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(54) Title: OPERATION SCENARIO FLOW AND MECHANICAL MODELING AND ANALYSIS SYSTEM OF CARDIOVASCULAR REPAIR OPERATIONS FOR NEWBORN AND FOETUS

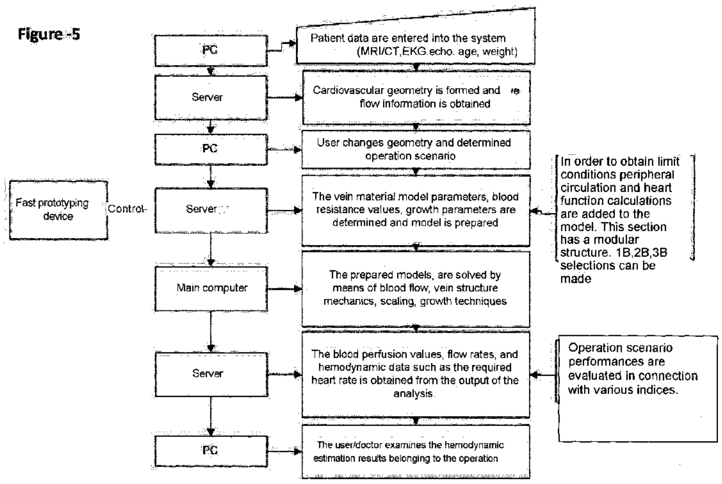

Figure -5

(57) Abstract: This invention is related to an operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for *newborn and fetus cardiovascular repair operations*, developed in order to be used for training of doctors and patient specific post surgery performance prediction in hospitals following and prior to, cardiovascular operations within the field of bioengineering in the health sector. Moreover it can be used for both vivo implantation plans of patient specific cardiovascular devices (custom cardiac valve and cardiac support pumps) and adaptation of said devices to the physiology of the patient.

DESCRIPTION

OPERATION SCENARIO FLOW AND MECHANICAL MODELING AND ANALYSIS SYSTEM OF CARDIOVASCULAR REPAIR OPERATIONS FOR NEWBORN AND FOETUS

TECHNICAL FIELD OF THE INVENTION

This invention is related to an operation scenario flow, mechanical modeling and analysis system comprising web-based, (i) growth (ii) scaling and (iii) quality control aimed, patient-specific fast prototyping functions, for *newborn and fetus cardiovascular repair operation*s, developed in order to be used for training of doctors as well as patient specific post surgery performance prediction in hospitals following and prior to, cardiovascular operations within the field of bioengineering in the health sector. Moreover it can be used for both in vivo implantation plans of patient specific cardiovascular devices custom cardiac valve and cardiac support pumps) and adaptation of said devices to the physiology, of the patient.

PRIOR ART (KNOWN STATE OF THE ART)

The pediatric clinician has to evaluate several operation scenarios/configurations in the treatment of cardiovascular diseases via surgery, during which blood circulation performance carries great importance. The doctor decides upon one of these scenarios by taking into consideration the ideas and opinions of other doctors and his own experiences. Moreover the doctor examines prior cases and their results. The doctor gives a final decision by taking into consideration all these facts. Estimating the changes that will occur in the cardiovascular system following an operation, as mentioned above, according to the known state of the art, could be misleading in many cases and may necessitate far too much experience. Moreover many cases and their results may be overlooked and they may not be examined in sufficient detail. The decision processes during fetus and newborn operations are even more difficult, because the systems of these patients are more complex in comparison to adults and they are also more susceptible to change. Moreover the patient's cardiovascular system keeps growing together with their body and their tissue characteristics continue to change. The decisions must be given specific to the patient and the artery, vein and artificial material's vein sizes must be taken into consideration. This growth and change of structure mentioned above is three-dimensional and it is quite difficult to estimate. In addition to these, the size of the patients and their circulatory networks are different from each other. It is not currently possible to normalize hemodynamic performance parameters. There is no pediatric patient-specific analaysis system, which takes these effects into consideration. Scaling is especially important during the fetal stage where the cardiovascular system continues to develop and the present invention is also advantageous in planning fetal cardiac interventions.

AIMS OF DEVELOPING THE INVENTION

A system, which can carry out the following especially in fetus and newborn cardiovascular surgeries, has been aimed, when improving operation scenario flow, mechanical modeling and an analysis system to be used during newborn and fetus cardiovascular repair operations developed by means of this invention,

- To plan the operation to be carried out on the patient and the techniques to be used, prior to the operation in a virtual environment,
- To be able the present to the evaluation of the user, the estimations taken regarding the results to be anticipated from the operation, via quantitative models produced, using engineering tools having industrial standards, visually and statistically,
- To create a model together with the cardiovascular structure of the blood flow, using data belonging to the patient and the plans that the doctor shall carry out,
- To estimate the changes that shall occur in tissue characteristics and how the cardiovascular system will take future form and also the natural development of the patient,
- To be able to present the operation results not only transiently but also taking into consideration the growth that shall occur in time,
- To be able to integrate heart function calculations (patient based, as threshold value) and peripheral circulation (microcirculation) to the surgery analysis results.

It is aimed for this operation scenario flow, mechanical modeling and analysis system to that has been developed according to the present invention for newborn and fetus cardiovascular repair operations to be used in cases where numerical models and intuitive estimations are not sufficient and as an aid to doctors during the decision stages regarding surgerys by the presentation of statistical and visual information. As a result, the percentage of error in relation to the operations that are to be carried out on complex structures for which the doctor cannot carry out estimation by only depending on his/her own experience can be significantly decreased. Consequently, the estimated scenarios typical to the operations will be able to be carried out independent from the experiences of the surgeons and as a result the number of specialists that will be able to perform said surgerys will be increased.

The success rate of operations where the operation scenario flow, mechanical modeling and analysis system is applied for newborn and fetus cardiovascular repair operations developed according to the invention shall be increased by means of this model and together with this, the fatality risks that could occur during the operations of fetus and newborn babies will also be decreased. In the known state of the art, in several cases the fetus and newborn babies may need multiple operations. One of the reasons for multiple operations to be carried out is because it is difficult to correctly estimate the growth process and the mechanical characteristics of the cardiovascular system prior to an operation and following an operation. This situation increases the necessary number of operations and the occurrence of unwanted situations. The modeling techniques of the system developed according to this invention will also help decrease the number of operations.

Description of the drawings

The drawings prepared in order to be able to better explain the operation scenario flow, mechanical modeling and analysis system for newborn and fetus cardiovascular operations developed according to the present invention have been attached to this description. The description of the drawings has been mentioned below.

Figure 1- Illustrates the hardware structure of the system developed according to this invention. The high-speed prototype device with which the suggested patient based, surgical configuration is checked has not been shown hereFigure 2- Shows the electrical analog circuit (network) that is used in the circulation model, the novel compartmentalizing techniques used in the scaling system and the circuit members.

Figure 3- Shows a cartoon of the circuit model obtained by the compartmentalizing method using the circulation anatomy of the patient.

Figure 4- Shows the basic parameters that the invention can scale and the illustrative surgical conduit that is simulated (T: time, C: Compliance, R: Flow resistance)

Figure 5- Shows the flow diagram developed according to the invention

DESCRIPTION OF THE ASPECTS/COMPONENTS/PARTS OF THE FIGURES

The parts in the figures that have been prepared in order to better explain the operation scenario flow, mechanical modeling and analysis system to be used in newborn and fetus cardiovascular repair operations developed according to the present invention have each been numbered. The references of the numbered have been listed below.

1 : User (PC)
2 : Server
3 : Host computer
4 : Web cloud
5 : Task entry and result notification
A : Circuit network of the circulation segment
B : Compartments
C : Resistances
i and j : Node points
Sis : Systemic
Pul : Pulmonary,
Art : Artery,
Ven : Vein,
SVR : Systemic vascular resistance
PVR : Pulmonary vascular resistance
V : Ventricle (Ventricle-Heart)

DESCRIPTION OF THE INVENTION

The surgery scenario blood flow, growth mechanical modeling and analysis system for newborn and fetus cardiovascular operations developed by means of the present invention basically comprises the following:

- A user computer – PC (1),
- Server (2),
- Host computer (3),
- Web cloud (4),
- Task entry and result notification (5), and
- Models /Software

The user computer – PC (1) is a PC having standard characteristics that can be connected to the internet, developed to be used for standard end users. It comprises input/output units for keyboards and a mouse. It is presumed that the users already own such a computer. The PC should be installed with commonly used operating systems and again with commonly used internet browsers. The user uses this computer to send the information such as MRI/CT, echo, ECG data of the patient via the internet to the server. The user forms the operation scenario in the interface of the internet page, by using the input/output tools such as the keyboard and the mouse of the computer. During this stage, the user can cut the veins from any section or at any angles he/she prefers, the user can by-pass any of the veins or the ventricle; can connect any of the veins from any point he/she desires; and make any other necessary changes for the operation. This new operation scenario geometry that has been established by the user is submitted to the server computer via the internet.

The server computer (2) is a more powerful server type computer in comparison to a standard PC. The server must be able to respond to the prompts that can be received from tens or hundreds of user PC's (1) at the same time. The server processes the prompts received from user PC's (1) through the internet and establishes the operation estimation model. This model uses the real geometries, echo, ECG data, age, weight information belonging to the patient. The model that has been formed is sent to the host computer in order for a simulation to be carried out. The results of the simulated model are received from the host computer and are converted into the data that the user doctor requests. This data can be the flow rate sent to the organs, the blood that the heart can pump, and the energy required by the functioning of the heart. The data obtained is sent via the internet to the user PC (1).

Moreover the cardiovascular geometry of a patient is formed automatically, within the server (2) using the patient screening data such as CT/MRI, which have been received from the user PC (1). The geometry that has been formed is sent back to the user PC (1) via the Internet. The user can see this geometry on his/her screen by means of the Internet interface and can examine the cardiovascular system of his/her patient, from the inside and the outside and from various angles. The user forms the operation scenario using this geometry and sends the scenario information to the server.

The server computer (2) shall have a database, which can store all models and results. The users should then be able to see the previously entered patient data, geometries that have been formed, the scenarios, and the results that have been obtained within the framework of security and authorization protocols.

The host computer (3), is a more powerful computer system which can carry simulation of multiple models at the same time, wherein more than one computer with multi processors can be connected to each other via network connection. The model information received from the server is converted into real calculation models and is solved. This analysis is carried out by means of, previously installed various software. These software, are specialized software in carrying out computational structural analysis (HYA), computational fluid mechanics (HAM), structural fluid interaction, solving differential equation with ordinary derivatives and partial derivative differential equations. The software to be used to solve the models is defined in advance on this host computer.

The models and software herein, have been designed to have the following characteristics: determining what kind of limit conditions should be established for methods such as HAM, HYA for values like echo, blood pressure belonging to the patient; scaling with data such as weight, volume of the patient; new structure of the operation scenario that will be formed after the patient grows; determining the perfusion, flow rate value of the patient following operation; determining how the cardiovascular system (using MRI/CT data dependent on time) of the patient will change due to pressure or by means of the MRI/CT data of the material characteristics of the cardiovascular system of the patient and using these material characteristics in the HYA software; determining the blood resistance values again using MRI/CT data and using them in the HAM, HYM and AYE software.

In Figure 2, the electrical circuit (network) used in the circulatory model, compartmentalizing technique and circuit means have been shown. The circulation model of the patient is established by using the anatomical characteristics of the disease and the flow and pressure measurements taken from the cardiovascular system and parameters related to the model are calculated. In the simplest pressure flow model within this method, electrical circuit analogy is used (1B modeling). There are two types of circuit means in the nodes, which are the capacitance (C) and resistances at the sides. The pressure values (P) on the model have been defined such that they can be measured on the nodes. The circuit network (A) of the model can be classified into sections (B) having a node point (i) in each, and carrying sides (I,j) that connect this node point to adjacent node points. (C) In the method used, the side that connects any one of the node pairs (i,j), comprises diodes (S_{ij},S_{ji}) that allow single direction flow and two resistances (R_{ij}, R_{ji}) (as different values can be taken depending on the flow direction of the resistor, the necessary indices have been used to represent the resistor at the flow direction: **ij** shows the flow from i to j and **ji** shows the flow from j to i). During compartmentalizing the resistances are distributed equally between two adjacent sections. The aim of the compartmentalizing method is to be able to evaluate/examine the circulatory system and model modularly and to be able to apply the scaling/growth methods used on the basis of compartments. The parameters for each compartment during scaling, have been made to be "non dimensional" using Buckingham Pi Theorem. The parameters that have been developed within the scope of this invention; is

$$\omega RC, \frac{C_{min}}{C_{max}}, \frac{P_i}{P_0}, \frac{Q}{\omega C P_0}, \frac{E}{\omega C P_0^2}$$

Wherein, ω: is the pulse frequency, R: is resistance, C: capacitance, min/max: minimum maximum (related to the ventricles); P_i: the blood pressure measurement in a section; P_0: blood circulation pressure, Q: flow, and E: is energy loss. In the method improved by the operation scenario flow and mechanical modeling and analysis system for newborn and fetus cardiovascular repair operations developed according to the present invention, "normal" and "sick/abnormal" value ranges have been determined by taking into consideration the age/weight/clinical characteristics of the patient, type/etc of the diseases, for the non dimensional parameters. These ranges are determined from databases that can additionally be formed from academic and clinical literature.

In Figure 3, an illustrative circuit model is shown which has been obtained by means of a compartmentalizing method based on the circulation anatomy of the patient. According to the anatomic information of the patient, the circulation model (circuit) of the patient is formed. This model is formed basically only by using the electrical circuit means explained in the previous stage. The circulation anatomy of a healthy person can be defined by an electrical circuit comprising six sections (sections illustrated with striped hexagons). Sections can be added/omitted/ modified by adding circuit means/changed with higher order models (higher order, for example 2-B or 3-B) in order to increase the details at the section that is to be examined and/or in accordance with the anatomical differences of a patient. The flow rate, pressure or material characteristics of the patient can be used in order to calculate the parameters of the model. In order to reach this aim, HAM calculations, classical hydrodynamic and electrical equations (Hagen-Poiseuille, etc.) in connection with flow-pressure and geometry can be used. If the sections used in the model are solved with HAM techniques in 3D, more realistic results can be obtained. For this reason these calculations must be preferred as far as possible. However sufficient amount of data may not be valid in all cases and in order to obtain a quick result the 1D modeling methods mentioned above are used.

Figure 4, shows the illustrative surgical conduits of the simulation and the basic performance parameters that the invention can scale (T: Time, C: Compliance, R: Flow resistance).

Figure 5, shows the flow diagram of the system. A model of the cardiovascular system, is created mechanically and solved; by means of the operation scenario flow, mechanical modeling and analysis system for newborn and fetus cardiovascular repair operations developed according to the present invention.

For a model to be created;

- First of all various data such as CT/MRI, echo, ultrasound of the patient is uploaded to the system via the internet. The rate and pressure data depending on the time received from the circulation system together with the cardiovascular system geometry are automatically obtained by means of a server.
- In the next stage, the clinician who will be performing the operation envisions on the surgery scenario via the internet using tools such as the mouse, etc. of the PC. The simulation of this operation scenario is carried out using the models that has been created by the clinician. During the simulation, computational fluid mechanics, computational structural mechanics techniques are used. The model parameters are obtained automatically using the clinical data that the doctor has sent within the framework of the protocols prepared by the model parameters.

The model formed according to the operation scenario flow, mechanical modeling and analysis system for newborn and fetus cardiovascular repair operations developed according to the present invention comprises many non-linear characteristics of the cardiovascular system in order to create a realistic simulation. It has been taken into account without having flow characteristics according to non-Newtonian and the cardiovascular tissue is modeled by taking into account micro and macro mechanical characteristics.

Moreover the geometric changes of the patient dependent on time and the tissue parameters of the patient are obtained and used in modeling. The model of the surgery scenario flow, mechanical modeling and analysis system for newborn and fetus cardiovascular repair operations that has been developed according to this invention, is customized especially for the fetus and newborns and it takes into consideration their growth and tissue characterization changes in time. Various scaling methods used in order to reach this aim, ensure that the difficulties faced when evaluating the circulation parameters depending on the size of the body and the cardiovascular performance analysis, are overcome.

Local and general performance evaluations are carried out by means of said scaling methods. Following operation, the growth of the cardiovascular system foreseen by the model is, monitored and the healing process of the patient can be evaluated and new estimations can be made by updating the model according to the evolving physiological state of the patient.

While these procedures are being carried out, in order to determine the hemodynamic performance of the surgerys, many hemodynamic performance indices such as, the cavo pulmonary pressure gradient (CPPG), hydrodynamic power loss, hepatic flow distribution etc. shall be used. These values shall be calculated either along the respiration cycles or their average is calculated. Other parameters in addition to these parameters can also be determined. The differences between the average vena cava pressure and the bilateral pulmonary artery (PA) pressure are used in order to calculate CPPG.

The total caval flow pulsatile index (TCPI) is obtained as a percentage of the ratio of the flow rate of the total vein calculated by taking the average in time of the total fluctuating flow component of the total vein. The Stagnant flow index (SFI) is used to determine the stagnant sections inside the cardiovascular system and their sizes quantitatively. When this value is being calculated, the values of the blood resistance time of the cardiovascular circuits are used.

The modeling results in the operation scenario flow, mechanical modeling and analysis system for newborn and fetus cardiovascular repair operations developed according to this invention can be observed via the web by the doctor. All of the data are stored within secure cloud storage systems such that the doctors can access them whenever they wish. Some patient data, operation scenarios, results, growth information, success statistics can be shared via the system developed according to this invention when desired.

The procedures of the operation scenario flow, mechanical modeling and analysis system for newborn and fetus cardiovascular repair operations developed according to this invention are performed by carrying out the following steps:

1) The user connects to the web page of the system via a standard web browser, using his/her PC (1) and connects by entering his/her user name and password

2) The user creates a new patient log. (In this step the identification information of the patient is not entered due to security reasons. The system assigns a suitable patient registration number for the patient. The user/doctor records this patient number to his patient file at the hospital).

3) The user uploads data such as the MRI/CT, echo, ECG, blood pressure results, and weight of the patient to the system.

4) The web system transfers such data to the server (2) via the internet,

5) The server automatically obtains the three dimensional (3D) geometry of the cardiovascular system by means of the previously loaded software,

6) The server sends the 3D geometrical data it has obtained, to the user through the internet and the cardiovascular system is formed if desired by the user by means of the fast prototyping device. (If necessary artificial/organic tissue can be used during this step).

7) The user, uses the web interface in order to examine the geometry from various angles and to carry out changes to the geometry if he/she wishes,

8) The operation scenario that is being planned to be carried out is formed by the user using the geometry. (When the user is carrying this out; he/she can cut the veins from any of the points and shorten them; can add veins and lengthen them; can constrict or enlarge the veins; can by-pass any vein section or ventricle; can connect any of the veins to veins of any thicknesses, from any angle or section he/she wishes)

9) The user notifies via the web that the scenario has been created,

10) The user can create if he/she desires; different scenarios for the same patient,

11) The scenario information that has been created is transmitted to the server through the web.

12) The material mode parameters of the veins from the data belonging to the patient, the blood resistance values, scaling and growth parameters are available automatically in the server and as it can be seen in Figure 2 and Figure 3, the electrical circuit analogy is used. The circulation model and the parameters related to the model are calculated, based on the anatomical characteristics of the disease and the flow and

pressure measurements taken from the cardiovascular system. Electrical circuit analogy is used in the most simple pressure flow model in this method (1D modeling). The parameters belonging to each section during scaling are "non dimensionalized" using Buckingham Pi Theorem. During this stage the parameters $\omega RC, \frac{C_{min}}{C_{max}}, \frac{P_i}{P_0}, \frac{Q}{\omega C P_0}, \frac{E}{\omega C P_0^2}$ are used. Wherein ω: is the pulse frequency, R: is resistance, C: capacitance, min/max: minimum maximum (related to the ventricles); P_i: the blood pressure measurement in a section; P_0: blood circulation pressure, Q: flow, and E: is energy loss. In the method improved by the operation scenario flow and mechanical modeling and analysis system for newborn and fetus cardiovascular repair operations developed according to the present invention, "normal" and "sick/abnormal" value ranges have been determined by taking into consideration the age/weight/clinical characteristics of the patient, type/etc of the diseases, for the non dimensional parameters. These ranges are determined from databases that can additionally be formed from academic and clinical literature.

13) Compartmentalizing method is applied (It is possible to evaluate/examine the cardiovascular system and models modularly and to apply the scaling/growth methods used based on sections. This way, the desired sections can be added to the model as 1D, 2D or 3D images. 1D modeling gives faster results, whereas 3D modeling can provide more realistic results. These preferences, dependent on the data/time have been left to the doctor/user's choice).

14) The parameters, data, geometry, scenarios, model information obtained, are sent to the host computer (3) via the internet.

15) The simulation of the model is performed by means of the software installed on the host computer (3) and the values following operation are obtained haemodynamically.

16) The data obtained are again sent to the server (2) over the internet.

17) The server (2) receives the simulation results, processes them, and produces the blood perfusion flow rate values belonging to the patient using these results. (During this stage the amount of energy that is required for the heart to operate under various scenarios are determined. Moreover various indexes are used in order to calculate the operation scenario performance: Total caval flow pulsatile index (TCPI), is obtained by giving the rate to the total vein flow whose average rate has been taken from the total

vein flow fluctuating component in time. Stagnant flow index (SFI) is used to determine the sections and sizes that are stagnant inside the cardiovascular system. This index is obtained by dividing the stagnant blood volume inside the index conduit to the total volume and then multiplying it by a hundred. When the stagnant blood volume is being calculated, the blood resistance times (RT) of the cardiovascular circuits are used. If the RT is over certain values, this volume is defined as the stagnant volume).

18) The data produced are sent via the internet to the user PC (1).

19) The user receives the values

20) The user creates new scenarios if he/she desires

21) The user logs out of the system.

The operation scenario flow and mechanical modeling and analysis system, for newborn and fetus cardiovascular repair operations developed according to the present invention is characterized in that it provides the following:

- Operation scenario planning for the fetus's
- Operation scenario planning for the newborn
- An operation scenario plan comprising the growth following operation
- Modeling of the fetus and newborn growth together with scaling
- Planning the operation scenarios of the fetus and the new born using the scaling technique and by taking into consideration the growth and the change in time of the tissue characteristics and estimating the change of the operation results together with age
- Modeling the growth of the fetus and the newborn together with the scaling method that is compatible to all circulation systems.

The operation scenario flow and mechanical modeling and analysis system, for newborn and fetus cardiovascular repair operations developed according to the present invention can be used to test the bio inspired designs faster and to apply them to life. The CT/MRI data of various other living beings can also be used instead of using patient data. The changes that may be desired to be carried out on the geometries that shall be obtained can be carried out using the system improved with this invention.

CLAIMS

1- This invention is related to an operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for *newborn and fetus cardiovascular repair operation*s, developed in order to be used for training of doctors and patient specific post surgery performance prediction in hospitals following and prior to, cardiovascular operations within the field of bioengineering in the health sector; characterized in that it comprises as basic elements, a user computer (PC), a server (2) and a host computer (3) and in that it comprises the following steps:

- The user connects to the web page of the system via a standard web browser, using his/her PC (1) and connects by entering his/her user name and password.
- The user creates a new patient log.
- The user uploads data such as the MRI/CT, echo, ECG, blood pressure results, and weight of the patient to the system.
- The web system transfers such data to the server (2) via the internet,
- The server automatically obtains the three dimensional (3D) geometry of the cardiovascular system by means of the previously loaded software,
- The server sends the 3D geometrical data it has obtained, to the user through the internet and the cardiovascular system is formed if desired by the user by means of the fast prototyping device,
- The user, uses the web interface in order to examine the geometry from various angles and carries out changes to the geometry if he/she wishes,
- The operation scenario that is being planned to be carried out is formed by the user using the geometry,
- The user notifies via the web that the scenario has been created,
- The user can create if he/she desires; different scenarios for the same patient,
- The scenario information that have been created is transmitted to the server through the web,
- The server (2) stores the patient data and operation scenarios,
- The compartmentalizing method is applied,

- All of the parameters, data, geometries, scenarios, model information that have been obtained is sent to the host computer (3),
- The simulation (analysis) of the model is performed by means of the software that has been loaded into the host computer (3) and the values following the operation are obtained haemodynamically,
- The data that has been obtained is sent to the server (2) via the internet,
- The server (2) obtains simulation data, processes said data, and from this point of view produces blood perfusion and flow rate values belonging to the patient
- The data produced is sent to the user PC (1) via the internet,
- The user receives the data,
- The user forms new scenarios again if he/she desires,
- The user logs out of the system.

2- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claim 1, characterized in that; the 3D geometry data obtained by the server (2), is sent to the user via the internet, and artificial and organic tissues are used during the stage of formation of the cardiovascular system by means of the fast prototyping device according to the preferences of the user.

3- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claim 1, characterized in that; during the stage of forming the operation scenario that he/she plans to carry out, using the geometry, the user can cut the veins from any section he desires and shorten them, the user can add and extend veins, the user can contract or expand the veins, can by-pass any of the veins or ventricles, and can connect any of the veins from any angle or section to veins of any thickness.

4- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claim 1, characterized in that; during obtaining the material model parameters of the veins from the data belonging to the patient, the blood resistance values, and growth parameters the scaling and growth parameters are available automatically in the server (2) and electrical circuit analogy is used; wherein the circulatory model of the patient is created based on the anatomical features of the disease, the pressure and flow rate measurements taken from the cardiovascular system; and the parameters related to the model are calculated.

5- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claims 1 or 4, characterized in that; the parameters for each section are non dimensionalized using the Buckingham Pi Theorem during scaling at the stage of obtaining the material model parameters of the veins, blood resistance values and growth parameters belonging to the patient that are automatically available in the server (2).

6- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claims 1 or 4, characterized in that; ωRC, $\frac{C_{min}}{C_{max}}$, $\frac{P_i}{P_0}$, $\frac{Q}{\omega C P_0}$, $\frac{E}{\omega C P_0^2}$ parameters are used wherein ω: is the pulse frequency, R: is resistance, C: capacitance, min/max: minimum maximum related to the ventricles; P_i: is the blood pressure measurement in a section; P_0: is the blood circulation pressure, Q: is flow, and E: is energy loss, during the stage of obtaining the material model parameters of the veins, blood resistance values and growth parameters belonging to the patient that are automatically available in the server (2).

7- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claims 1 or 4, characterized in that; "normal" and "sick/abnormal" value ranges are determined by taking into consideration the age/weight/clinical characteristics of the patient, type/etc of the diseases, for the non dimensional parameters and that these ranges are determined from academic and clinical literature and databases, during the stage of obtaining the material model parameters of the veins, blood resistance values and growth parameters belonging to the patient that are automatically available in the server (2).

8- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claim 1, characterized in that; during the stage of applying the compartmentalizing method, the sections can be added to the model according to the preferences of the doctor as 1D, 2D or 3D images.

9- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claim 1, characterized in that; the amount of energy required by the heart to operate under various scenarios are determined during the stage where the server (2) receives and processes the simulation results, and produces the flow rate values and blood perfusion belonging to the patient using said results.

10- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claims 1 or 9, characterized in that; the total caval flow pulsatile index (TCPI), which is obtained by giving the rate to the total vein flow whose average rate has been taken from the total vein flow fluctuating component in time is used in order to calculate the operation scenario performance during the stage where the server (2) receives and processes the simulation results, and produces the flow rate values and blood perfusion belonging to the patient using said results.

11- An operation scenario flow, mechanical modeling and analysis system comprising web based, (i) growth (ii) scaling and (iii) quality control aimed, patient based fast prototyping functions, for newborn and fetus cardiovascular repair operations, according to claims 1 or 9, characterized in that; the stagnant flow index (SFI) is used which is obtained by dividing the stagnant blood volume inside the index conduit to the total volume and then multiplying it by a hundred; in order to quantitatively determine the locations and sizes of the stagnant sections inside the cardiovascular system, to calculate the operation scenario performance at the stage where the server (2) receives and processes the simulation results, and produces the flow rate values and blood perfusion belonging to the patient using said results.

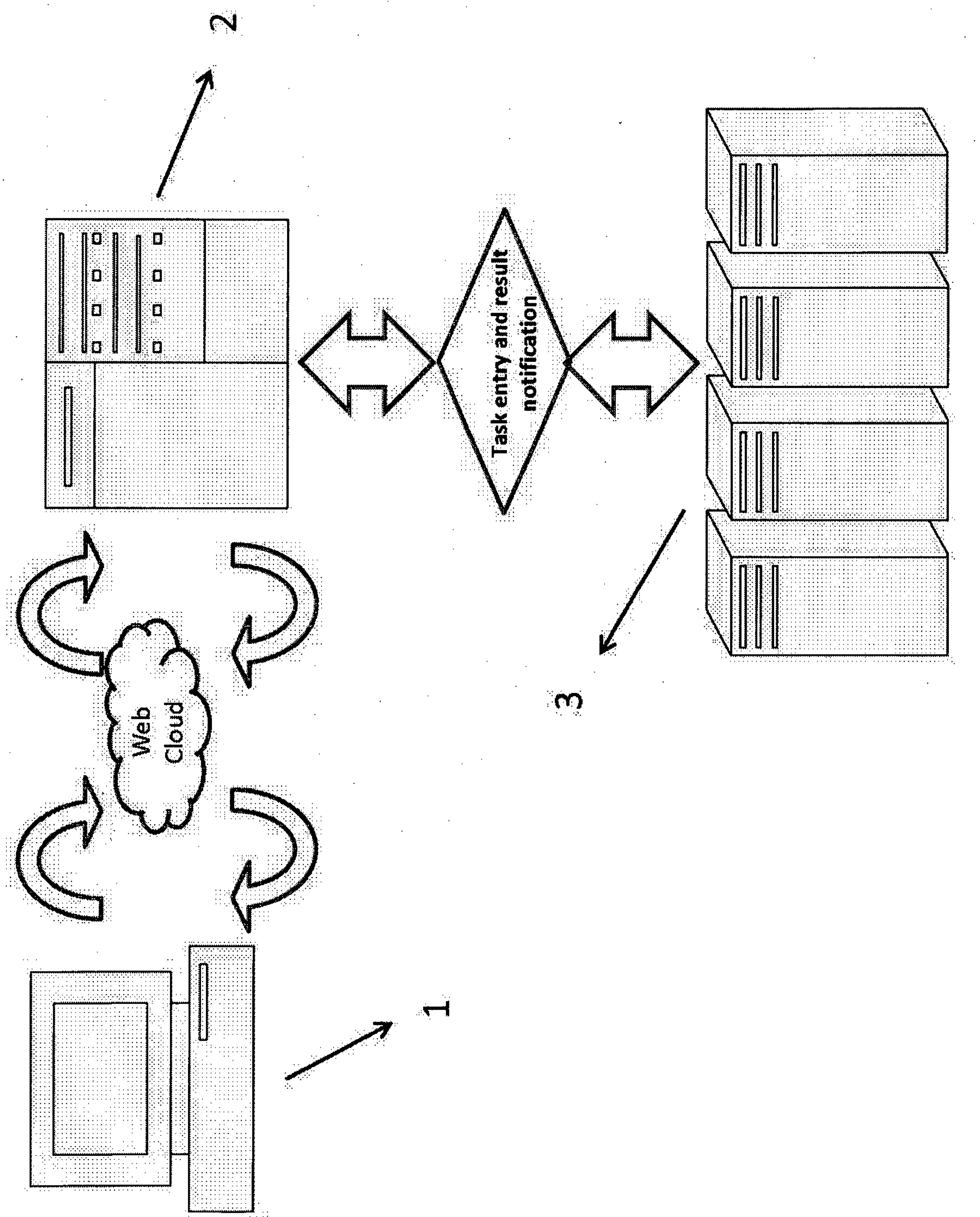

Figure -1

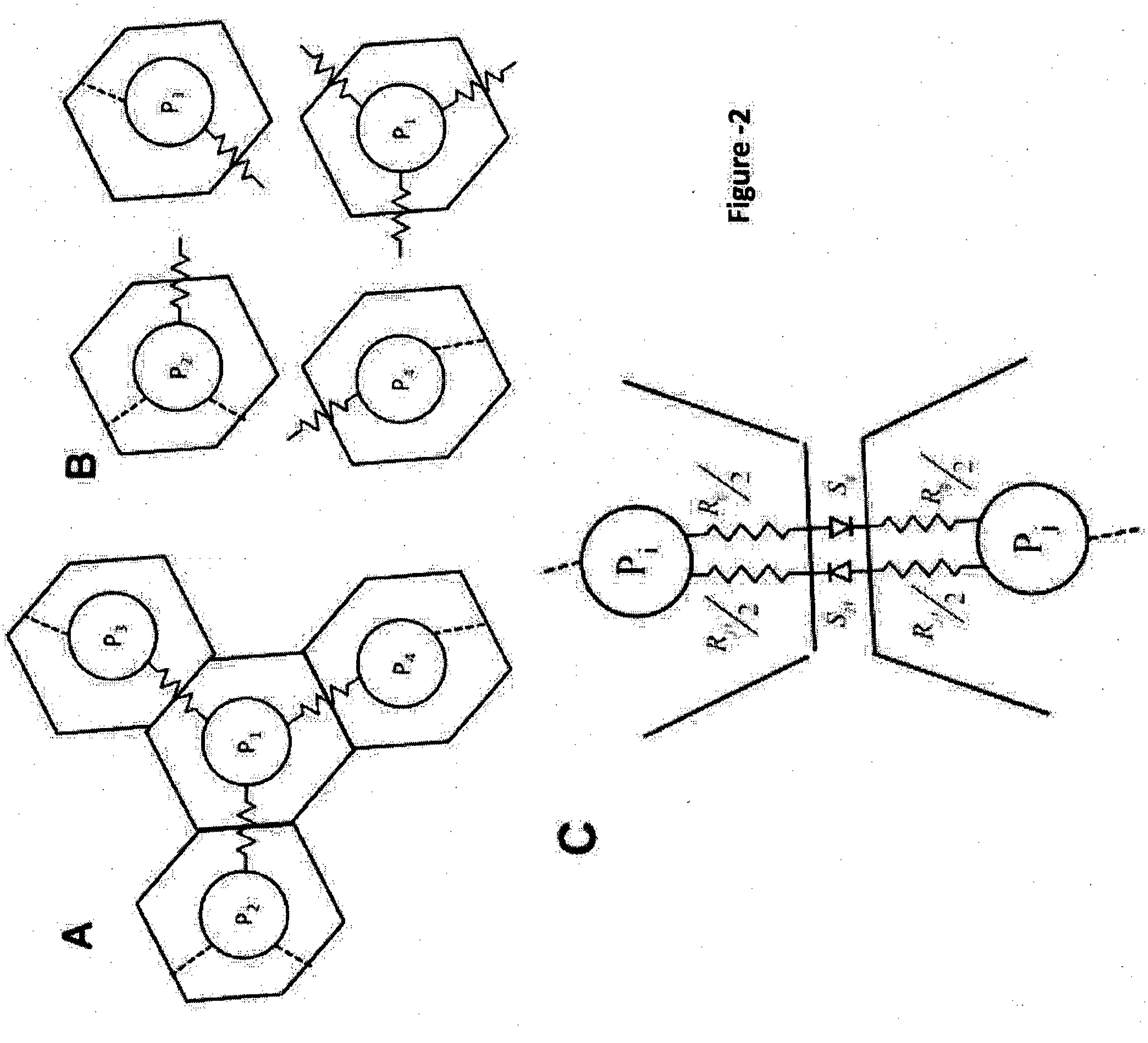

Figure -2

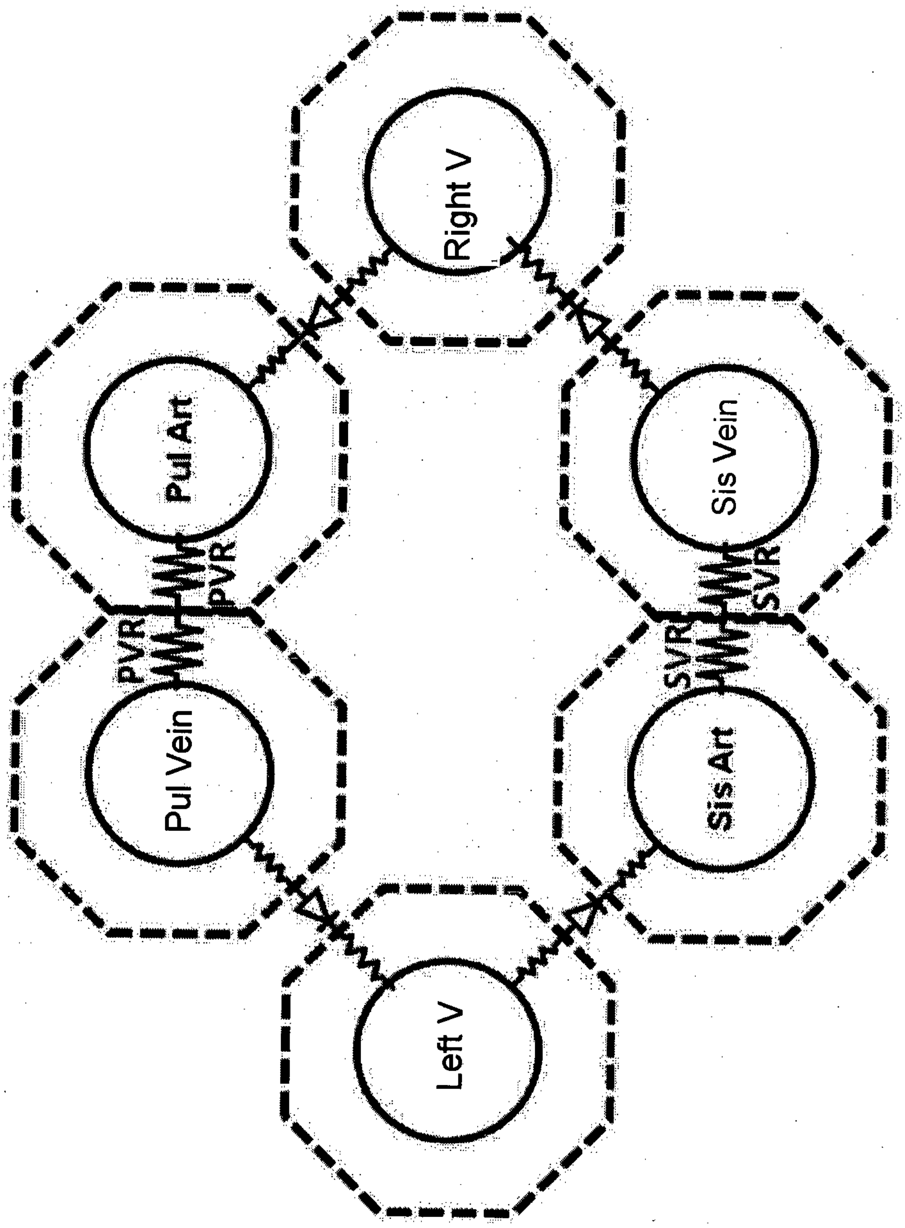

Figure -3

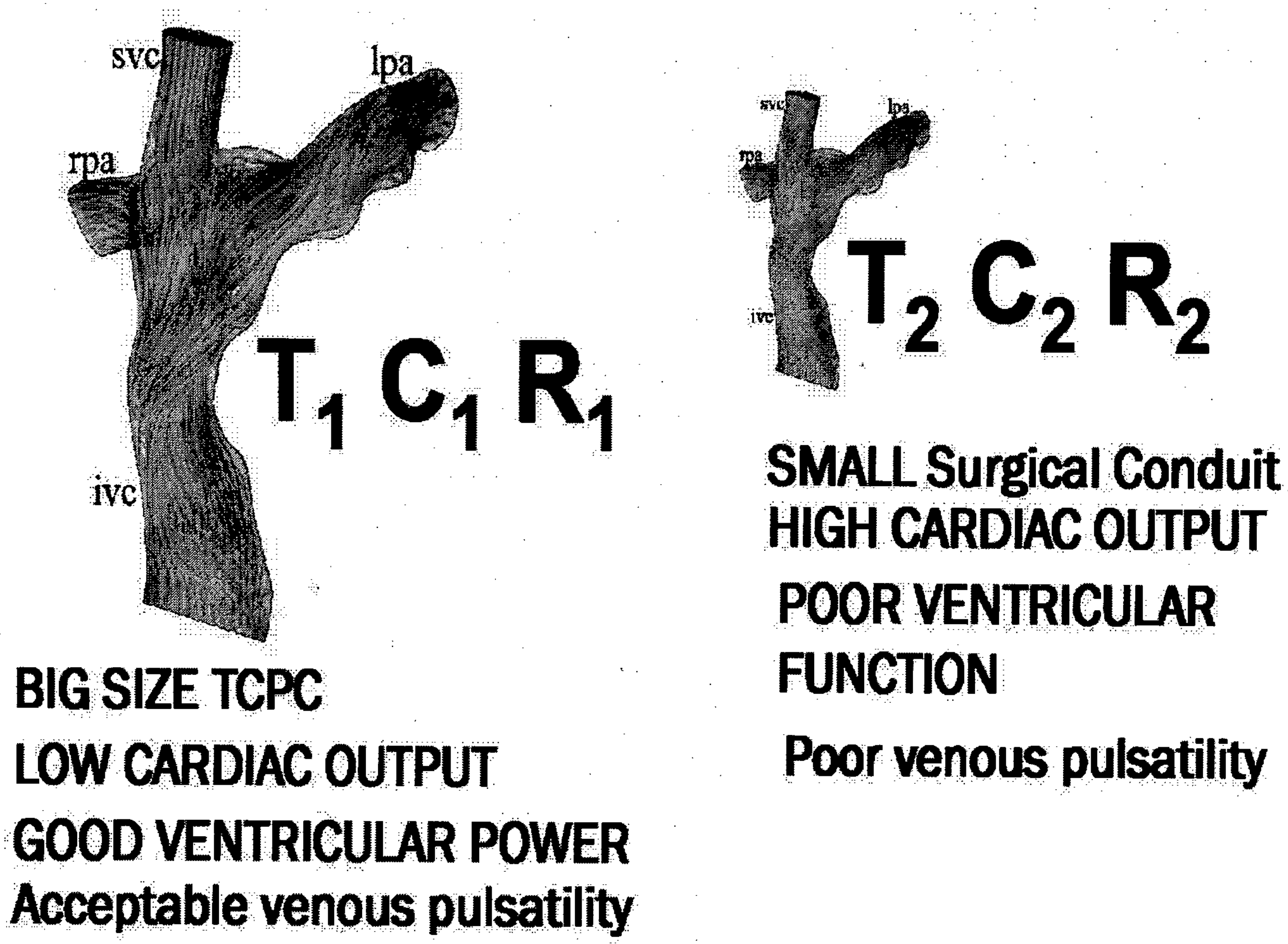
svc
lpa
rpa
ivc
T1 C1 R1
BIG SIZE TCPC
LOW CARDIAC OUTPUT
GOOD VENTRICULAR POWER
Acceptable venous pulsatility
svc
lpa
rpa
ivc
T2 C2 R2
SMALL Surgical Conduit
HIGH CARDIAC OUTPUT
POOR VENTRICULAR
FUNCTION
Poor venous pulsatility

Figure -4

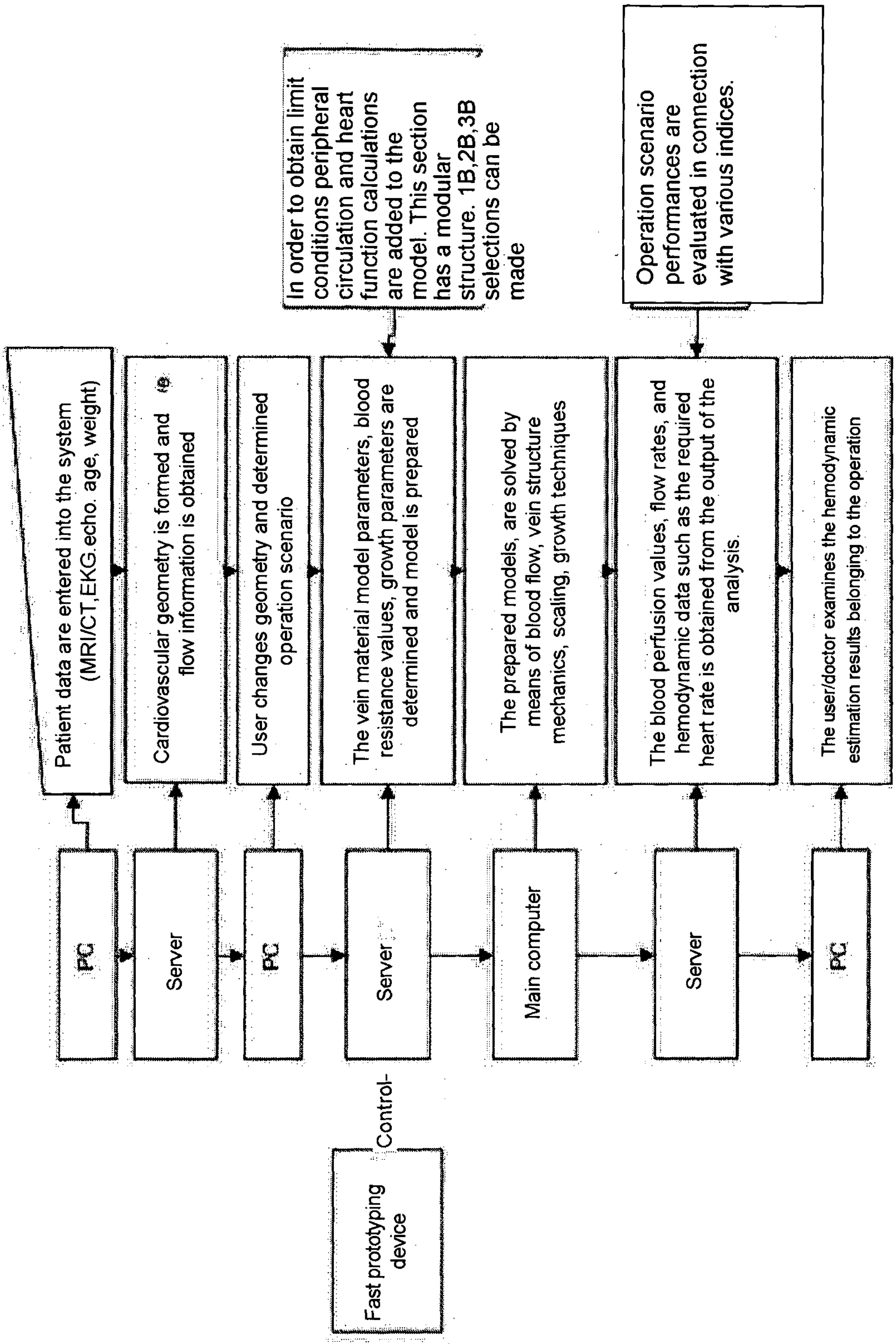
PC
Patient data are entered into the system (MRI/CT,EKG,echo. age, weight)
Server
Cardiovascular geometry is formed and flow information is obtained
PC
User changes geometry and determined operation scenario
Server
The vein material model parameters, blood resistance values, growth parameters are determined and model is prepared
In order to obtain limit conditions peripheral circulation and heart function calculations are added to the model. This section has a modular structure. 1B,2B,3B selections can be made
Fast prototyping device
Control-
Main computer
The prepared models, are solved by means of blood flow, vein structure mechanics, scaling, growth techniques
Server
The blood perfusion values, flow rates, and hemodynamic data such as the required heart rate is obtained from the output of the analysis.
Operation scenario performances are evaluated in connection with various indices.
PC
The user/doctor examines the hemodynamic estimation results belonging to the operation

Figure -5

INTERNATIONAL SEARCH REPORT

International application No
PCT/TR2014/000263

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06F19/00
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)
G06F G06Q

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, 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	WO 2012/021307 A2 (HEARTFLOW INC [US]; TAYLOR CHARLES A [US]; FONTE TIMOTHY A [US]; CHOI) 16 February 2012 (2012-02-16) paragraph [0002] - paragraph [0288] claim 109 -----	1-11
X	ONUR DUR ET AL: "Pulsatile venous waveform quality affects the conduit performance in functional and "failing" Fontan circulations", CARDIOLOGY IN THE YOUNG, vol. 22, no. 03, 19 October 2011 (2011-10-19), pages 251-262, XP055171793, ISSN: 1047-9511, DOI: 10.1017/S1047951111001491 the whole document -----	1-11

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[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 application or patent but published on or after the international filing date

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"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
26 February 2015	09/03/2015

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	Darlagiannis, V

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	US 2007/014452 A1 (SURESH MITTA [US] ET AL) 18 January 2007 (2007-01-18) the whole document -----	1-11
X	Andres Ceballos: "A MULTISCALE MODEL OF THE NEONATAL CIRCULATORY SYSTEM FOLLOWING HYBRID NORWOOD PALLIATION", , 1 August 2011 (2011-08-01), XP055170938, Retrieved from the Internet: URL:http://etd.fcla.edu/CF/CFE0004037/Ceballos_Andres_201108_MS-1.pdf [retrieved on 2015-02-19] the whole document -----	1-11
X	WO 2013/071219 A1 (SIEMENS CORP [US]; SHARMA PUNEET [US]; ITU LUCIAN MIHAI [US]; GEORGESC) 16 May 2013 (2013-05-16) the whole document -----	1-11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/TR2014/000263

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012021307 A2	16-02-2012	AU 2011289715 A1	07-03-2013
		CA 2807586 A1	16-02-2012
		CN 103270513 A	28-08-2013
		EP 2499589 A1	19-09-2012
		EP 2538361 A2	26-12-2012
		EP 2538362 A2	26-12-2012
		EP 2845537 A2	11-03-2015
		EP 2849107 A1	18-03-2015
		JP 2013534154 A	02-09-2013
		JP 2014079649 A	08-05-2014
		KR 20130138739 A	19-12-2013
		KR 20140071495 A	11-06-2014
		US 2012041318 A1	16-02-2012
		US 2012041319 A1	16-02-2012
		US 2012041320 A1	16-02-2012
		US 2012041321 A1	16-02-2012
		US 2012041322 A1	16-02-2012
		US 2012041323 A1	16-02-2012
		US 2012041324 A1	16-02-2012
		US 2012041735 A1	16-02-2012
		US 2012041739 A1	16-02-2012
		US 2012053919 A1	01-03-2012
		US 2012053921 A1	01-03-2012
		US 2012059246 A1	08-03-2012
		US 2012150516 A1	14-06-2012
		US 2013054214 A1	28-02-2013
		US 2013064438 A1	14-03-2013
		US 2013066618 A1	14-03-2013
		US 2013151163 A1	13-06-2013
		US 2013211728 A1	15-08-2013
		US 2014107935 A1	17-04-2014
		US 2014148693 A1	29-05-2014
		US 2014155770 A1	05-06-2014
		US 2014207432 A1	24-07-2014
		US 2014222406 A1	07-08-2014
		US 2014236492 A1	21-08-2014
		US 2014243663 A1	28-08-2014
		US 2014247970 A1	04-09-2014
		US 2014249791 A1	04-09-2014
		US 2014249792 A1	04-09-2014
		US 2014348412 A1	27-11-2014
		US 2014355859 A1	04-12-2014
		WO 2012021307 A2	16-02-2012
US 2007014452 A1	18-01-2007	US 2007014452 A1	18-01-2007
		WO 2007090093 A2	09-08-2007
WO 2013071219 A1	16-05-2013	CN 104081401 A	01-10-2014
		EP 2776960 A1	17-09-2014
		JP 2014534889 A	25-12-2014
		KR 20140091741 A	22-07-2014
		US 2013132054 A1	23-05-2013
		WO 2013071219 A1	16-05-2013