The use of thermography in early detection of tissue perfusion disorders in rats

Marek Łokaj[1], Norbert Czapla[1], Aleksander Falkowski[2], Piotr Prowans[1]

[1]Clinic of Plastic, Endocrine and General Surgery, Pomeranian Medical University, Police, Poland
[2]Department of Interventional Radiology, Pomeranian Medical University, Szczecin, Poland

Videosurgery Miniinv 2014; 9 (3): 329–336
DOI: 10.5114/wiitm.2014.43023

Abstract

Introduction: *Tissue perfusion disorders can be present in various diseases and progress in the form of arterial ischemia or venous stasis with accompanying local changes in temperature.*
Aim: *To use of thermography in the diagnostics of early periods of tissue perfusion disorders before the clinical symptoms occur.*
Material and methods: *Thirty-two male rats were used. After anesthesia the skin on lower limbs was shaved and femoral vessels of both sides were exposed. In 10 rats the left femoral artery was ligated, in 12 rats the left femoral vein was ligated and in the 10 remaining rats both left femoral vessels were ligated. Thermography of the limbs was performed before the vessels were ligated and after a period of 24 h. The pictures were taken every 5 s during 3 min. Before the measurement, the tissues were cooled down for 20 s with a 5°C water compress. The rate of temperature return to the limbs was evaluated.*
Results: *Statistically significant differences were observed after the 24-hour period on the thigh after the ligation of the vein, and on the shank and the foot after ligation of the artery. After the ligature of both vessels, statistically significant differences occurred immediately after their ligature within the thigh and shank and after 24 h on the foot.*
Conclusions: *The results show that cameras with an accuracy of 0.05°C can be used to detect tissue perfusion disorders. The special diagnostic value is the ability to detect perfusion disorders before clinical symptoms occur.*

Key words: *thermography, ischemia, venous congestion.*

Introduction

The body temperature is closely connected with the blood circulation in the skin and subcutaneous tissue and can change during various diseases. These include atheromatosis, diabetes, venous thrombosis, vasomotor disturbances, inflammatory diseases of the arteries such as Buerger's disease, Takayasu disease and dermatological diseases [1–4].

Vascular disorders of tissues can be caused by a surgical trauma especially during the dissection of tissue flaps. During the dissection the sympathetic innervation is harmed, causing vasomotor reactions and in the end hypoxia of the flap. The skin within the flap loses its thermoregulatory function. The highest risk of necrosis occurs within 8–12 h because the circulation in the flap is not stabilized and the amount of flowing blood can be insufficient to properly supply the flap. The forming hemodynamic changes cause the reduction of blood flow up to 20% on the circle of the flap, compared to its base. Peripheral ischemia can be the result of an arteriovenous leak caused by the opening of arteriovenous anastomosis. This leads to a reduction or even omission of the capillary

Address for correspondence
Norbert Czapla MD, PhD, Clinic of Plastic, Endocrine and General Surgery, Pomeranian Medical University, 2 Siedlecka St, 70-010 Police, Poland, phone: +48 606 113 653, e-mail: norbertczapla@gmail.com

network responsible for the nourishment of cells. The greatest leakage occurs within the first 12 h after the surgery and normalizes during the next 12 h. Collateral circulation on the border of the flap and tissues of the donor site occurs on the 4th day. The clinical evaluation of perfusion disorders is based among others on defining the color and temperature of skin. Pale skin can indicate arterial inflow disorder, while cyanosed skin can be caused by venous outflow disorder. Coolness of the transplanted tissue can also indicate its ischemia. Another element in the clinical examination is the vessel activity, which should be similar to the vessel activity in the donor site tissues [5–7]. Taking into consideration the hemodynamic phenomena mentioned before, the clinical evaluation is very often unsure and requires a lot of experience. The change of skin color can be caused by both natural hemodynamic phenomena taking place in the skin as well as pathological perfusion of the flap. Thrombosis in microanastomosis is one of the most common causes of failures after microsurgeries. The early stage of ischemia is difficult to detect by clinical examination. Nowadays, the most used diagnostic ways are Doppler ultrasound, computed tomography angiography (CTA), and magnetic resonance angiography (MRA). These solutions require expensive equipment and highly qualified personnel. The available literature suggests that thermography can be a valuable diagnostic method in diseases with tissue perfusion disorders. The temperature changes can occur before the clinical symptoms of ischemia, so it seems reasonable to examine the usefulness of thermography in postoperative monitoring of transplanted tissues. As for now there are no standards based on which thermography could be a reliable way of revising vascular anastomoses after microsurgery operation.

Aim

The aim of the paper is to evaluate the use of thermography in the diagnostics of early periods of tissue perfusion disorders before clinical symptoms occur.

Material and methods

Thirty-two three-month old male Wistar rats were used. Animals were divided randomly into groups: A – 10 rats with the femoral artery ligated; group B – 10 animals with both the femoral artery and the femoral vein ligated; and group C – 12 animals with the femoral vein ligated. The thermovisual measurements were taken after cooling the limbs down with a 5°C water compress for 20 s. The pictures were taken every 5 s for 3 min. We focused on the time in which the temperature returned to tissues and not absolute values of temperatures of examined areas. After anesthetization with ketamine, the femoral vessels of rats were exposed on both sides. The first temperature measurement was taken before the ligation of vessels, the second after a 20-minute pause immediately after the ligation of the proper vessel, and the third after 24 h. The vessels on the left limb were ligated with 5.0 suture. The right limb was used as a control. During 24 h of observation rats were isolated in cages; there were no losses or exclusion. The efficiency of the vascular system was evaluated on the basis of temperature changes in time, which corresponded to the area under the curve of the graphs. The points for reading the temperature were placed halfway along the thigh, halfway along the shank, and in the middle of the foot. A FLIR T 335 camera was used allowing for the evaluation of temperature changes with an accuracy of 0.05°C. It was placed 20 cm above the examined area, directed perpendicularly. Different persons performed the surgical procedures and the temperature measurements. The analysis of the statistical results was done with the sign test and Wilcoxon signed-rank test.

Results

The calculations were done using measurements from the first 60 s after cooling down, because after that time the temperature of both limbs remained at a constant level. The results of the efficiency of the vascular system in group A are presented in Table I for the shank and Table II for the foot.

The return of warmth in the shank and the foot 24 h after ligature of the artery was statistically slower in comparison to the control limbs. For the shank the sign test $p = 0.004$, Wilcoxon test $p = 0.005$. For the foot the sign test $p = 0.027$, Wilcoxon test $p = 0.007$.

The results of the efficiency of the vascular system in group B are presented in Table III for the thigh, Table IV for the shank, and Table V for the foot.

The return of warmth in the thigh 24 h after the ligature was statistically slower. The sign test

Table I. Shank temperature changes after ligation of the artery, expressed as the area under the curve

No.	Measurement before artery ligation		Measurement after artery ligation		Measurement after 24 h	
	Control limb (PO_N_0) [cm²]	Studied limb (PO_T_0) [cm²]	Control limb (PO_N_1) [cm²]	Studied limb (PO_T_1) [cm²]	Control limb (PO_N_2) [cm²]	Studied limb (PO_T_2) [cm²]
12	136.95	135.15	130.15	136.05	131.75	107.55
13	136.3	150.25	131.7	130.75	119.9	114.3
14	126.95	137.35	119.45	128.7	119.4	106.7
15	136.45	127.15	129.55	127.2	134.55	123.2
16	139.1	144	133.15	131.4	145.75	135.4
17	151.7	135	132.8	130.9	124.7	120.65
18	144.1	143.3	141.65	140.25	140.2	132.05
19	145	128.15	144.9	135.25	141.75	127
20	142.2	147.55	133.65	135.9	132.85	120
21	130.75	129.3	127.05	133.85	138.4	133.85
Average	138.95	137.72	132.41	133.03	132.93	122.07
Standard deviation	7.19	8.25	7.10	3.95	9.13	10.30

Table II. Foot temperature changes after ligation of the artery, expressed as the area under the curve

No.	Measurement before artery ligation		Measurement after artery ligation		Measurement after 24 h	
	Control limb (ST_N_0) [cm²]	Studied limb (ST_T_0) [cm²]	Control limb (ST_N_1) [cm²]	Studied limb (ST_T_1) [cm²]	Control limb (ST_N_2) [cm²]	Studied limb (ST_T_2) [cm²]
12	121.55	116.1	92.9	83.65	122.8	115.05
13	126.45	146.6	81.2	99.2	116.25	121.3
14	123.05	147.4	117.65	119.6	122.55	113.05
15	125.25	116.5	93.5	88.95	126.35	96.1
16	119	122.75	98.2	103.25	135.5	105.8
17	154.05	134.95	118.15	96.8	126.7	117.6
18	123.8	129.65	104.2	103.4	133.35	116.5
19	119.1	108.6	110.55	96.8	127.1	115.55
20	138.3	135.3	104	97.3	132.95	99.65
21	111.75	92.6	92.45	118.3	134.05	118.3
Average	126.23	125.01	101.28	100.73	127.76	111.89
Standard deviation	11.89	17.24	11.91	11.32	6.20	8.46

$p = 0.004$, Wilcoxon test $p = 0.005$. Statistically significant differences were observed also in the shank immediately after the ligature, Wilcoxon test $p = 0.047$ and in the foot after 24 h, sign test $p = 0.004$ and Wilcoxon test $p = 0.005$.

The results of the efficiency of the vascular system in group C are presented in Table VI.

There was a significantly faster return of the temperature in the foot 24 h after the ligature of veins, Wilcoxon test $p = 0.017$.

Table III. Thigh temperature changes after ligation of artery and vein, expressed as the area under the curve

No.	Measurement before artery ligation		Measurement after artery ligation		Measurement after 24 h	
	Control limb (ST_N_0) [cm²]	Studied limb (ST_ZT_0) [cm²]	Control limb (ST_N_1) [cm²]	Studied limb (ST_ZT_1) [cm²]	Control limb (ST_N_2) [cm²]	Studied limb (ST_ZT_2) [cm²]
22	102.95	103	84.15	94.45	124	111.45
23	140.05	154.9	113.4	119.85	148.65	122.35
24	144.15	130.4	97.95	89.35	128.55	117.4
25	116.3	91.85	101.35	92.45	116.6	115.8
26	139.6	113.6	99.45	99.95	103.7	102.15
27	154.75	129.1	128.2	109.3	102.25	98.95
28	127.85	127.35	102.45	92.65	133.95	118.25
29	131.4	132.55	99.9	114.5	119.9	119.35
30	118.8	106.1	89.55	89.55	138.05	132.5
31	121.7	113.55	120.45	105.5	105.1	97.65
Average	129.76	120.24	103.69	100.76	122.08	113.59
Standard deviation	15.37	18.19	13.46	10.95	15.64	11.12

Table IV. Shank temperature changes after ligation of the artery and vein, expressed as the area under the curve

No.	Measurement before artery ligation		Measurement after artery ligation		Measurement after 24 h	
	Control limb (PO_N_0) [cm²]	Studied limb (PO_ZT_0) [cm²]	Control limb (PO_N_1) [cm²]	Studied limb (PO_ZT_1) [cm²]	Control limb (PO_N_2) [cm²]	Studied limb (PO_ZT_2) [cm²]
22	133.95	137.15	122.35	129	139.8	133.4
23	137.75	143.5	134.25	131.35	141.1	126
24	146.3	128.65	132.75	122.8	137.9	132.5
25	134	133.35	132.05	137.45	132.05	138.85
26	150.85	128.05	137.2	123.6	137.7	133.4
27	154.9	143.3	152.3	128.4	124.5	127.65
28	154.5	131.2	140.8	127.25	141.2	128.65
29	137.85	144.05	143.4	136.55	136.55	138.6
30	141.9	137.55	127.4	128.7	133	133.3
31	145.05	133.55	148.35	132.45	130.85	129.5
Average	143.71	136.04	137.09	129.76	135.47	132.19
Standard deviation	7.91	6.07	9.28	4.84	5.32	4.33

Table V. Foot temperature changes after ligation of artery and vein, expressed as the area under the curve

No.	Measurement before artery ligation		Measurement after artery ligation		Measurement after 24 h	
	Control limb (PO_N_0) [cm²]	Studied limb (PO_ZT_0) [cm²]	Control limb (PO_N_1) [cm²]	Studied limb (PO_ZT_1) [cm²]	Control limb (PO_N_2) [cm²]	Studied limb (PO_ZT_2) [cm²]
22	102.95	103	84.15	94.45	124	111.45
23	140.05	154.9	113.4	119.85	148.65	122.35
24	144.15	130.4	97.95	89.35	128.55	117.4
25	116.3	91.85	101.35	92.45	116.6	115.8
26	139.6	113.6	99.45	99.95	103.7	102.15
27	154.75	129.1	128.2	109.3	102.25	98.95
28	127.85	127.35	102.45	92.65	133.95	118.25
29	131.4	132.55	99.9	114.5	119.9	119.35
30	118.8	106.1	89.55	89.55	138.05	132.5
31	121.7	113.55	102.45	105.5	105.1	97.65
Average	129.76	120.24	103.69	100.76	122.08	113.59
Standard deviation	15.37	18.19	13.46	10.95	15.64	11.12

Table VI. Thigh temperature changes after ligation of vein, expressed as the area under the curve

No.	Measurement before artery ligation		Measurement after artery ligation		Measurement after 24 h	
	Control limb (UD_N_0) [cm²]	Studied limb (UD_Z_0) [cm²]	Control limb (UD_N_1) [cm²]	Studied limb (UD_Z_1) [cm²]	Control limb (UD_N_2) [cm²]	Studied limb (UD_Z_2) [cm²]
1	135.6	137.05	125.25	129.85	101.5	101.2
2	137.5	131.9	135.95	125.95		
3	139.5	126.45	131.95	130.05	96.95	99.75
4	145.25	130.05	130.85	125.3		125.3
5	142	140.6	146.5	140.6		
6	133.95	129	114.1	118.8		
7	139.8	141.05	144.1	139.5	106.85	110.05
8	129.8	125.75	153.85	154.9	133.05	142.95
9	146.95	144.85	146	145.7	140.9	147.05
10	157	146.5	156.5	150.45	131.15	137.9
11	149.1	143.3	131.9	135.5	136.8	143.15
12	144.8	148.45	149.25	155.75	130.8	138.8
Average	141.77	137.08	138.85	137.70	122.25	127.35
Standard deviation	7.41	8.14	12.60	12.19	17.47	18.95

Discussion

Searching for methods of more accurate imaging of temperature distribution, many authors have tried to use thermovisual cameras. In the conducted research a FLIR T335 camera was used allowing for the evaluation of temperature changes with an accuracy of 0.05°C. Based on my own and other authors' observations it seems that cameras with an accuracy above 0.05°C do not considerably improve the diagnostic possibilities but significantly increase the cost of study [8, 9]. In the present research the temperature changes in the skin of lower limbs after the ligature of the femoral artery, femoral vein or both of those vessels were measured. The design of the study was supposed to verify the usefulness of thermography in the evaluation of early symptoms of tissue ischemia. The research proved that acute arterial ischemia after 24 h caused a statistically significantly slower return of the temperature in the shank and the foot compared to healthy limbs, whereas immediately after the ligation of the femoral artery there were no statistically significant differences. The blood supply of the rat's lower limb is different than that of a human. The ligature of the rat's femoral artery will not cause the same disorders of perfusion as occur after an immediate stop of flow in the human femoral artery. The lack of differences in time needed for the temperature to return immediately after the ligature of the femoral artery in comparison to the healthy limbs may be a result of compensatory work of arterio-arterial anastomoses. After the blockage of flow in the artery anastomoses allow blood from other arteries to flow to the ischemic areas. However, after 24 h of ischemia, degenerative changes started to occur in the tissues. They were revealed in the sensitive thermovisual examination. Acute occlusion of a large blood vessel usually results in characteristic clinical symptoms allowing for quick diagnosis of a problem. In the case of occlusion in smaller arteries the symptoms are unclear. It seems that in such cases the use of a thermovisual camera could make the diagnosis easier and faster and stand as a good alternative to presently used vascular examinations [10–13]. Similar experiments involving artery ligation were conducted by other researchers. Malafaia *et al.* examined intestinal ischemia in relation to the time of superior mesenteric artery occlusion in rats. The measurements were related to histopathological changes in the intestine. It was found that after 90 min of ischemia the intestine looked uncertain and it would be difficult to estimate the borders of ischemic tissue. In thermography however, large areas of ischemic intestine were revealed. Malafia *et al.* made the measurements in short periods of time. It was justified because the ligation of the mesenteric artery, which is the only vessel supplying this area, completely deprived the intestine of blood supply. In our research the ligation of the femoral artery did not completely deprive the limb of blood flow because of the existing collateral circulation. The existing blood inflow from other vessels was so efficient that we did not observe clinical symptoms of ischemia. Those changes were visible on the thermovisual image only 24 h after the ligation of the femoral artery. It seems that the experimental model presented in this paper better reflects the diagnostic value of thermography, which displays perfusion disorders with a lack of clinical symptoms. The ligation of the mesenteric artery will finally cause bowel necrosis which will be visible in the clinical examination. Small impairments of blood circulation do not cause visible necrosis; they can however be the cause of many aliments difficult to differentiate [14].

The research on myocardial blood flow shows the immense usefulness of the thermovisual camera. Lack of blood flow in one of the coronary arteries causes permanent damage to the muscle but only after a few hours. Forming necrosis, caused by ischemia, weakens the functions of the muscle. The use of a thermovisual camera allows one to detect acute ischemia before the necrosis occurs. Lekas *et al.* examined the usefulness of thermography in the intraoperative detection of pericardium temperature changes after the ligation of the left anterior descending coronary artery. It was revealed that after clamping the coronary artery the temperature of the epicardium in the area of its circulation fell by 1–5° in 20 min. However, after loosening the clamps it returned to the starting temperature in 1 to 3 min. The purpose of research by Lekas *et al.* was to determine the relationship between the temperature fall of the heart surface revealed in thermovision and the risk of arrhythmias. The research showed that a temperature fall of more than 2° increases the risk of arrhythmias, mainly ventricular fibrillation [15]. Similar observations were made by Papp *et al.*, who observed the temperature fall of the myocardium after ligation of the coronary vessel [16]. The influence of

ischemia on the temperature of the tissues was also examined by Abookasis *et al.* They registered the temperature fall of the brain after the ligation of rat's middle cerebral artery [17]. Sonmez *et al.* from Istanbul evaluated the flow in 4015 vessels used to bypass coronary vessels in 1401 patients. The saphenous vein, internal thoracic artery and radial artery were used as transplants. The temperature differences between the myocardium and coronary vessels were visible in the thermovisual image after the application of both cold and warm liquids used in cardioplegia before performing proximal anastomosis. The researcher also evaluated the overflow of blood through vascular anastomosis. In 34 cases because of the deep intramuscular position of coronary arteries or coverage with a thick fat layer, the thermovisual image was unclear. Due to quick intraoperative thermovisual evaluation of anastomotic patency and detection of occlusion in 12 patients, revision of the anastomoses was done without complications [18]. Coronary vessels and coronary bridges are positioned on the surface, which makes them available for the thermovisual camera. That is why the quoted authors could base their research on registered temperature differences. In our experiment the matter of the evaluation was the lower limb of a rat. Femoral vessels lie deep in the tissues and cannot be visualized in the thermovisual image. That is why in evaluating the circulation as a parameter reflecting the patency of vessels we focused on the time in which the temperature returned to tissues and not, like other researchers, absolute values of temperatures of examined areas. The temperature fall in the tissues can also be a result of capillary circulation disorders. In our research the temperature changes were the result of the ligation of main vascular trunks. Quoted works relate to various tissues and parts of the body. The results show that the reduction of blood flow independently of diameter and type of clogged arteries causes tissue temperature to fall. These changes can be exposed with the use of thermography before irreversible ischemic changes in tissues occur. It must be underlined that the results of measurements are affected by vascular anatomy, present collateral circulation and the time that has passed since the occlusion occurred. In the examination of the impact of venous congestion after ligation of the femoral vein, a statistically quicker return of the temperature in the thigh after 24 h was noted. Changes on the shank and the foot right after the ligation of femoral veins and after 24 h were not observed. Deng *et al.* researched the treatment of rabbit's deep femoral vein thrombosis. The thermovisual measurements were made 2 and 48 h after the application of thrombin. They concluded that deep vein thrombosis caused a statistically significant rise of the temperature already after 2 h [19]. Those results are consistent with the results obtained in our research in which a statistically significant rise of the temperature occurred after 24 h. The measurements on shanks and feet did not result in statistically significant differences. This can be explained by the small size and weight of tissue in the shank and the foot, which made it more difficult to take the measurements. In the case of Deng's research it must be noted that the weight of a rabbit's lower limb and also the diameter of veins are much greater than in analogous rat tissue. This caused clearer results of the changes caused by venous thrombosis in the rabbits than in our study. The rat's thigh is the only part with a large mass of tissue, which helps in precise measurement. It must be underlined that despite presenting statistically significant differences within the thigh, no clinical symptoms characteristic for venous stasis were observed in our research. The experimental model proposed in this paper illustrates very clearly the value of thermography in the diagnosis of asymptomatic vascular disorders.

Two cases within our results need to be discussed. Comparing the temperature return in group B, in which the vein and artery were both ligated, statistically significant changes were observed in measurement zero before ligature of the vessels. Those differences concerned the foot measurements. Similar results were obtained in group C in which the femoral vein was ligated. Statistically significant differences occurred in measurement zero before the ligation of the thigh vein. Analyzing the tissue temperatures after cooling them down, some significant differences were observed. This indicates the technical imperfection of simultaneous cooling down of such small objects. The likely cause was uneven adhesion of the water compress to rats' paws. Moreover, in some cases anesthetized animals made involuntary movements, which could have changed the adhesion of the cooling compress and influenced the measurement. The other results fall into the logical whole and the statistically significant differences obtained in the study can be interpreted based on available literature, anatomy and physiology of

tissues. In the study conducted in this paper, disorders of the rat lower limb blood flow were studied. The phenomena resulting from the impairment of arterial and venous blood flow can happen in various parts of the body. A special case concerns the free tissue flaps used in modern reconstructive surgery. The early detection of disorders, before clinical symptoms occur, is essential for the success of the operation as it allows one to avoid complications such as total or partial necrosis of the tissue flap. The time needed for an efficient collateral circulation to rise and provide support for the tissues is a few days long, whereas just a few hours of ischemia can cause irreversible changes. It seems therefore that the method researched in this paper allowing one to recognize early and asymptomatic disorders of blood supply can be particularly valuable. The results obtained in this paper encourage continuation of the research using thermovisual cameras and establishing standards of diagnosis, especially in cases of diagnostically difficult ischemic conditions.

Conclusions

Statistically significant differences in the return of temperature between the studied and healthy limb were noted after the 24-hour period on the thigh after the ligation of the vein, and on the shank and the foot after ligation of the artery. After the ligature of both vessels, statistically significant differences occurred immediately after their ligature within the thigh and shank and after 24 h on the foot.

The results show that cameras with an accuracy of 0.05°C can be used to detect tissue perfusion disorders. The special diagnostic value is the ability to detect perfusion disorders before clinical symptoms occur. In the case of vessels lying deep in the tissues and inaccessible for direct thermovisual examination, the evaluation should be conducted by comparison of the rate of temperature return in the examined area in proportion to an analogous healthy area.

References

1. Swirski FK, Nahrendorf M. Leukocyte behavior in atherosclerosis, myocardial infarction, and heart failure. Science 2013; 11: 161-6.
2. Gibbons GW, Shaw PM. Diabetic vascular disease: characteristics of vascular disease unique to the diabetic patient. Semin Vasc Surg 2012; 25: 89-92.
3. Bruce A, Massicotte MP. Thrombophilia screening: whom to test? Blood 2012; 120: 1353-5.
4. Fiessinger JN. Juvenile arteritis revisited. Buerger's disease-Takayasu's disease. Pathophysiol Haemost Thromb 2002; 32: 295-8.
5. Restifo RJ, Ahmed SS, Rosser J, et al. TRAM flap perforator ligation and the delay phenomenon: development of an endoscopic/laparoscopic delay procedure. Plast Reconstr Surg 1998; 101: 1503-11.
6. Rozen WM, Whitaker IS, Ashton MW, Grinsell D. Changes in vascular anatomy following reconstructive surgery: an in vivo angiographic demonstration of the delay phenomenon and venous recanalization. J Reconstr Microsurg 2012; 28: 363-5.
7. Christiano JG, Rosson GD. Clinical experience with the delay phenomenon in autologous breast reconstruction with the deep inferior epigastric artery perforator flap. Microsurgery 2010; 30: 526-31.
8. Pavlov IuI. Characterization of blood flow in different forms of diabetic foot syndrome. Angiol Sosud Khir 2005; 11: 21-5.
9. Jaworski Ł, Siondalski P, Jarmoszewicz K, et al. Arm temperature distribution in thermographic pictures after radial artery harvesting for coronary bypass operation. Inter Cardiovasc Thor Surg 2007; 6: 598-602.
10. Walker TG. Acute limb ischemia. Tech Vasc Interventional Rad 2009; 12: 117-29.
11. Robert BR. Clinical staging of acute limb ischemia as the basis for choice of revascularization method: when and how to intervene. Semin Vasc Surg 2009; 22: 5-9.
12. Mahmood KR. Detection and treatment of acute thromboembolic events in the lower extremities. Tech Vasc Interv Rad 2011; 14: 80-5.
13. Shields DA, Scurr JH. Treatment of the critically ischaemic lower limb. Postgrad Med J 1994; 70: 5-9.
14. Malafaia O, Brioschi ML, Aoki SM, et al. Infrared imaging contribution for intestinal ischemia detection in wound healing. Acta Cir Bras 2008; 23: 511-9.
15. Lekas R, Jakuska P, Krisciukaitis A, et al. Monitoring changes in heart tissue temperature and evaluation of graft function after coronary artery bypass grafting surgery. Medicina (Kaunas) 2009; 45: 221-5.
16. Papp L, Alló G, Szabó Z, et al. Natural history of acute regional myocardial ischaemia revealed by infrared thermography in the canine heart. Acta Morphol Hung 1985; 33: 123-42.
17. Abookasis D, Lay CC, Mathews MS, et al. Imaging cortical absorption, scattering, and hemodynamic response during ischemic stroke using spatially modulated near-infrared illumination. J Biomed Opt 2009; 14: 24-33.
18. Sönmez B, Arbatli H, Tansal S, et al. Real-time patency control with thermal coronary angiography in 1401 coronary artery bypass grafting patients. Eur J Cardiothorac Surg 2003; 24: 961-6.
19. Deng F, Tang Q, Zheng Y, et al. Infrared thermal imaging as a novel evaluation method for deep vein thrombosis in lower limbs. Med Phys 2012; 39: 7224-31.

Received: 5.10.2013, **accepted:** 2.12.2013.