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Heat exchange during cardiopulmonary bypass

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1. Introduction: During cardiac surgery, many procedures require the support by heart–lung machines. Procedures are carried out under mild or moderate hypothermia. Today, hypothermia is induced via the heater–cooler device integrated into the oxygenator. In this device, a water circuit parallels the blood circuit. The blood temperature is adjusted via the water temperature, which is controlled manually by the perfusionist. In this paper, we propose a model for the heat exchange in the patient and in the extracorporeal circuit that can serve as a basis for the development of an automatic control of the heater–cooler device. Further on this control shall be part of an automatic control system for the heart–lung machine.

2. Methods: The model for heat exchange in the patient and in the extracorporeal circuit consists of five subsystems: the model of the heater–cooler device, the model of the heat exchanger in the oxygenator, the model of the heat exchange between the blood and the organs and tissues, the model of the heat exchange between the body surface of the patient and the environment, and the model of the patient's thermoregulation. The model of the heat exchange between the blood and the organs and tissues is a two-compartment model. The model of the patient's thermoregulation considers the special conditions during an open-heart surgery, especially the effects of anaesthesia on the patient's heat production. External heating devices apart from the heater–cooler device are not included in the model yet. The model is fitted to the condition of complete bypass, so the time periods of partial bypass at the beginning and the end of surgery are not represented.

3. Results: For the purpose of analysing heat exchange during cardiopulmonary bypass, temperature curves during cardiopulmonary bypass were recorded. Therefore, water circuit temperature, arterial and venous blood temperature (in- and output of the oxygenator), body core temperature and room temperature during an experimental set-up were recorded every 20 s and compared with the simulations. The simulation results for blood temperature and water temperature agreed well with the experimental data, but the patient's thermoregulation is not appropriately represented yet.

4. Discussion: Modelling the patients' heat exchange will be important for the further development of control algorithms used in cardiopulmonary bypass. Control algorithms might improve the reproducibility and safety of cardiopulmonary bypass. Our model shows good agreement with the heat exchange under standard conditions. Models for the heat exchange need to encounter the non-physiologic situation during cardiopulmonary bypass and anaesthesia, but more detailed models for the human thermoregulation itself might be avoided. Different perfusion regimes and cannulation techniques have to be considered. Validation of the model in controlled experimental set-ups will be required.

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