards the inside of the dark region by approximately the size of the filter.

To reconstruct such eroded edges, a local sliding minimum filter of the same size may be applied, which propagates the boundary back to its approximate original location. The filtered images then contain almost no foreground information.

Subtraction of the original frame from its maximum-and minimum-filtered background version thus leaves the foreground vessel information. The succession of maximum and minimum filtering may be referred to as morphological closing and taking the difference between the original and its closing may be called top hat filter.

A vesselness or vessel enhancement filter may be an image processing tool which is adapted to search for geometrical structures, e.g. in an X-ray image, which can be regarded as tubular. Therein, the search for vessels can be restricted to vessel having a diameter larger than a certain minimum value. One possible vessel enhancement filtering method is described in A.F. Frangi et al. “Multiscale vessel enhancement filtering”, Medical Image Computing & Computer Assisted Interventions, MICCAI98, vol. 1496 of lecture Notes in Computer Science, pp. 130-7, 1998.

According to another exemplary embodiment of the present invention the inventive method further comprises a smoothening of the 2-dimensional X-ray images before generating a 3-dimensional reconstruction of the myocardium.

According to another exemplary embodiment of the present invention this smoothening comprises morphological filtering.

The smoothening can be formed, for example, by a grey-level opening and followed by a gray-level closing. As a result of the smoothening step background artifacts can be removed and hence the quality of the 3-dimensional reconstruction of the myocardium can be increased. In the case that the 3-dimensional reconstruction of the myocardium is generated from the free of coronary arteries 2-dimensional X-ray images , e.g. artifacts caused by erasing of the coronary arteries can be removed.

According to another exemplary embodiment of the present invention contrast agent may be introduced selectively into the left or right branch of the coronary arteries prior to the acquisition of the 2-dimensional X-ray images

The contrast agent may be an X-ray absorbing fluid, which can be introduced e.g. using a catheter inserted into one of the coronary vessels such as coronary arteries. A balloon may be deployed within an artery in order to temporarily suppress the blood flow and hence to prevent the contrast agent from being washed out too quickly.

According to another exemplary embodiment of the present invention the acquisition of the 2-dimensional X-ray images may be gated based on an electrocardiogram (ECG) signal.

According to another exemplary embodiment of the present invention the 3-dimensional reconstruction of the myocardium may be gated based on an electrocardiogram (ECG) signal.

The gating is performed, for example, in order to improve the correspondence of the X-ray images acquired for the substantially same motion states. For this purpose, while acquiring the plurality of X-ray images, an electrocardiogram is measured and the X-ray image acquisition may be triggered by certain characteristic signals of the ECG. For example, the R-peak may trigger or synchronize the X-ray image acquisition.

According to another exemplary embodiment of the present invention the 3-dimensional reconstruction of the myocardium and the 3-dimensional reconstruction of the coronary arteries are fused.

This provides a medical practitioner with a 3-dimensional visualization of the myocardial blush and coronary arteries, which visualization can be used during all phases of a treatment/intervention related to a myocardial infarction or coronary microembolization.

According to another exemplary embodiment of the present invention the 3-dimensional reconstruction of the myocardium is generated using all of the plurality of 2-dimensional X-ray images.

Advantageously, according to this exemplary embodiment of the present invention, this leads to a higher quality of the 3-dimensional visualization of the myocardial blush and coronary arteries and hence improves the diagnostic quality.

According to another exemplary embodiment of the present invention, an apparatus for acquiring 3-dimensional images of myocardial blush of myocardium is proposed, the apparatus being adapted to perform the above-described method.

The apparatus may include a C-arm system comprising an X-ray source for emitting X-rays and an X-ray detector for acquiring 2-dimensional X-ray images; optionally, a contrast medium injector for introducing a contrast medium into vessels such as arteries of a patient; a control unit for controlling at least one of the X-ray source, the X-ray detector and the optional contrast medium injector; and a computing unit for computing 3-dimensional images of myocardium and/or coronary arteries based on the acquired 2-dimensional X-ray images provided by the X-ray detector.

According to further exemplary embodiments of the invention, a computer program element adapted to perform the above method when executed on a computer and a computer readable medium with such computer program element are proposed.

It has to be noted that embodiments of the invention are described with reference to different subject matters. In particular, some embodiments are described with reference to method type claims whereas other embodiments are described with reference to apparatus type claims. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters is considered to be disclosed with this application.

The aspects defined above and further aspects, features and advantages of the present invention can also be derived from the examples of embodiments to be described hereinafter and are explained with reference to examples of embodiments. The invention will be described in more detail hereinafter with reference to examples of embodiments but to which the invention is not limited.

Brief Description of the Drawings

Fig. 1 shows a flow diagram schematically representing a method for acquiring a 3-dimensional image of a myocardial blush according to an embodiment of the present invention.

Fig. 2 shows a schematic representation of an apparatus for acquiring 3-dimensional images of a myocardial blush according to an embodiment of the present invention.

Detailed description of preferred embodiments

Fig. 1 can be used to explain the basic steps of a method for acquiring a 3-dimensional image of a myocardial blush according to an embodiment of the present invention.

After locating a patient in a suitable apparatus such as a C-arm X-ray apparatus, contrast agent is injected selectively into a left or right branch of the coronary arteries using a catheter (step 101).

Then, a plurality of 2-dimensional X-ray images 13 of an acquisition region including a myocardium 12 and coronary arteries 11 is acquired in different states (phases) of the motion and under different projection angles while rotating the C-arm around the patient's body (step 103) (only two images 13 shown exemplary). It is advantageous to start the acquisition of the plurality of 2-dimensional X-ray images after the injection of the contrast agent into coronary arteries. During the acquisition the contrast agent is washed into myocardium, which enhances its contrast. Simultaneously with the acquisition of the 2-dimensional X-ray images an ECG is recorded in the step 103, so that the acquisition or the reconstruction can be gated based on the ECG.

At least a part of the 2D images acquired during the cardiac rest state is used to calculate a high-quality reconstruction 15 of the coronary arteries in one state of the motion, preferably in the cardiac rest state, in (step 105).

The motion vector field inside of a reconstruction volume comprising myocardium (12) is estimated (step 107), for example, from the motion of the coronary arteries. To this end, centerlines of the 3-dimensional coronary arteries are detected in the reconstruction 15, which now serves as a reference reconstruction. This can be done with a 3-dimensional vesselness filter. For each phase of the motion: (a) A suitable set of 2-dimensional X-ray image projections 13 is selected from a rotational sequence. (b) Centerlines of the coronary arteries 11 are detected in the selected 2-dimensional X-ray images 13 and squared distance maps are computed from the centerlines. (c) An unfiltered back-projection of the squared distance maps into a volume is performed. (d)

The centerlines of the 3-dimensional coronary arteries 11 of the reference reconstruction 15 are deformed elastically to minimize the integral of the volume distance map along the 3-dimensional centerlines. (e) The above-determined elastic transformation describes the motion of the heart for the respective motion state. (f) The combination of the motion information for all phases of the cardiac motion gives the motion vector field over the whole heart cycle.

The coronary arteries 11 are erased from the 2D images 13 (step 109) using suitable filters in order to reduce image artifacts from the high-contrast coronary arteries 11 in the subsequent 3-dimensional reconstruction of the myocardium blush. A possible filter combination is to first filter the 2-dimensional projection data with a morphological top-hat filter to flatten the projection background, then detect coronary arteries 11 with a vesselness filter, and finally subtract the coronary arteries 11 from the original 2D projection data 13. 2D images 17, which are now free of coronary arteries 11 can be further smoothed, e. g., by morphological filters in order to reduce further artifacts.

Using the motion vector field estimated in the step 107 a 3D motion compensated reconstruction 19 of the myocardial blush from the free of coronary arteries 2D images 17 is performed (step 111) including possibly all 2D images 13 acquired from the rotational angiography sequence.

Optionally, the resulting 3D reconstruction 19 of the contrast agent enhanced myocardium 12 and the high-quality 3D reconstruction 15 of the coronary arteries 11 are fused (step 113) in order to receive the 3D visualization 20 of the myocardial blush with the coronary arteries.

According to another embodiment (not shown diagrammatically) the method can be performed without erasing in step 109 coronary arteries 11 from the 2D images 13. As a consequence in this embodiment the 3D reconstruction of the myocardial blush in the step 111 will be performed from the 2D images 13 and hence will comprise also coronary arteries 11.

In Fig.2 an apparatus for acquiring 3-dimensional images of myocardial blush according to an embodiment of the present invention is schematically shown. A C-arm system 1 comprises an X-ray source 3 and an X-ray detector 5. The C-arm 7 can be moved in the different directions a, b, c, d. For acquiring the different 2-dimensional X-ray projection images 13 according to the above-described method, the C-arm is preferably moved in the direction b along the holder 8 and/or in the direction c. The acquisition of the X-ray projection may be gated based on an ECG signal, which may be detected using electrodes 27 which can be attached to the patient and which may be connected to the control system 9.

A control unit 9 is connected to the C-arm system 1. The control unit 9 is adapted to control the X-ray source 3 and the X-ray detector 5 and the movement of the C-arm 7. The control system 9 includes a computing unit 21, which is adapted to perform the method according to the invention. Therefore, the computing unit can receive 2-dimensional image data from the detector 5, compute the same and output the derived 3-dimensional myocardial blush e.g. on a screen 23 or on a video system 25.

It should be noted that the term “comprising” does not exclude other elements or steps and the “a” or “an” does not exclude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

CLAIMS:

1. A method for acquiring 3-dimensional images of a myocardial blush of a myocardium (12), the method comprising:

acquiring (103) a plurality of 2-dimensional X-ray images (13) of an acquisition region comprising the myocardium (12) and coronary arteries (11) under different projection angles using a C-arm system (1); and

generating (111) a 3-dimensional reconstruction (19) of the myocardium (12) from the acquired 2-dimensional X-ray images (13).

2. The method according to claim 1, the method being adapted for acquiring 3-dimensional images of a myocardial blush of a myocardium (12) moving in a motion, wherein

a motion vector field of a reconstruction volume comprising the myocardium (12) is estimated (107); and

the 3-dimensional reconstruction (19) of the myocardium (12) is generated (111) in one state of the motion using the estimated motion vector field.

3. The method according to claim 1 or 2, wherein

free of the coronary arteries 2-dimensional X-ray images (17) are generated by erasing (109) the coronary arteries (11) from the 2-dimensional X-ray images (13); and

the 3-dimensional reconstruction (19) of the myocardium (12) is generated (111) from the free of the coronary arteries 2-dimensional X-ray images (17) .

4. The method according to one of claims 1 to 3, wherein

at least two of the 2-dimensional X-ray (13) images are acquired in a substantially same state of the motion under different projection angles, the method further comprising generating (105) at least one 3-dimensional reconstruction (15) of the coronary arteries in one state of motion (11) from the at least two 2-dimensional X-ray images (13) acquired in the substantially same state of the motion under different projection angles.

5. The method according to claim 4, wherein

at least two of the 2-dimensional X-ray (13) images are acquired in substantially different states of the motion; and

the motion vector field of the reconstruction volume is estimated from matching of a geometry of the 3-dimensional reconstruction (15) of the coronary arteries (11) in one state of motion to projections of the coronary arteries (11) in the 2-dimensional X-ray images (13) of the acquisition region in substantially different states of the motion.

6. The method according to one of claims 3 to 5 further comprising

detecting vessels with a vesselness filter before erasing (109) coronary arteries (11).

7. The method according to claim 6 further comprising

background flattening of the plurality of 2-dimensional X-ray images (13) using morphological top-hat filtering before detecting the vessels.

8. The method according to one of claims 1 to 7, further comprising

smoothening of the 2-dimensional X-ray images before generating the 3-dimensional reconstruction (19) of the myocardium (12).

9. The method according to of claim 8, wherein

the smoothening comprises morphological filtering.

10. The method according to one of claims 1 to 9, further comprising

injecting (101) selectively contrast agent into a branch of the coronary arteries (11) before acquiring (103) the 2-dimensional X-ray images (13).

11. The method according to one of claims 1 to 10, wherein the acquisition (103) of the 2-dimensional X-ray images (13) is gated based on an electrocardiogram signal.

12. The method according to one of claims 1 to 11, wherein the 3-dimensional reconstruction (19) of the myocardium (12) is gated based on an electrocardiogram signal.

13. The method according to one of claims 4 to 12, further comprising fusing (113) the 3-dimensional reconstruction (19) of the myocardium and the 3-dimensional reconstruction (15) of the coronary arteries (11).

14. The method according to one of claims 1 to 13, wherein 3-dimensional reconstruction of the myocardium (12) is generated using all of the plurality of 2-dimensional X-ray images (13).

15. Apparatus for acquiring 3-dimensional images of a myocardial blush of a myocardium the apparatus being adapted to perform the method according to one of the preceding claims.

16. Apparatus according to claim 15, including

a C-arm system (1) comprising an X-ray source (3) for emitting X-rays and an X-ray detector (5) for acquiring 2-dimensional X-ray images (13);

a control unit (9) for controlling at least one of the X-ray source (3) and the X-ray detector (5);

a computing unit (21) for computing 3-dimensional images the myocardial blush of the myocardium (12) using acquired 2-dimensional X-ray images (13) provided by the X-ray detector (5).

17. Computer program element adapted to perform the method according to one of claims 1 to 14 when executed on a computer (21).

18. Computer readable medium with a computer program element according to claim 17.

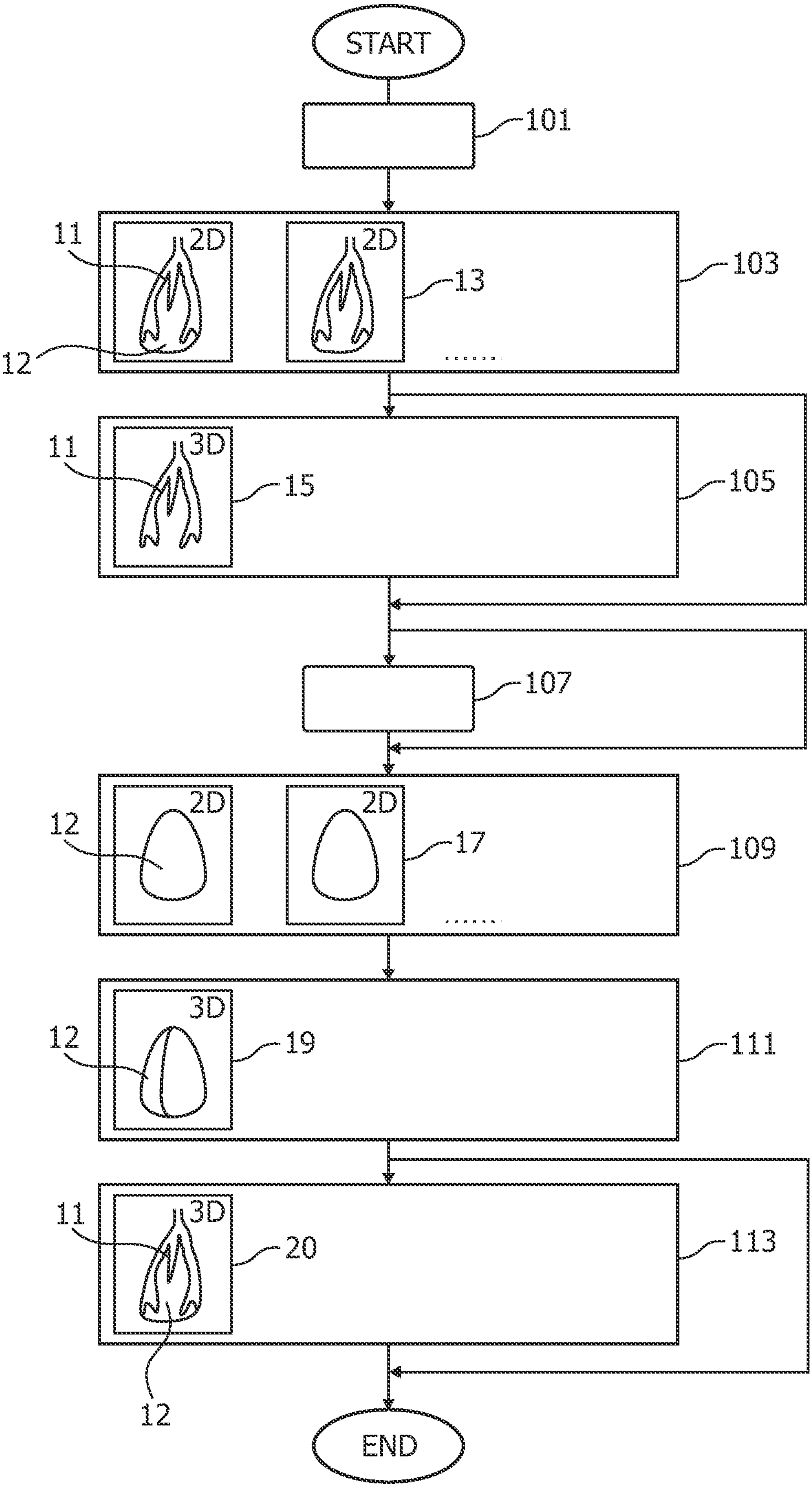
START
101
11
2D
2D
13
103
12
11
3D
15
105
107
12
2D
2D
17
109
3D
12
19
111
11
3D
20
113
12
END

FIG. 1

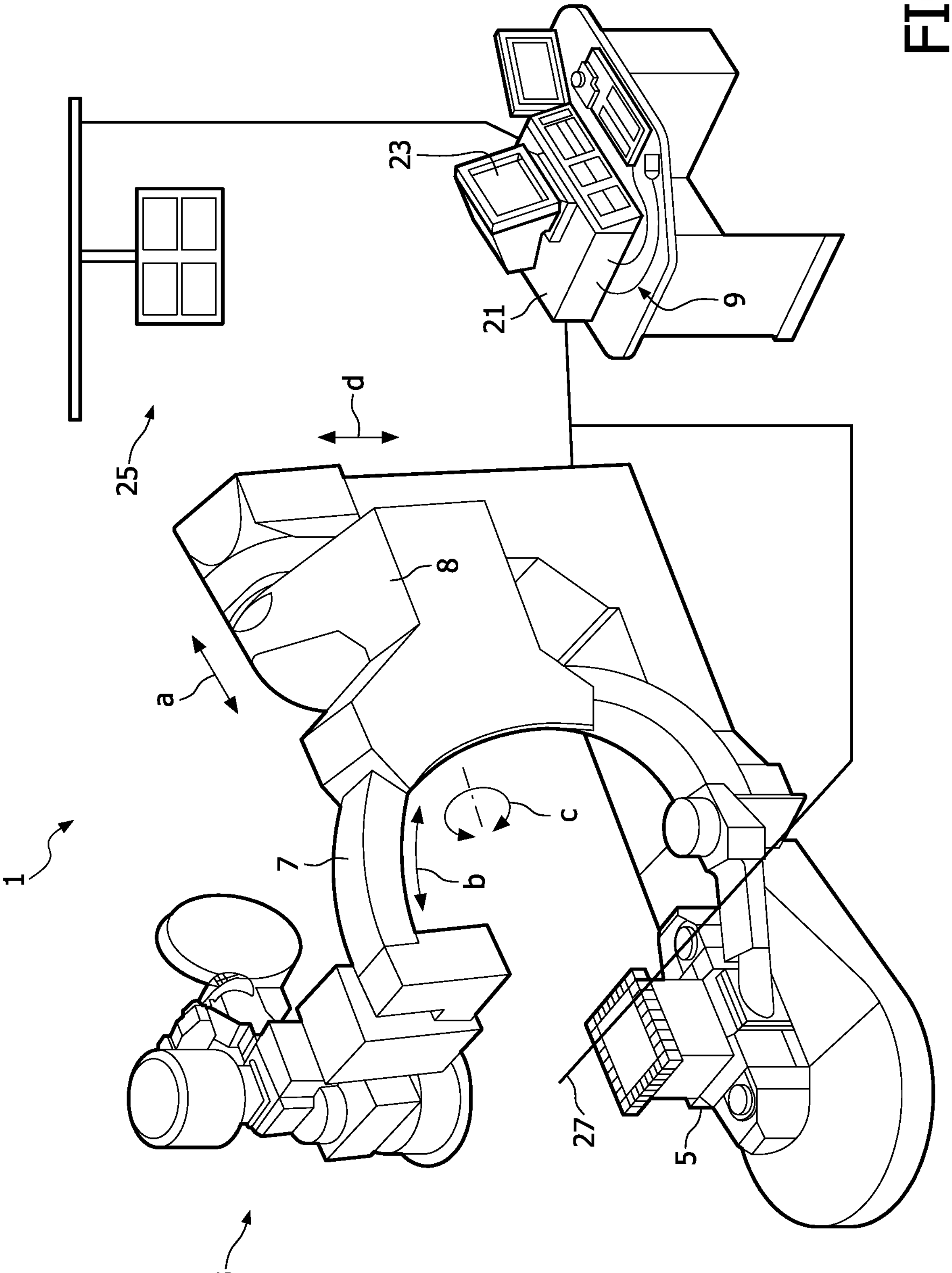

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2008/055325

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06T11/00

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)
G06T

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, INSPEC, COMPENDEX, 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	SCHÄFER D, JANDT U ET AL: "Motion compensated reconstruction for rotational X-ray angiography using 4D coronary centerline models" PROCEEDINGS OF THE INTERNATIONAL MEETING ON FULLY THREE-DIMENSIONAL IMAGE RECONSTRUCTION IN RADIOLOGY AND NUCLEAR MEDICINE, 9 July 2007 (2007-07-09), - 13 July 2007 (2007-07-13) pages 245-248, XP007907537 the whole document	1-17

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

[ ] See patent family annex.

* Special categories of cited documents :

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

"E" earlier 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
6 March 2009	23/03/2009

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	Werling, Alexander

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2008/055325

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	& JANDT U, SCHÄFER D ET AL: "Automatic generation of time resolved 4D motion vector fields of coronary arteries" PROCEEDINGS OF THE INTERNATIONAL MEETING ON FULLY THREE-DIMENSIONAL IMAGE RECONSTRUCTION IN RADIOLOGY AND NUCLEAR MEDICINE, 9 July 2007 (2007-07-09), - 13 July 2007 (2007-07-13) pages 249-252, XP002518076 the whole document	
A	BLONDEL CHRISTOPHE ET AL: "Reconstruction of coronary arteries from a single rotational X-ray projection sequence" IEEE TRANSACTIONS ON MEDICAL IMAGING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 25, no. 5, 1 May 2006 (2006-05-01), pages 653-663, XP002506502 ISSN: 0278-0062 page 653 - page 661, left-hand column; figure 3	1-17