THERMOGRAPHIC AND ELECTRICAL MEASUREMENTS FOR CARDIAC SURGERY INSPECTION

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Abstract - **The aim of the paper is to analyze validity of new methods applicable for cardiac surgery intra-operation inspection. In vivo measurements on pigs using passive and active thermography as well as electroimpedance spectroscopy applied to investigation of the heart tissue properties during open chest cardiac surgery are related. The measurement results clearly show that each of proposed modalities is giving different information valuable for evaluation of the heart muscle biological properties. This information may have very high importance in terms of intra-operation inspection as well as for decisions of proper medical interventions. Series of cardiac operations on anaesthetized pigs involving controlled heart infarct followed by extensive histopathologic study allowed to made objective evaluation of the value of the discussed methods.**

Keywords - **Thermography, bio-electroimpedance spectroscopy, heart inspection, cardio-surgery**

I. INTRODUCTION

One of the main goals of using modern technology for inspection of open-heart surgery is to decrease the number of post-operation complications and mortality. We are concentrating our notice on thermographic methods [1,2,3] and on electroimpedance measurement instrumentation [4]. Those are non-invasive and safe methods, developed also in other laboratories [5,6,7,8,9]. But even *in vitro* and *in vivo* experiments on human tissues show high practical importance of the methods still reliable reference data are necessary for proving validity of those techniques.

Here we discuss some *in vivo* experiments on domestic pigs followed by full histopathologic study of inspected hearts to compare the measured data with the reliable knowledge of the state of a tested heart muscle.

II. METHODOLOGY

There is no other animal having the heart and the circulation system so close to the human than domestic swine. Experiments on pigs were carried out according to the permission of the Local Committee for Ethics and Good Practice. Experiments on 5 pigs of average weight 32±3 kilograms are here reported. Blood pressure, heart rate, body temperature, and heart temperature of a tested pig were measured simultaneously. The pigs were intubated after induction. Then, Fentanyl and NO continued the anesthesia. The thorax cavity was opened using the sternum approach as it is shown in Fig.1. Two parts of the pericardium were opened out. By clamping the left descending artery (LAD) the myocardial infarction was induced. The artery was clamped in the proximity of the first diagonal artery as it is shown in Fig. 2a. The infarction zone around the left ventricle wall, shown in the cross-section - Fig. 2b, was examined over a period of about four hours after which the pigs died, usually as a result of arrhythmia.

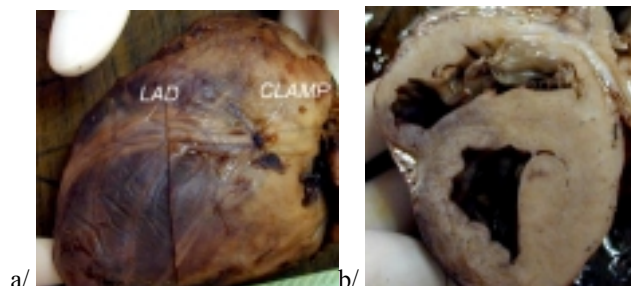Fig.1. A view of the open-heart operation theater.

Fig.2. The heart – a/ indicated are the LAD and the clamp; b/ the cross-section is showing the infarct area - left side.
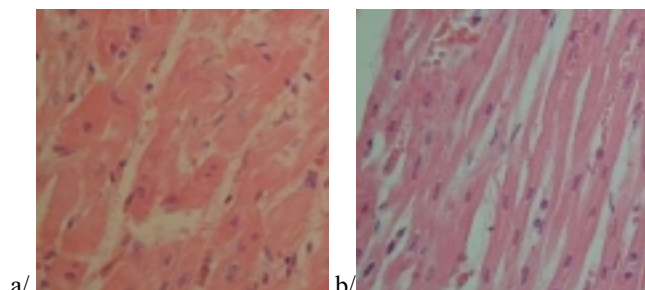

Fig.3. Pig's heart muscle - the micro-histopathologic pictures showing the healthy tissue a/ and cell necrosis b/.

The effect of the infarct on the tissue structure was examined basing on micro-histopathologic investigation as it is shown in Fig. 3. The destroyed tissue is from the left ventricle wall – this region may be seen on the left bottom side in Fig. 2b.

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Abstract

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Instrumentation

Thermography

The basic measurement set-up used in thermographic experiments consists of the Agema THV 900 thermographic camera system. For the dynamic active thermography experiments additionally several heat sources; the optical power meter R-752 - Terahertz Technologies; a control unit for driving the system and a specially designed meter of tissue thermal properties to determine the contact reference data are in use. The hardware allows generation of heating pulses using a set of halogen lamps with possibility of setting the duration ($t_I > 10ms$) of each impulse and the number of impulses. In the "pulse" thermography, which is favorable for active thermography experiments, the starting point of recording can be synchronized with the heating or cooling phases or with any other arbitrary chosen delay time. A number of recorded images; recording speed and the stop condition are setting from the Erica 3.11 software.

For practical reasons very important is to assure a uniform irradiation, to avoid misinterpretation of measurement data. The dynamic properties of heating sources must be taken into account during modeling of the different shapes of excitation in dynamic thermography. To avoid the interaction between a lamp, which is self-heated during experiments, and a tested object a special shutter is needed to assure proper shape of a heating signal. The main information is given by temporal answer of heated tissues, which may be used for calculation of equivalent thermal tissue properties. For more about the procedures and equipment see our publications [10,11].

Electroimpedance

Experimental set up for studying bio-electroimpedance properties consists of a specially developed probe composed of two annular, compound electrodes; electronic interface circuit; Gain/Phase Meter Solartron SI 1260 and a computer. The construction of the probe is based on four-electrode technique in order to avoid influence of polarization phenomena on a value of measured impedance.
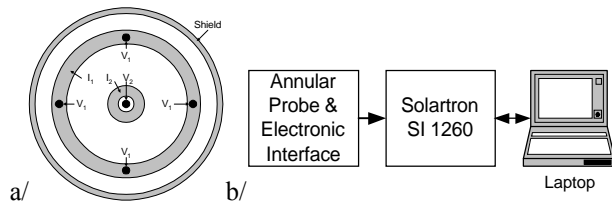

Fig.4. a/ The compound electrode (V_1, V_2 – voltage electrodes; I_1, I_2 – current electrodes); b/ Experimental set up used to monitor conductivity changes of myocardium evoked by ischemia process.

The compound electrode contains of two interleaved parts for current application and voltage measurements, Fig. 4a. Such construction of the electrode allows reduction of a volume of the negative sensitivity region [12]. As a result, the sensitivity of the probe to conductivity changes in the examined myocardium is only positive, i.e. increase of conductivity involved is evidenced as decrease of measured impedance. The properties of the probe were examined experimentally [13]. An electronic interface circuit is applied to the probe in order to reduce stray capacitance effects, Fig. 4b. Additionally, it improves measurement properties of the Solartron SI 1260; i.e. input impedance and CMRR.

During surgical interventions measurements of impedance are repeated every fifteen minutes on the average. Duration of a measurement is 50 sec. The frequency and amplitude of measurement current are respectively 5 kHz and 0.1 mA$_{p-p}$.

III. RESULTS and DISCUSSION

A. Classical thermography

This modality is showing temperature distribution on the observed surfaces and it's temporal local changes caused by external interactions (heating and cooling) as well as changes dependent on physiological processes existing in the living tissues. In our experiments the room temperature was stabilized on the level of 25^0C, therefore the radiation conditions were very stable and mainly physiological processes existing in the heart muscle were responsible for it's temperature changes. In Fig. 5 the first diagonal artery D1 (LI02) and the left coronary artery LAD (LI01) are indicated. The relatively uniform temperature distribution on the heart surface is visible before clamping the LAD – a/ (differences in the temperature distribution are not exceeding 1^0C), while 60 minutes after clamping it – b/ a significant decrease of the left ventricle wall temperature is evident (around 4^0C). Lower temperature indicates the region where the blood perfusion is eliminated due to the clamp, causing in effect the heart infarct. The observed decrease of temperature is typical for all regions of affected circulation.
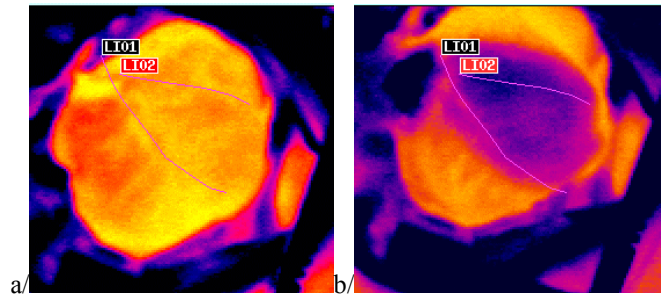

Fig.5. Thermograms of the same heart: before – a/ and 60 minutes after clamping the LAD – b/.

Interpretation of classical thermograms may be also facilitated in a form of differences resulting from two measurements (Fig. 6b). Important information is given by quantitative data; e.g. absolute value or change in time of temperature in a specific region may be indicating a specific state or process existing in examined tissues. This may be additionally evidenced by comparison to reference data as it is for example indicated in Fig. 6c, where temperature changes in time in the healthy right ventricle wall and in the blood deficient due to LAD clamping left ventricle wall are shown. In Fig. 6d temperature profiles along the line LI01 before (Fig. 5a and 6a) and after (Fig. 5b) clamping the LAD are shown. These pictures clearly indicate the region as well as the state of the affected tissue.
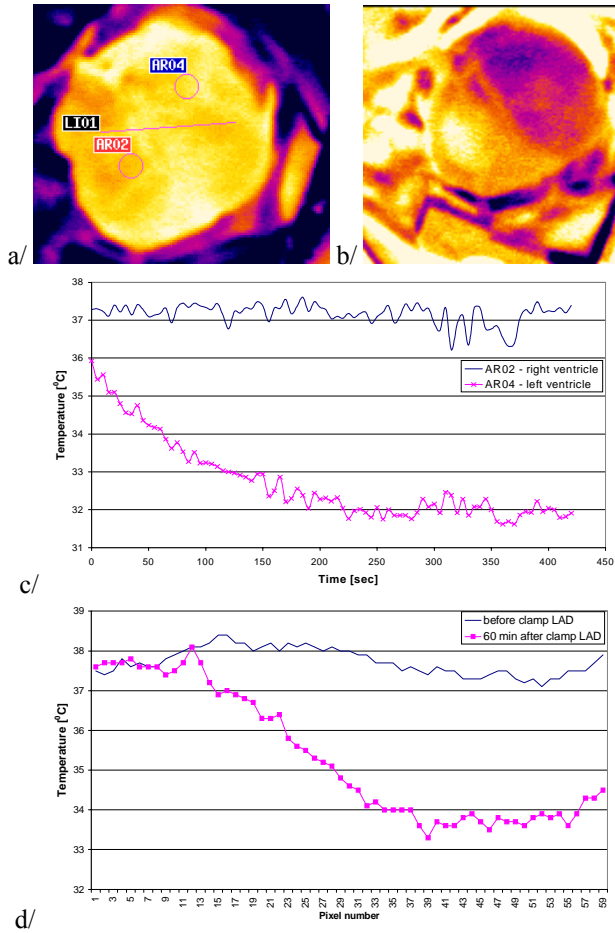
Fig.6. a/ Thermogram of the same heart as in fig.5a with indicated regions AR02, AR04 and the line LI01; b/ Differential picture of 5a - 5b; c/ The plot of temperature change in time (average values in regions AR02, AR04); d/ Temperature profile along the line LI01 before and after clamping LAD.

B. Active thermography

Dynamic processes existing at transient states while heating or cooling surfaces of tested objects are here studied. Therefore this modality is carrying information of physical thermal properties of tested tissues. The thermal time constant τ_{th} may be regarded as the main figure of merit. For the simplest heat transfer model this figure is calculated as the ratio of thermal capacity to thermal conductivity of the tested tissue region. Because thermal conductivity of the tissue plays the main role in the heat flow therefore correlated physical features of a tested organ could be reconstructed basing on temperature measurements. It should be underlined that the initial temperature is not important for the measurement result. The simplest one layer model to be applied in active thermography is of the form:

$$T = y_0 + A \cdot \exp(\, -t\, /\tau_{th}\,) \tag{1}$$

As an example two thermograms from a series forming a response to a heating pulse lasting 30 seconds and taken 60 minutes after clamping the LAD are shown in Fig. 7. Mean temperature changes of indicated regions AR02 (right ventricle) and AR03 (left ventricle) while cooling in consequence of pulsed irradiation are represented using best fitting normalized models of (1) as it is presented in Fig. 8

before and after clamping the LAD. The model parameters are gathered in the following table allowing quantitative evaluation of tissue properties. The change of tissue properties due to necrosis caused by clamping the LAD is evident.
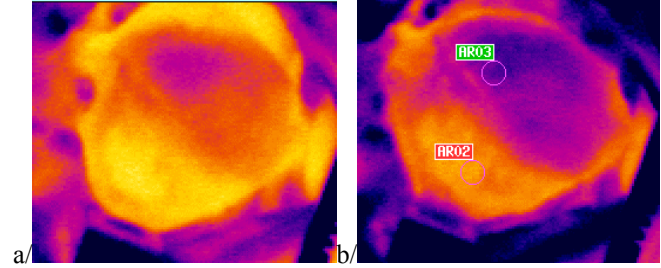

Fig.7. Thermograms of the heart 60 min. after clamping the LAD; response to irradiation instantly after it was switched off a/ and 210 seconds later b/.
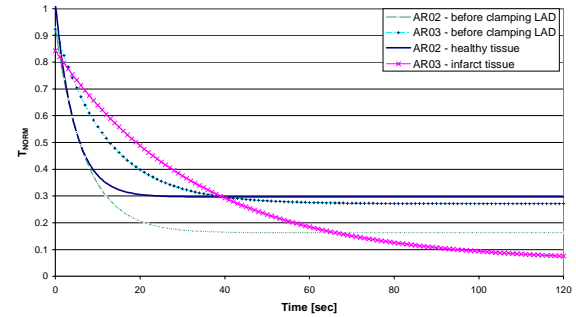

Fig.8. Mean temperature of regions AR02 (right ventricle wall) and AR04 (left ventricle wall) before and after clamping the LAD.

		Model parameters					
	Field	y_0	$\pm\, y_0$	A	$\pm\, A$	τ_{th}	$\pm\, \tau_{th}$
Before clamping LAD	AR02	0.1623	0.0076	0.7634	0.044	7.0063	0.6674
	AR03	0.2710	0.0117	0.6528	0.0461	12.227	1.5223
60 min after clamping	AR02	0.2353	0.0065	0.8343	0.0613	6.1907	0.7222
	AR03	0.1803	0.0126	0.6928	0.0385	33.249	3.5197
120 min after clamping	AR02	0.2966	0.0127	0.7179	0.0979	4.5641	1.0250
	AR03	0.0536	0.0159	0.7894	0.0213	33.446	2.4961

Typical presentation of active thermography results is also possible using synthetic pictures of τ_{th} (see [10]) or normalized parametric image [11] as it is shown in Fig.9.
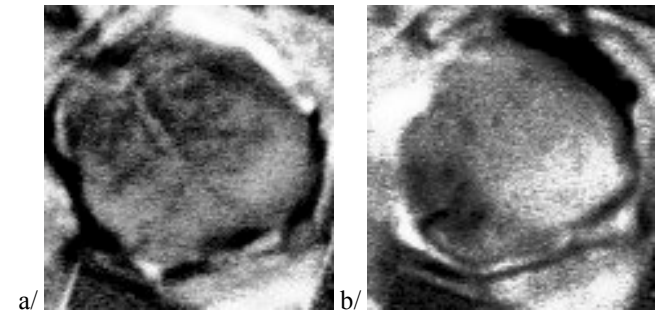

Fig.9. NDPTI – Normalized Differential Pulse Thermography Index of the heart: a/ before and b/ 2 hours after clamping the LAD.

C. *Electroimpedance*

Electrical properties of the heart muscle caused by the necrosis after the clamping LAD are changing what is shown in Fig. 10. This is obvious if we compare the biopsy results (see fig. 3 a/ and b/). The physical structure of cells is changed resulting in changes of thermal as well as electrical properties of tissue. Observation of electrical impedance changes allows recognition of the beginning of the necrosis process as well as the regions of affected electrical properties.
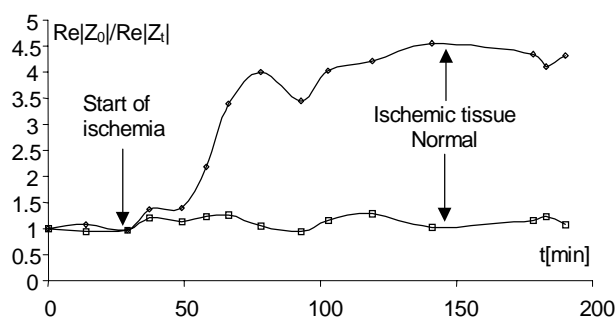

Fig. 10. Changes of impedance modulus (related to its initial value measured before clamping of LAD) during the time of experiment; reference data obtained for normal tissue are also presented.

V. CONCLUSION

The analysis performed shows that the information taken from thermography, active thermography and electroimpedance measurements allows to make direct inspection of the state of the heart. It is giving in each case data of different nature but always of great importance in terms of the evaluation of surgical procedures as well as visualization of actual state of the tested heart. The main disadvantage of all methods is that only surfaces accessible for observation may be inspected.

Classical thermography is unbeatable by any other method in terms of non-invasive, clean, affordable and easy in use observations for determination of temperature distribution, what is basic for evaluation of cardioplegia, by-pass grafting, vascularisation and some other cases important in cardio-surgical interventions. Quantitative information may be used for measurements related to reference points.

Active thermography and electroimpedance measurements are giving similar information of the state of inspected tissue. Necrosis may be easy discriminated. Some quantitative data given in these modalities also may be important for proper diagnosis. Active thermography is showing total observed area while electrical measurements are only local. Also geometrical resolution of thermography is much better. On the other hand electrical measurements are much cheaper although direct contact to the heart tissue is necessary causing much more aseptic problems. Synthetic pictures may be of the highest value but this needs some more research to be done, also more experiments are necessary for valuable medical conclusions.

The final conclusion: we may strongly advise the use of all three techniques in the cardio-surgical theater.

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