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Mini Review

Application of model of heat exchange for miocardium provided stationary convection laminar flow

Abstract

Intraoperative infrared thermography (IRT) of the heart attracted the attention of scientists and clinicians for many years. IRT thermography of the heart in the experiments confirmed the importance of the diagnostic information obtained. The aim was expansion of available information about protection of the myocardium and the state of its vascular bed using heat transfer model based on the pericardial temperature propagation in circumstances of CPB.

Keywords: thermogram myocardium, model, temperature distribution, MSC sinda

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Introduction

IRT until now it is not widely used in the practice cardiac surgery because of many reasons: the quality of information is limited by exposition distance, temperature artifacts of the air, accessible visualization of the heart surface, available exposure time and other disturbances. The IRT method was used to assess the degree of cooling of the human heart and brain during cardio-surgical the CPB conditions.[1] The conducted researches proposed new in medical applications technique as a promising diagnostic tool. The method is completely non-invasive and handy, which gives a qualitative overview of the investigated heart surfaces, as well as an objective quantitative result of temperature measurement. The technology of the IRT method makes it available for many applications in surgery, including screening of affected vessels and tissues.

For assess the state of the blood vessels and tissues, the most important question is to obtain qualitative information about the coronary flow. The determination of the state of the coronary vessels was not so easy to solve for the not visible side of the heart, provided that the evaluation is known from the only visible side of the heart in CPB conditions. To obtain data on the coronary flow, a 3D model of heat exchange in the myocardium is constructed. The model uses modern information technology in MSC Sinda, which provide new solutions for heat exchange in tissues. The results obtained can be useful for monitoring heart temperature during CPB.

Description of the numerical model for heart transfer

A numerical model was of the heart permitted to identify different zones with specific morphology. To determine the thermodynamic characteristics of the myocardium for farther modelling, an inverse thermo-electrodynamic problem was solved in conditions of radiofrequency catheter ablation in more than 210 patients (3227 applications) (Figure 1 & Table 1).[2]

Thermal conductivity coefficient for all zones was in ranges from 0,495 to 0,506 W/(K x m).[2] It allows to estimate the inhomogeneity of the process of temperature propagation and the quantitative values of the temperature gradients on the surface of the myocardium in CPB conditions on the basis of sequential recording in time of thermal images of the heart. The model of heat exchange for the local area of the myocardium is built for two conditions of heat transfer: heat conduction and free convection for the myocardial area, which is depleted of the coronary vessels and the myocardial region with double the density distribution of the coronary vessels in the myocardium, relative to the case of depleted distribution.

Table 1 Mass heat capacity of different myocardial zones ($p<0.05$)[2]

Myocardial zone	Wall Thickness, mm	Mass heat capacity, J/(K x kg)
Right atrium	3	31,2
Atrial ventricular groove	8	18,7
Atrial septum	1,5	15,1
Left atrium	3	18,8
L & R Ventricles	10	29,7

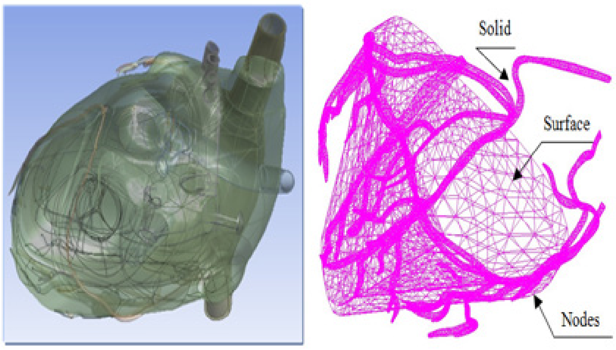

Figure 1 A numerical model of the heart permitted to identify different zones with specific morphology.

Implementation of heat transfer model for process myocardium cooling is executed in the Sind MSC system. On the final step process myocardium cooling in establishing the heat balance the temperature difference at the boundary between the myocardium and coronary vessels not more than 0,5°C. However, in the areas of the myocardium that are removed from the coronary perfusion the temperature difference exceeds 1,0°C. Thus, a discrete 3D-model of heat transfer in the layer structure of the myocardium and coronary vessels allows us to investigate the process of hypo- and hyperthermia of the heart during cardiopulmonary bypass.

The values of the temperature gradients on the heart surface during perfusion and cardioplegia during cooling of the heart, after cooling and during warming of the heart are a reliable indicator that can be used as a diagnostic criterion for assessing the state of the flow in the vessels and determining the ischemic areas in the myocardium. The common approach for discriminating temperature gradient on thermal image from the background frames is background subtraction. The idea is to subtract the current image from a reference image, which is acquired from a static background of thermal image during a period of time. The essence of the method is to determine the temperature gradients between blood in the vessels and the myocardium at successive instants of time when warming or cooling in the conditions of CPB (Figure 2a). For identification of involved artery the method of image processing for contouring of coronary vessels was used (Figure 2b).

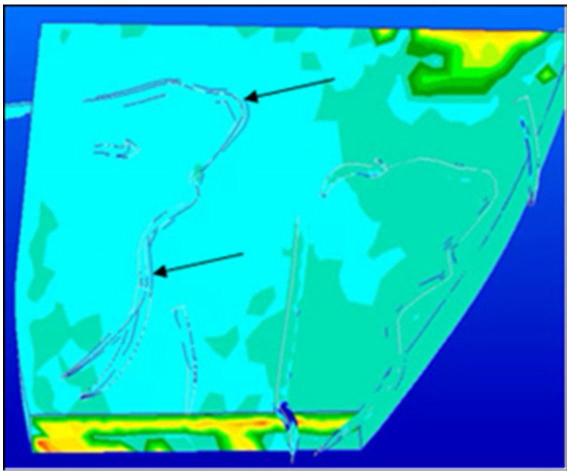

Figure 2a Visualizing the contours of the vessels on the model.

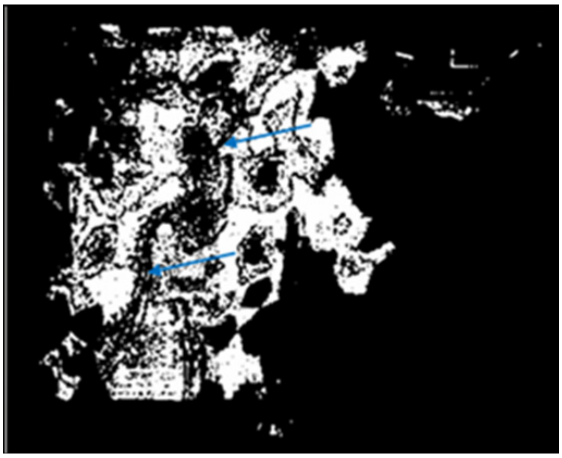

Figure 2b Visualizing the contours of the vessels on the model.

Application of model of heat exchange

In 12 cases of aortic and heart valves surgery, methods of the heart IRT control was used with FLIR i7 thermograph in spectral range of 8-14 microns on the basis of not cooled matrix of 320 × 240 elements size and with temperature sensitivity of 0.1°C. The method of comparative analysis for thermograms of myocardium allows to obtain the thermal picture for open heart in ranges from $+4^0$C up to + 37^0C in conditions of CPB in ranges +28°C – +37°C.

Application of model of heat exchange provided stationary convection laminar flow across the border surface of blood and myocardium gives the numerical description of the processes of heat transfer at the boundary between the myocardium and coronary vessels. The use of discrete physical models of heat exchange for the myocardial and coronary vascular system makes it possible to calculate the magnitude of the inhomogeneity of the temperature field on the surface of the myocardium and thereby determine the contours of the areas of ischemia in the heart. Comparison of the model with real patients IRT shows that this method can provide additional important information regarding temperature and vascular uniformity in time of myocardial cooling and heating (Figure 3).[3-5]

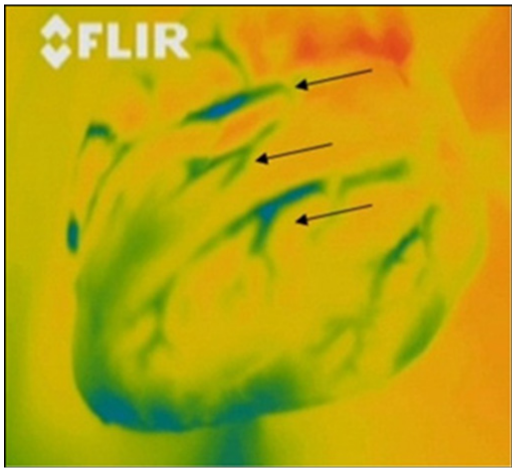

Figure 3 Visualizing the contours of the vessels of myocardium in situ.

Conclusion

The IRT method allowed the evaluate the dynamics of the cooling process and warming the heart and determine the temperature gradient at the surface of the myocardium. Image processing and modelling the registered thermograms of hypo- and hyperthermia showed the propagation of temperature profiles, which enables diagnosis of ischemic lesions in the myocardium because of temperature gradients and to identify involving artery. In addition, the temperature gradient and the dynamics of temperature changes on the surface of the myocardium during cooling and warming of the heart can be used to assess the state of the coronary vessels, and also as a diagnostic criterion for determining ischemic areas to CPB conditions on the surface of the myocardium.

Acknowledgments

None.

Conflicts of interest

There were no financial interest or conflict of interest.

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