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(54) Title: FRACTIONAL FLOW RESERVE DETERMINATION

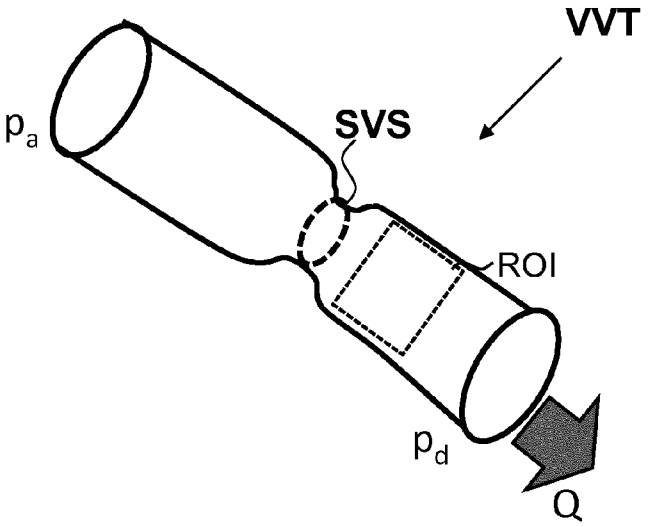

Fig. 3

(57) Abstract: The present invention relates to a device (1) for fractional flow reserve determination. The device (1) comprises a model generator (10) configured to generate a three-dimensional model (3DM) of a portion of an imaged vascular vessel tree (VVT) surrounding a stenosed vessel segment (SVS), based on a partial segmentation of the imaged vascular vessel tree (VVT). Further, the device comprises an image processor (20) configured to calculate a blood flow (Q) through the stenosed vessel segment (SVS) based on an analysis of a time-series of X-ray images of the vascular vessel tree (VVT). Still further, the device comprises a fractional-flow-reserve determiner (30) configured to determine a fractional flow reserve (FFR) based on the three-dimensional model (3DM) and the calculated blood flow.

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FIELD OF THE INVENTION

The present invention relates to the field of coronary angiography. In particular, the present invention relates to a device and a method for fractional flow reserve determination.

BACKGROUND OF THE INVENTION

Coronary angiography allows for excellent visualization of coronary arteries. However, assessment of functional stenosis severity is limited. Fractional flow reserve, FFR, is a reliable measure for grading stenosis. Based on the aortic pressure P_a and the pressure P_d distal total stenosis, FFR is defined as: FFR = P_d / P_a.

Recently, the so-called virtual FFR method is receiving increasing interest for replacing the invasive pressure measurements by computational fluid dynamics simulation. This method is based on a geometric model of the coronary tree, which can be obtained either from computer-aided tomography angiography or from X-ray angiography images.

To evaluate the hemodynamic severity of coronary stenosis is a critical task in planning of cardiac interventions. Traditionally, the local reduction of the vessel diameter at the stenosis is assessed visually on cardiac images for this purpose.

US 8,157,742 B2 describes a system for planning treatment for a patient. The system may include at least one computer system configured to receive patient-specific data regarding a geometry of an anatomical structure of the patient, create a three-dimensional model representing at least a portion of the anatomical structure of the patient based on the patient-specific data, and determine a first fractional flow reserve within the anatomical structure of the patient based on the three-dimensional model and a physics-based model relating to the anatomical structure of the patient.

WO 2014/072861 A2 describes methods and systems for fractional flow reserve calculations, wherein classifying of an unknown fractional flow reserve metric for a cardiac vessel with a stenosis as one of a plurality of different pre-defined classes based on extracted features and a learning model is performed.

SUMMARY OF THE INVENTION

There may be a need to improve devices and methods for fractional flow reserve determination.

This is met by the subject-matter of the independent claims. Further exemplary embodiments are evident from the dependent claims and the following description.

A first aspect of the present invention relates to a device for fractional flow reserve determination. The device comprises a model generator, which is configured to generate a three-dimensional model of a portion of an imaged vascular vessel tree surrounding a stenosed vessel segment, based on a partial segmentation of the imaged vascular vessel tree. Further, the device comprises an image processor, which is configured to calculate a blood flow through the stenosed vessel segment based on an analysis of a time-series of X-ray images of the vascular vessel tree. Still further, the device comprises a fractional-flow-reserve determiner, which is configured to determine a fractional flow reserve based on the three-dimensional model and the calculated blood flow.

The imaged vascular vessel tree may be modeled by creating a three-dimensional model representing at least a portion of the vascular vessel tree of a patient.

The present invention is based on a combination of the fractional flow reserve simulation with flow velocity measurements from angiographic images. For example, the flow velocity measurements may be based on an analysis, for example on an image processing analysis such as an image brightness analysis or an intensity analysis or contrast analysis.

The present invention advantageously improves the reliability of the boundary conditions of the simulated fractional flow reserve, since an accurate determination of the fractional flow reserve is provided. Further, the present invention advantageously reduces the geometric modeling requirements, since a blood flow through the stenosed vessel segment can be calculated with improved precision.

The present invention advantageously provides a combination of fractional flow reserve simulations with flow velocity measurements from a series of X-ray images, in particular angiographic images. A region of interest is marked in a first angiographic image and tracked over time in the subsequent images of the series following an injection of a contrast agent.

For example, by integrating the calibrated image intensities over the region of interest, the volumetric flow Q can be calculated as the slope of the time intensity curve at the

time of arrival of the contrast bolus. Further, the aortic pressure is measured using known techniques as an inlet boundary condition.

For example, the present invention advantageously uses deriving the blood flow through the stenosis from a series of X-ray images and measuring the aortic pressure in order to calculate a corrected fractional flow reserve.

The present invention advantageously allows calculating, for example, the distal pressure at the stenosis from the determined FFR and a measurement of the aortic pressure.

According to a further, second aspect of the present invention, a medical imaging system is provided comprising a display device and a device according to the first aspect of the present invention or according to any implementation form of the first aspect of the present invention. The display device is configured to display the determined fractional flow reserve.

According to a further, third aspect of the present invention, a method for fractional flow reserve determination is provided, the method comprising the steps of:

a) generating a three-dimensional model of an imaged vascular vessel tree based on a partial segmentation of an imaged vascular vessel tree surrounding a stenosed vessel segment by a model generator;

b) calculating a blood flow through the stenosed vessel segment based on an analysis of a time-series of X-ray images by an image processor; and

c) determining a fractional flow reserve based on the three-dimensional model of the imaged vascular vessel tree and the calculated blood flow by a fractional-flow-reserve determiner.

According to an exemplary embodiment of the present invention, the image processor is configured to conduct the analysis of the time-series of X-ray images within a period of up to 12 s, preferably of up to 5 s, most preferably of up to 1 s. This advantageously provides a temporal evaluation of the blood flow through the stenosed vessel.

According to an exemplary embodiment of the present invention, the device further comprises a controllable injector configured to provide a predefined flow profile of a contrast agent injected into the vascular vessel tree. This advantageously provides a reliable and normalized blood flow detection and analysis.

According to an exemplary embodiment of the present invention, the image processor is configured to perform a brightness calibration prior to the analysis of the time-

series of X-ray images. This advantageously improves the accuracy of the blood flow detection and measurement.

According to an exemplary embodiment of the present invention, the image processor is configured to perform the brightness calibration by top-hat filtering or by image filtering or by bone removal or by digital subtraction of a reference image in at least one image of the time-series of X-ray images or in an image recorded prior to the recording of the time-series of X-ray images. The image filtering may refer to a preprocessing or filtering technique which improves the brightness analysis. This could also be dual energy angiography or angiography using a spectral detector which enables accurate iodine quantification.

In an example, the image processor is configured to calculate the blood flow using calibrated intensities over a region of interest including the stenosed vessel segment. This advantageously improves the accuracy of the blood flow detection and measurement.

According to an exemplary embodiment of the present invention, the image processor is configured to calculate the blood flow using a slope of a plot of the calibrated intensities as a function of integration time. This advantageously also improves the accuracy of the blood flow detection and measurement.

According to an exemplary embodiment of the present invention, the fractional-flow-reserve determiner is configured to calculate the fractional flow reserve using at least one boundary condition on an inlet and/or an outlet of the imaged vascular vessel tree. Advantageously, this improves the accuracy of the blood flow detection and measurement, too.

According to an exemplary embodiment of the present invention, the fractional-flow-reserve determiner is configured to use as the at least one boundary condition a pressure flow or flow constraint or a lumped element model composed of a resistor, a non-linear resistor or a capacitor. Improving the accuracy of the blood flow detection and measurement is advantageously also achieved.

The term “lumped element model” as used by the present invention refers to a parameter model that simplifies the description of the behavior of spatially distributed physical systems into a topology consisting of discrete entities that approximate the behavior of the distributed system under certain assumptions.

According to an exemplary embodiment of the present invention, the fractional-flow-reserve determiner is configured to adjust the at least one boundary condition

to a determined diameter of a vessel of the imaged vascular vessel tree. This advantageously improves the accuracy of the blood flow detection and measurement.

According to an exemplary embodiment of the present invention, the fractional-flow-reserve determiner is configured to calculate a distal pressure of the stenosed vessel segment using a three-dimensional fluid dynamics simulation or a lumped components model, wherein a resistance of the stenosed vessel segment is approximated from a cross-sectional area of the stenosed vessel segment. This advantageously provides a reliable and normalized blood flow detection and analysis.

According to an exemplary embodiment of the present invention, the model generator is configured to generate the three-dimensional model of the portion of the imaged vascular vessel tree based on a portion of the vascular vessel tree distal to the stenosed vessel segment.

These and other aspects of the present invention will become apparent from and be elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the present invention and the attendant advantages thereof will be more clearly understood with reference to the following schematic drawings, which are not to scale, wherein:

Fig. 1 shows a schematic diagram of region of interest on an image vascular vessel tree for explaining the present invention;

Fig. 2 shows a schematic diagram of an intensity as a function of time plot for explaining the present invention;

Fig. 3 shows a schematic diagram of a simple geometric model of a stenosed vessel segment for explaining the present invention;

Fig. 4 shows a schematic diagram of a coronary vessel tree with typical boundary conditions for explaining the present invention;

Fig. 5 shows a schematic diagram of a complete segmentation of the coronary vessels and the proposed reduced segmentation for explaining the present invention;

Fig. 6 shows a schematic diagram of a flowchart diagram for explaining the present invention;

Fig. 7 shows a schematic diagram of a device for fractional flow reserve determination according to an exemplary embodiment of the present invention;

Fig. 8 shows a schematic diagram of a medical imaging device according to an exemplary embodiment of the present invention; and

Fig. 9 shows a schematic diagram of a flowchart diagram of a method for fractional flow reserve determination according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

The illustration in the drawings is purely schematic and does not intend to provide scaling relations or size information. In different drawings or figures, similar or identical elements are provided with the same reference numerals. Generally, identical parts, units, entities or steps are provided with the same reference symbols in the description.

Fig. 1 shows a schematic diagram of a region of interest on an image vascular vessel tree for explaining the present invention.

In Fig. 1, an imaged vascular vessel tree VVT is shown and a partial segmentation of the image vascular vessel tree VVT is performed around a stenosed vessel segment SVS of interest.

According to an exemplary embodiment of the present invention, the geometric model of the coronary tree can be obtained by segmentation of cardiac computed tomography, CT, image volumes or from a few preferably two orthogonal X-ray angiography projections.

A quantitative measurement of the blood flow in the stenosed segment may be performed. For example, a densitometric approach may be suited to estimate the flow from a short time-series of X-ray angiography images.

A power injector, or a controllable injector, e.g. an injector module, can be used to minimize the dilution of the contrast agent with blood. For quantitative measurement of the contrast agent inflow, the image may be calibrated properly. To this end, scatter and background structures may be removed (e.g. by top-hat filtering, bone removal or by digital subtraction of a reference image) and the imaged intensity may be calibrated (e.g. using a phantom with known attenuation or using information of the three-dimensional vessel geometry). A region of interest, ROI, may be marked, as illustrated later on in Fig. 3, and tracked over time.

Fig. 2 shows a schematic diagram of an intensity as a function of time plot for explaining the present invention. According to an exemplary embodiment of the present invention, when integrating the calibrated intensities over the ROI, the volumetric blood flow

Q can be calculated as the slope of the curve at bolus arrival time as shown in Fig. 2. Contrast transit-time or arrival-time methods for flow quantification might also be used, either as an alternative or in combination with the densitometric approach.

According to an exemplary embodiment of the present invention, as an inlet boundary condition, the aortic pressure can be estimated from arm cuff pressure measurements, or can be measured directly using an aortic catheter, as usually done in interventional cardiology. Using the flow boundary condition, the requirements for geometric modeling are significantly relaxed. A typical fractional flow reserve FFR simulation may be given by a detailed segmentation of the complete coronary tree (including fine distal branches).

Fig. 3 shows a schematic diagram of a simple geometric model of a stenosed vessel segment for explaining the present invention. Fig. 3 shows a partial segmentation of the image vascular vessel tree VVT around the stenosed vessel segment SVS.

According to an exemplary embodiment of the present invention, if the blood flow Q through the stenosis and the aortic pressure p_a are known, a model of the stenosed vessel segment alone (as shown in Fig. 3) is sufficient to calculate the distal pressure p_d. This can be achieved via a full three-dimensional computational fluid dynamics simulation or by a lumped components approach where the segment's resistance is approximated from its cross-sectional areas, considering the Poiseuille effect (or Poiseuille's Law), the Bernoulli principle and others. Then, the fractional flow reserve FFR can be calculated as in the following equation:

$$FFR = P_d / P_a.$$

Fig. 3 shows a simple geometric model of a stenosed vessel segment. The inlet and outlet boundary conditions are given by the aortic pressure p_a and the flow Q, respectively.

According to an exemplary embodiment of the present invention, the so-called virtual fractional flow reserve (vFFR) method may be used in combination with invasive pressure measurements by computational fluid dynamics (CFD) simulations. CFD simulations may be based on a geometric model of the coronary tree, which can be obtained either from CT angiography or from X-ray angiography images. A region of interest, ROI, may be marked and tracked over time.

Fig. 4 shows a schematic diagram of a coronary vessel tree with typical boundary conditions for explaining the present invention.

For accurate vFFR simulations, the choice of personalized boundary conditions at the inlets and outlets (as illustrated using Fig. 4) are considered. At each inlet and outlet, boundary conditions are assigned for non-ambiguous definition of all model variables. In general, these boundary conditions are pressure or flow constraints or lumped element models, composed of resistors, non-linear resistors (varistors) and dynamic elements (such as capacitors). For example, one can impose a pressure pin at the inlet (coronary ostium) and a particular resistance going to ground to each of the outlets.

The term "varistor" as used by the present invention refers to an electronic component with a nonlinear current–voltage characteristic, which is therefore also known as a voltage-dependent resistor (VDR).

The error of vFFR simulations depends at least linearly on a correct estimate of the flow value through the stenosis and hence on the correct choice of boundary conditions. If parts of the coronary tree are excluded from the segmentation, the flow through the remaining branches (especially through the stenosed segment) and hence the vFFR prediction would be compromised.

Fig. 5 shows a schematic diagram of a complete segmentation of the coronary vessels and the proposed reduced segmentation.

According to an exemplary embodiment of the present invention, the boundary conditions (pressures or resistances) at each outlet usually depend on the size (e.g. diameter, cross-sectional area) of the out-going vessel relative to the root vessel (e.g. LCA, RCA). Then, scaling laws can be applied to calculate the relative flow or impedance of each outlet. E.g. in case of a simple outlet resistance, resulting in equation 1:

$$R_{\text{out}} = 150\frac{Pa}{m/s} \cdot \sqrt[3]{\frac{d_{root}}{d_{out}}}$$

wherein R_{out} is the outlet resistance, d_{out} is the diameter of the outlet, d_{root} is the diameter of the root vessel, wherein the expression *"Pa"* of equation 1 refers to pascal (symbol: *Pa*) and is the SI derived unit of pressure, internal pressure, stress, Young's modulus and tensile strength, defined as one newton per square meter. The expression "*m/s*" of equation 1 refers to meter per second. Meter per second is an SI derived unit of speed (scalar) and velocity (vector), defined by distance in meters divided by time in seconds. Calculating the outlet resistance requires knowledge of the diameter d_{root} of the root vessel, which is not available with an incomplete segmentation.

According to an exemplary embodiment of the present invention, it is proposed to calculate vFFR with only a partial segmentation of the vascular tree together

with an explicit measurement of the diameter of the coronary ostium. This measure may be then used in a scaling law for the boundary conditions, e.g. as d_{root} in equation 1.

The basic principle is illustrated in Fig. 5. Conventionally, a complete segmentation of the coronary vessel tree is preferred to increase the accuracy of vFFR calculations. A detailed segmentation, however, may be tedious and may hamper clinical workflow, especially during cardiac interventions. As the fractional flow reserve (FFR) value depends mostly on the stenosis geometry and the flow through the stenosed vessel segment, a partial segmentation (e.g. of the branches distal to the stenosis) can be sufficient for vFFR calculations if the ostium diameter is used to calculate peripheral resistance, for example by equation 1.

Fig. 5 shows a complete segmentation of the coronary vessel tree (left) and proposed reduced segmentation (right).

According to an exemplary embodiment of the present invention, the ostium diameter can be obtained (a) by interactive or (semi-)automated measurement on X-ray images or CT-volumes or (b) approximated by the diameter of coronary catheter, which was chosen by the interventional radiologist.

In general, it will often be reasonable to exclude the major branches located proximal to a stenosis from the segmentation (as in Fig. 5) without introducing a large error. This is true if the pressure drop *Dp* from the inlet to the cropping point is small, i.e. no stenosis is located there. This is not very limiting, because if stenoses were located there, this branches would be included in the segmentation anyway. The blood flow through the stenosis can then still be estimated accurately by flow or impedance boundary conditions with a scaling law using the root diameter information.

Fig. 6 shows a schematic diagram of a flowchart diagram for explaining the present invention.

Initially, a three-dimensional model 3DM of an imaged vascular vessel tree VVT based on a partial segmentation of the imaged vascular vessel tree VVT surrounding a stenosed vessel segment SVS may be calculated.

Then, calculating a blood flow Q through the stenosed vessel segment SVS based on an analysis of a time-series of X-ray images may be performed.

Subsequently, a fractional flow reserve FFR based on the three-dimensional model 3DM and the calculated blood flow Q may be calculated.

Fig. 7 shows a schematic diagram of a device 1 for fractional flow reserve determination.

The device 1 for fractional flow reserve determination may comprise a model generator 10, an image processor 20, and a fractional-flow-reserve determiner 30.

The model generator 10 may be configured to calculate a three-dimensional model 3DM of an imaged vascular vessel tree VVT on a partial segmentation of an image vascular vessel tree VVT surrounding a stenosed vessel segment SVS. The three-dimensional model may be a virtual structure of a vessel structure, a complex branched tree structure, or any other structure as a circuit, wherein the vessel structure is modeled by a plurality of tubes each of which defined by, for instance parameters like size, length, position, and direction.

The image processor 20 may be configured to calculate a blood flow Q through the stenosed vessel segment SVS based on an analysis of a time-series of X-ray images. The analysis may be an image processing analysis, for instance, a brightness analysis or an image contrast analysis.

The fractional-flow-reserve determiner 30 may be configured to determine a fractional flow reserve based on the three-dimensional model of the imaged vascular vessel tree VVT and the calculated blood flow Q.

Further, the distance between the location, at which the diameter of the ostium was measured, and the part, at which the segmentation of the stenosed vessel segment SVS starts, may be used as an input parameter by the model generator 10.

Fig. 8 shows a schematic diagram of a medical imaging system 200 according to an exemplary embodiment of the present invention.

The medical imaging system 200 may comprise an example of the device 1 for fractional flow reserve determination. The medical imaging system 200 may be an X-ray guided cardiac medical intervention device, a CT-imaging system or a magnetic resonance (MR) angiography imaging system.

Further, the medical imaging system 200 may be used for coronary flow reserve determination.

Fig. 9 shows a schematic diagram of a flowchart of a method for fractional flow reserve determination. The method may comprise the following steps:

As a first step a) of the method, generating S1 a three-dimensional model of an imaged vascular vessel tree VVT based on a partial segmentation of the imaged vascular vessel tree VVT surrounding a stenosed vessel segment SVS by a model generator 10 may be conducted.

As a second step b) of the method, calculating S2 a blood flow Q through the stenosed vessel segment SVS based on an analysis of a time-series of X-ray images by image processor 20 may be conducted.

As a third step c) of the method, determining S3 a fractional flow reserve FFR based on the fractional flow reserve FFR and the calculated blood flow Q by a fractional-flow-reserve determiner 30 may be conducted.

According to an example, the step of calculating S2 the blood flow Q through the stenosed vessel segment SVS comprises calculating the blood flow Q using calibrated intensities over a region of interest including the stenosed vessel segment SVS.

In an example, the step of determining S3 the fractional flow reserve FFR is performed using at least one boundary condition on an inlet and/or an outlet of the imaged vascular vessel tree VVT.

It has to be noted that embodiments of the present 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 device type claims.

However, a person skilled in the art will gather from the above and the foregoing description that, unless otherwise notified, in addition to any combination of features belonging to one type of the subject-matter also any combination between features relating to different subject-matters is considered to be disclosed with this application.

However, all features can be combined providing synergetic effects that are more than the simple summation of these features.

While the present invention has been illustrated and described in detail in the drawings and the foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the present invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art and practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

In the claims, the word “comprising” does not exclude other elements or steps, and the indefinite article “a” or “an” does not exclude a plurality. A single processor or controller or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. A device (1) for fractional flow reserve determination, the device (1) comprising:

- a model generator (10) configured to generate a three-dimensional model (3DM) of a portion of an imaged vascular vessel tree (VVT) surrounding a stenosed vessel segment (SVS), based on a partial segmentation of the imaged vascular vessel tree (VVT);
- an image processor (20) configured to calculate a blood flow (Q) through the stenosed vessel segment (SVS) based on an analysis of a time-series of X-ray images of the vascular vessel tree (VVT); and
- a fractional-flow-reserve determiner (30) configured to determine a fractional flow reserve (FFR) based on the three-dimensional model (3DM) and the calculated blood flow (Q).

2. Device according to claim 1,

wherein the image processor (20) is configured to:

i) conduct the analysis of the time-series of X-ray images with a period of up to 12 s, preferably of up to 5 s, most preferably of up to 1 s; and/or

ii) to perform a brightness calibration prior to the analysis of the time-series of X-ray images.

3. Device according to claim 1 or 2,

further comprising a controllable injector (40), configured to provide a predefined flow profile of a contrast agent injected into the vascular vessel tree (VVT).

4. Device according to claim 2,

wherein the image processor (20) is configured to perform the brightness calibration by i) top-hat filtering, or by ii) bone removal, or by iii) digital subtraction of a reference image in at least one image of the time-series of X-ray images or in an image recorded prior to the recording of the time-series of X-ray images.

5. Device according to one of the preceding claims,

wherein the image processor (20) is configured to calculate the blood flow (Q) using a slope of a plot of the calibrated intensities.

6. Device according to one of the preceding claims,

wherein the fractional-flow-reserve determiner (30) is configured to calculate the fractional flow reserve (FFR) using at least one boundary condition at an inlet and/or an outlet of the imaged vascular vessel tree (VVT).

7. Device according to claim 6,

wherein the fractional-flow-reserve determiner (30) is configured to use as the at least one boundary condition a pressure or flow constraint or a lumped element model composed of a resistor, a varistor or a capacitor.

8. Device according to claim 7,

wherein the fractional-flow-reserve determiner (30) is configured to use an aortic pressure measurement as basis for the pressure constraint used as the at least one boundary condition.

9. Device according to any one of the claims 6 to 8,

wherein the fractional-flow-reserve determiner (30) is configured to adjust the at least one boundary condition on a determined diameter of a vessel of the imaged vascular vessel tree (VVT).

10. Device according to claim 9,

wherein the fractional-flow-reserve determiner (30) is configured to determine a coronary ostium diameter measurement as the determined diameter of the vessel of the imaged vascular vessel tree (VVT) for adjusting the at least one boundary condition.

11. Device according to one of the preceding claims,

wherein the fractional-flow-reserve determiner (30) is configured to calculate a distal pressure (Pd) of the stenosed vessel segment (SVS) using a three-dimensional fluid dynamics simulation or a lumped components model, wherein a resistance of the stenosed

vessel segment (SVS) is approximated from a cross-sectional area of the stenosed vessel segment (SVS).

12. Device according to one of the preceding claims,
wherein the model generator (10) is configured to generate the three-dimensional model (3DM) of the portion of the imaged vascular vessel tree (VVT) based on a portion of the vascular vessel tree (VTT) distal to the stenosed vessel segment (SVS).

13. A medical imaging system (200) comprising:
- display device; and
- a device (1) according to one of the preceding claims,
wherein the display device is configured to display the determined fractional flow reserve.

14. A method for fractional flow reserve determination, the method comprising the steps of:
a) generating (S1) a three-dimensional model (3DM) of an imaged vascular vessel tree (VVT) surrounding a stenosed vessel segment (SVS) by a model generator (10) based on a partial segmentation of the imaged vascular vessel tree (VVT);
b) calculating (S2) a blood flow (Q) through the stenosed vessel segment (SVS) based on an analysis of a time-series of X-ray images by an image processor (20); and
c) determining (S3) a fractional flow reserve (FFR) based on the three-dimensional model (3DM) and the calculated blood flow (Q) by a fractional-flow-reserve determiner (30).

15. Method according to claim 14,
wherein the step of calculating (S2) the blood flow (Q) through the stenosed vessel segment (SVS) comprises calculating the blood flow (Q) using calibrated intensities over a region of interest including the stenosed vessel segment (SVS).

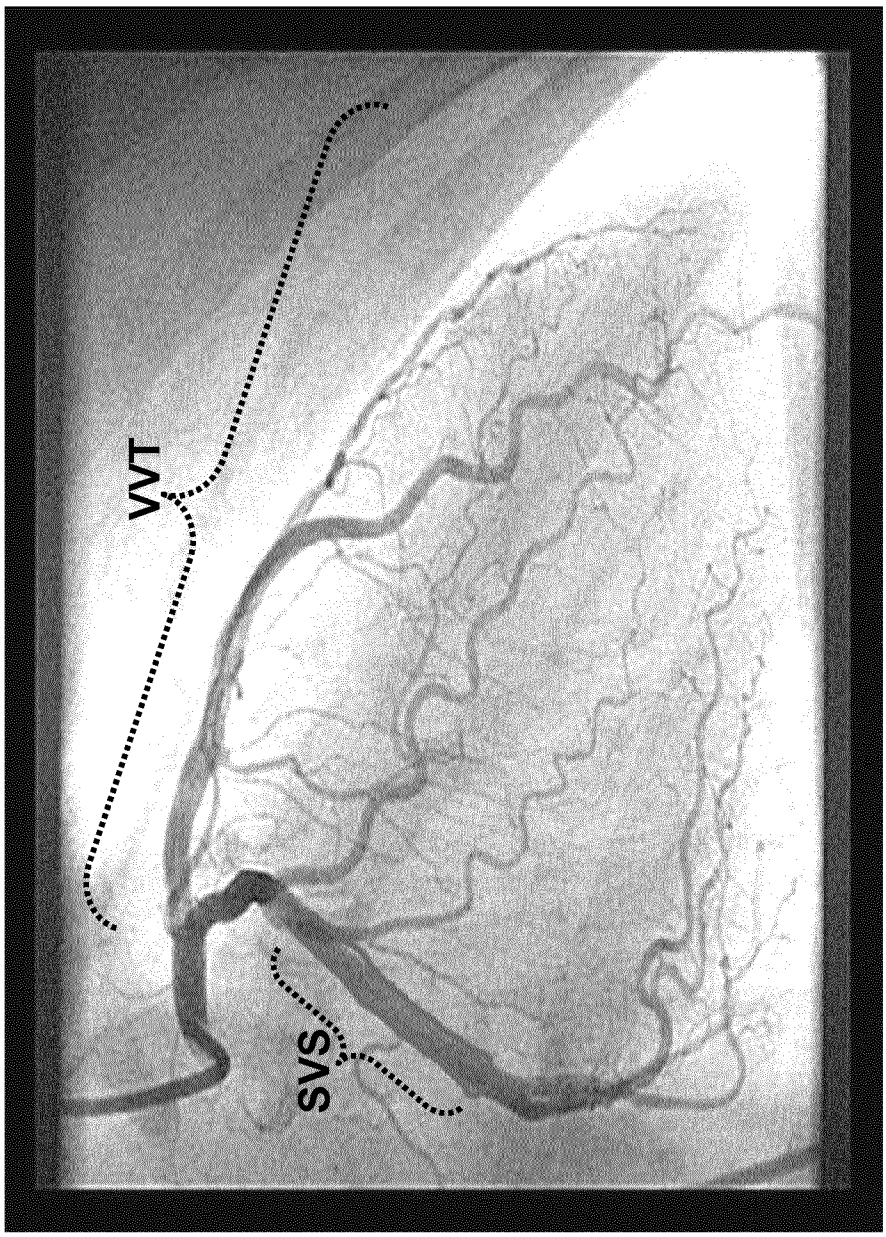

Fig. 1

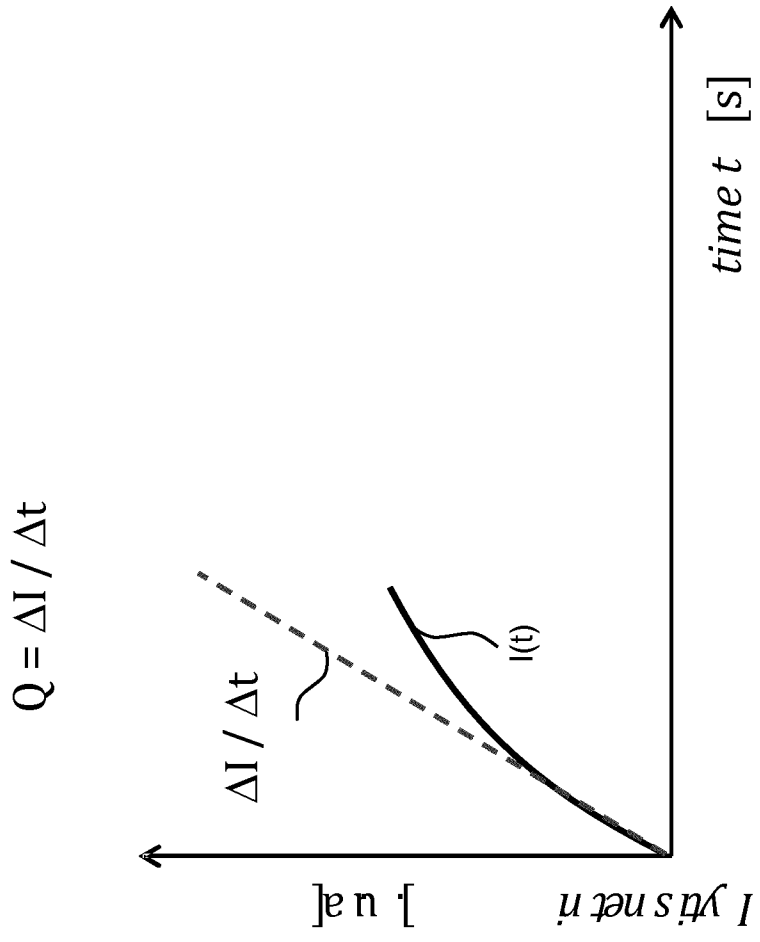

Fig. 2

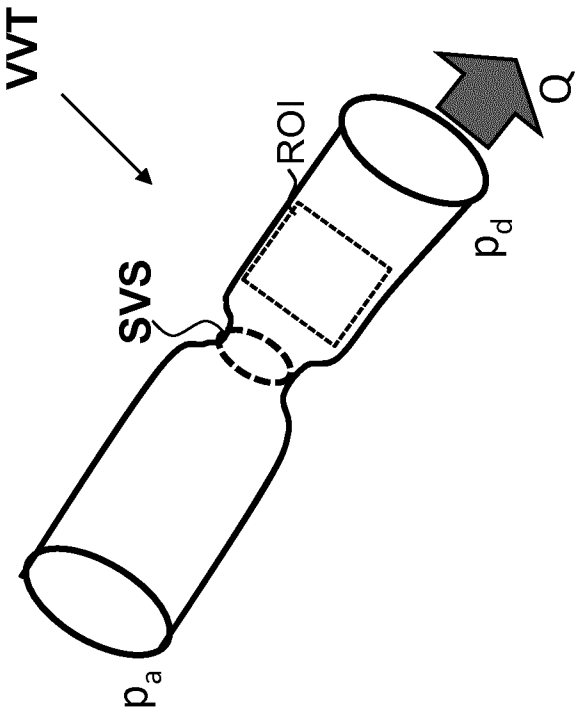

Fig. 3

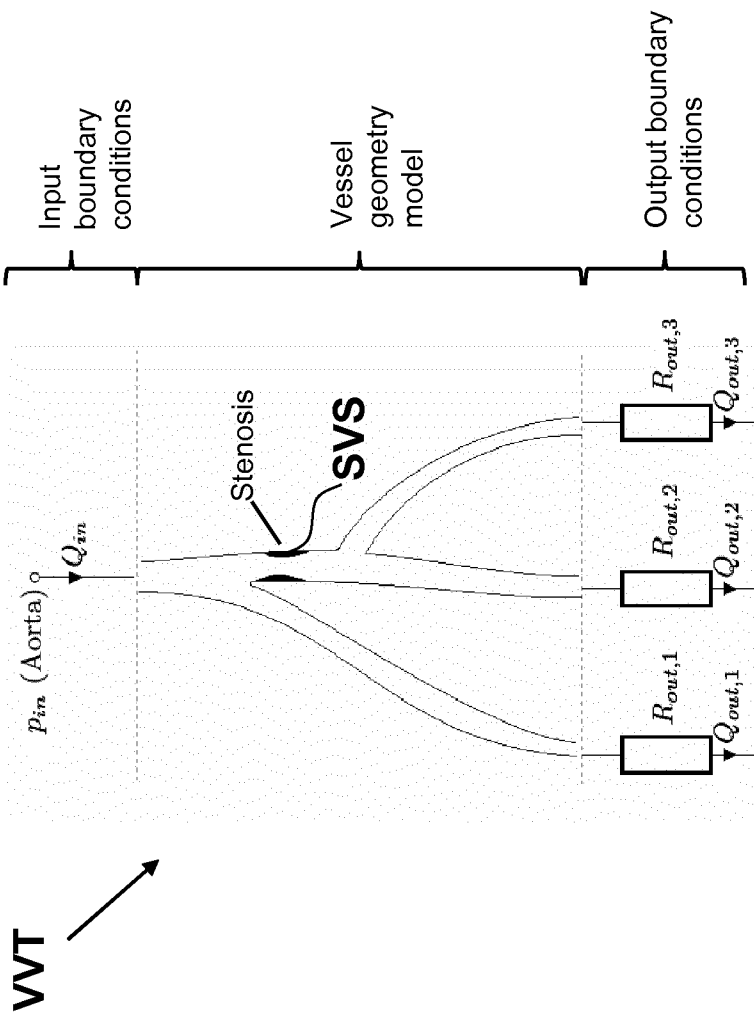
VVT
Input boundary conditions
Vessel geometry model
Output boundary conditions
p_{in} (Aorta)
Q_{in}
Stenosis
SVS
$R_{out,1}$
$R_{out,2}$
$R_{out,3}$
$Q_{out,1}$
$Q_{out,2}$
$Q_{out,3}$

Fig. 4

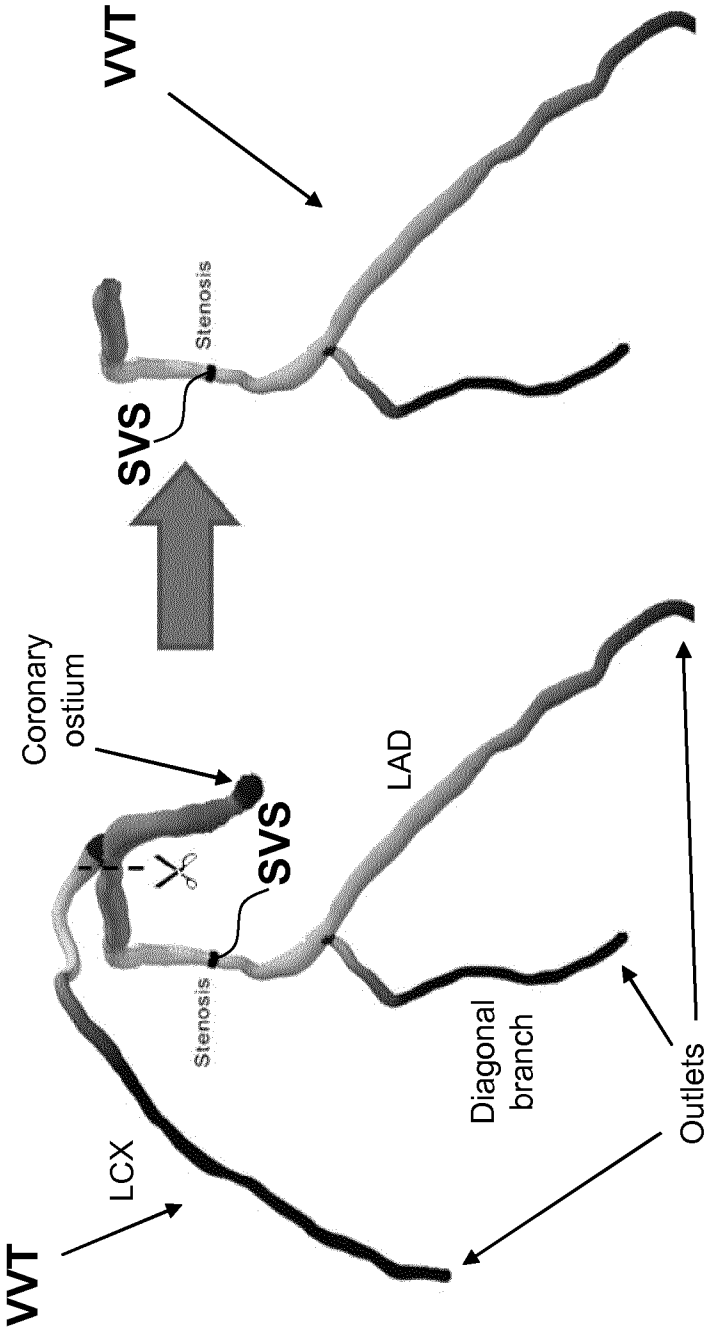
VVT
Stenosis
SVS
Coronary ostium
SVS
LAD
Stenosis
Diagonal branch
Outlets
LCX
VVT

Fig. 5

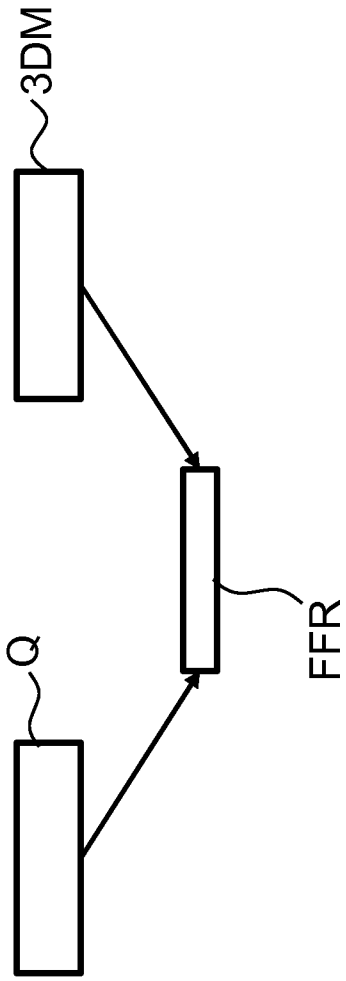

Fig. 6

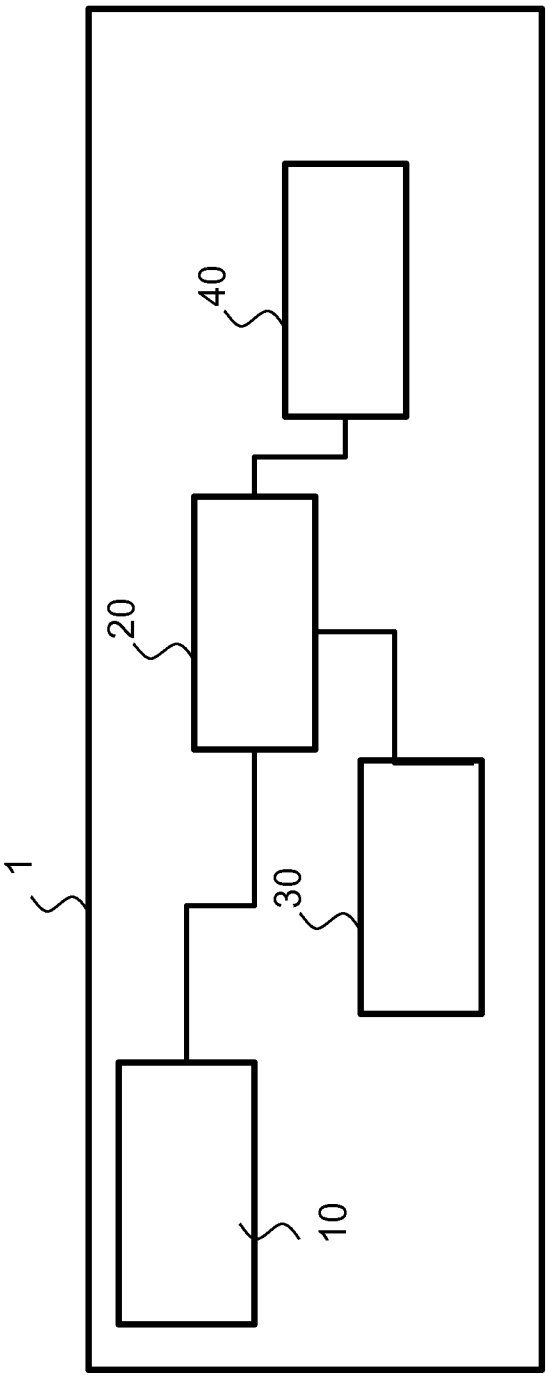

Fig. 7

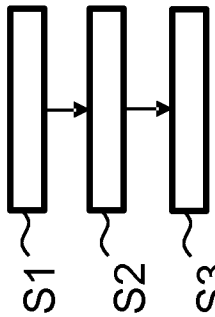

Fig. 9

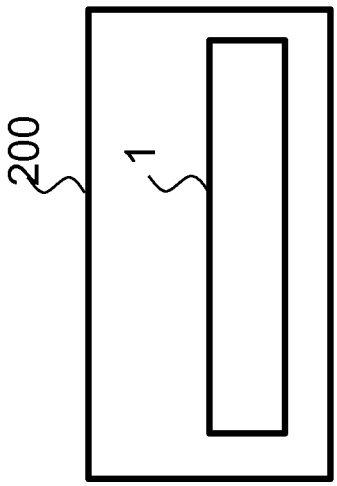

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/078117

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/00
ADD.

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)
A61B G06T G06F

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 practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2014/111927 A1 (CATHWORKS LTD [IL]) 24 July 2014 (2014-07-24) (2210); page 45, line 9 - page 49, line 12; page 47, line 23; page 51, line 19; page 52, line 4; page 73, lines 17, 27-29; page 76, line 18 & 21; page 82, line 16-18; page 85, line 29; page 87, line 25-29; page 89, lines 2, 10-11; page 94, line 7 -----	1-3, 12-14 2,4-7,15
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"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

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"&" 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 February 2016	29/02/2016

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	Anscombe, Marcel

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

INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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