Claims

1. A computer-implemented method (100) for predicting and/or simulating a plurality of temperatures in a human or animal body when said body is in a controllable environment, said controllable environment comprising controllable heating and/or cooling means for bringing a core body temperature of said body to a predetermined target temperature, the method comprising:
   - receiving (101) as input at least one property of said body obtained by measurements of the body, said at least one property of said body comprising anthropometric data such as weight, volume, dimensions, and/or composition of the body,
   - calculating (102) at least one body-specific parameter of a bioheat model based on the at least one property of the body, said at least one body-specific parameter comprising a thermal resistance value,
   - obtaining (103) at least one environment-specific parameter that is indicative of at least one thermal property of said controllable environment and/or of at least one property of a thermal exchange between said body and said controllable environment, and
   - calculating (104) said temperatures in the body by numerically solving said bioheat model taking said body-specific parameters and said environment-specific parameters into account,

   wherein said bioheat model comprises a plurality of equations representative of an equivalent thermal circuit (50) for modeling heat flows in the body and between the body and the controllable environment,

   said equivalent thermal circuit comprising a blood compartment (51) and a plurality of anatomical segments, the plurality of anatomical segments comprising at least a lower extremity segment (52), an upper extremity segment (53), a trunk segment (54) and a head segment (55),

   wherein each of the anatomical segments (52,53,54,55) comprises a plurality of compartments, the plurality of compartments comprising at least one interior compartment (56; 561,562,563) representative of a core and/or bone part of the anatomical segment, at least one intermediate compartment (57; 571,572) representative of a muscle and/or fat part of the anatomical segment and an exterior compartment (58) representative of a skin part of the anatomical segment,

   wherein the at least one interior compartment of the at least one trunk segment (54) comprises a plurality of organ compartments (561,562) representative of respectively at least two internal organs,

   wherein said at least two organ compartments (561,562) are connected in parallel in said equivalent thermal circuit,

   wherein said plurality of equations represent each of the anatomical segments (52,53,54,55) by a plurality of compartments with index i, each compartment comprising one or more nodes with index j, and the plurality of equations comprise:

   for the blood compartment, an equation of the form:

$$\sum_{i=1}^{N}\sum_{j=1}^{M_i} R_{b\to i,j}^{-1}.\left(T_{i,j}-T_b\right)+Q_{in}=\rho_b V_b c_b \frac{\partial T_b}{\partial \tau}$$

for each intermediate compartment, an equation of the form:

$$R_{b\to i,j}^{-1}.\left(T_b - T_{i,j}\right) + Q_{cond}(i,j-1) - Q_{cond}(i,j) + Q_{met}(i,j) = \rho_{i,j}V_{i,j}c_{i,j}\frac{\partial T_{i,j}}{\partial \tau}$$

for each exterior component, an equation of the form:

$$R_{b\to i,j}^{-1}.\left(T_b - T_{i,j}\right) + Q_{cond}(i,j-1) + Q_{met}(i,j) - Q_{evap}(i) - Q_{rad} - Q_{conv} - Q_{cond,E,i} = \rho_{i,j}V_{i,j}c_{i,j}\frac{\partial T_{i,j}}{\partial \tau}$$

and for each interior compartment that is an organ/remainder compartment, an equation of the form:

$$R_{b\to i,j}^{-1}.\left(T_b - T_{i,j}\right) - Q_{cond}(i,j) + \cdots + Q_{met}(i,j) = \rho_{i,j}V_{i,j}c_{i,j}\frac{\partial T_{i,j}}{\partial \tau}$$

where $R_{b\to i,j}$ is the thermal resistance between the blood compartment and a node (i,j),

where $T_{i,j}$ is the temperature of node (i,j) and T_b, is the temperature of the blood compartment,

where Q_{in} is an exogenous heating term,

where $Q_{cond}(i,j)$ is the heat flow by conduction to the next node,

where $Q_{met}(i,j)$ is the metabolic heat generated in the node (i,j),

where $Q_{evap}(i)$ is an evaporative heat loss term for compartment i,

where Q_{rad} is a term for radiative heat exchange with the environment,

where Q_{conv} is a term for convective heat exchange with the environment,

where $Q_{cond,E,i}$ is a term for conductive heat exchange with the environment in compartment i,

where $\rho_{i,j}$ is the density of node (i,j) and ρ_b is the density of blood,

where $V_{i,j}$ is the volume of node (i,j),

where $\omega_{i,j}$ is the blood perfusion rate of node (i,j),

where c_b is the specific heat of blood,

where $\frac{\partial .}{\partial \tau}$ is a partial derivative, or a discrete numeric approximation thereof, with respect to time τ,

and

wherein said at least one environment-specific parameter comprises one or more of: a value representative of a convection parameter and/or a temperature of an air flow to which the body is exposed in said environment, a value representative of a temperature of surroundings of the body in said environment for use in calculations of radiative heat transport, a value indicative of a temperature of an actively heated and/or cooled surface contacting at least part of the body in said environment, a value indicative of a temperature and/or a humidity of air inspired by the body in said environment, and a value indicative of a controllable thermal property of a heater and/or cooler for heating and/or cooling blood of the body in said environment.

2. The method of claim 1, wherein said obtaining (103) of the at least one environment-specific parameter comprises obtaining a plurality of different values of the or each environment-specific parameter, and performing the step of calculating (104) the temperatures for each of said different values to determine changes in said temperatures with respect to said at least one environment-specific parameter.

3. The method of claim 2, wherein said obtaining (103) of the at least one environment-specific parameter comprises adjusting (105) a previous value of said plurality of different values for which said temperatures were calculated (104) to determine a next value in said plurality of different values for which said temperatures are calculated (104), in order to optimize one or more of said temperatures toward one or more corresponding target temperatures and/or to meet one or more constraints on said temperatures.
4. The method of any of the previous claims, comprising receiving (106), as input, sensor data from one or more temperature sensors on or in the body, and taking said sensor data into account when numerically solving said bioheat model.
5. The method of any of the previous claims, wherein said at least one trunk segment (54) comprises an abdomen segment and a thorax segment, and wherein said plurality of organ compartments (561,562) are interior compartments of the abdomen segment.
6. The method of any of the previous claims, wherein said calculating (102) of the at least one body-specific parameter comprises determining values representative of thermal conduction between at least some of the compartments of said model based on said at least one property of the body.
7. The method of claim 1, further comprising:
   - calculating a value representative of a rate of convective heat exchange for each exterior compartment (58) based on the at least one value representative of the convection parameter and/or the temperature of the air flow to which the body is exposed in said environment, and/or
   - calculating a value representative of a rate of radiative heat exchange for each exterior compartment (58) based on the at least one value representative of the temperature of the surroundings in the environment, and/or
   - calculating a value representative of a rate of conductive heat exchange for an exterior compartment (58) based on the at least one value indicative of the temperature of the actively heated and/or cooled surface, and/or
   - calculating a value representative of a rate of heat exchange by respiration based on the at least one value indicative of the temperature and/or the humidity of the inspired air.
8. The method of claim 7, wherein calculating any of the values representative of the rate of convective and/or radiative and/or conductive heat exchange takes a surface area into account, said surface area being obtained or calculated from the at least one property of the body received (101) as input.
9. The method of any of the previous claims, wherein said at least one interior compartment of said trunk segment (54) that comprises the at least two organ compartments (561,562) also comprises a remainder compartment (563) representative of the remainder of the interior part of said trunk segment, said remainder compartment (563) and said at least two organ compartments (561,562) being connected in parallel in said equivalent thermal circuit (50).

10. A method (200) comprising: measuring (201) at least one property of a human or animal body, providing (202) the at least one property of the body as input to a computer-implemented method (100) in accordance with any of the previous claims, and performing the computer-implemented method (100).
11. A device (80) for carrying out the method according to any of claim 1–9, the device (80) comprising:
    - an input (81) for carrying out the receiving step, and
    - a processor (82),

    wherein said processor is adapted for carrying out:
    - said calculating of said at least one body-specific parameter,
    - said obtaining of said at least one environment-specific parameter, and
    - said calculating of said temperatures in the body by numerically solving said bioheat..
12. A hyperthermia treatment planning workstation, comprising a device in accordance with claim 11.
13. A hyperthermia treatment system, comprising a device in accordance with claim 11, a controllable environment comprising controllable heating and/or cooling means for bringing a core body temperature of said animal or human body to a predetermined target temperature, and a plurality of temperature sensors for measuring temperatures on or in the body,

    wherein said device is adapted for receiving sensor data from said plurality of temperature sensors, taking said sensor data into account for calculating said temperatures in the body, and controlling said controllable heating and/or cooling means in response to said calculated temperatures in the body.
14. A computer-program product for, when executed on a computing device, performing a method in accordance with any of the claims 1 to 9.