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A Role of Thermography in the Diagnostics of Carpal Tunnel Syndrom

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BIOGRAPHICAL NOTES

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Ing. Radovan Hudak, PhD. Was born in 1976 in Košice, Slovakia. He received his MS and PhD. degree in biomedical engineering at Technical University in Košice in 2000 and 2008. Today Mr. Hudak is an assistant professor and head of prosthetics and orthotics study program and head of Biomedical Engineering Division at the Department of Biomedical Engineering, Automation and Measurement, Technical University of Košice. His research interests include, medical thermography, industrial thermography, human biomechanics and rehabilitation technologies. Since 2004 he is technical assistant at the Center of Refractive Surgery in Košice. Mr. Hudak has more than 70 publications in home and foreign journals. He is co-author of one monography and 2 books.

Mária Tkáčová was born in 1983 in Michalovce, Slovakia. She works for CEIT- KE, s. r. o. Her postgraduate study in area of biomedical engineering, she successfully completed at Technical University of Košice, at the Department of Biomedical Engineering, Automation and Measurements, in 2010. Today continuing her research interests for application of medical thermography for the musculoskeletal and neurovascular diseases, application of thermography for the maxillofacial area etc., human biomechanics and rapid prototyping. She is an author and co-autor of eleven publications in home and in foreign scientific journals and many presentations home and abroad.

Ján Švehlík was born in 1976 in Košice, Slovakia. He received his MD degree in general medicine at Medical Faculty of P.J. Safarik University in Košice in 2001 and Plastic surgery certification at Slovak Medical Health University in 2009. Today Mr. Švehlík is working as a specialist doctor at Clinic of plastic, reconstructive and aesthetic surgery at Univer-

sity hospital of L. Pasteur, Košice concentrating his interests on hand and reconstructive surgery and is responsible for replantation program of the hospital. His research interests include medical thermography, hand surgery, and pressure ulcer problematic. He attended one fellowship in Brno, Czech republic in 2006 and one observership in Rome, Italy in 2008. Mr. Švehlík has 6 publications in home and foreign journals. He is an author and co-author of many presentations home and abroad.

KEY WORDS
Medical Thermography, Carpal Tunnel Syndrome, Physiological Temperature of Hands

ABSTRACT
Presented paper deals with infrared thermography (IRT) used for the diagnostics of Carpal Tunnel Syndrome (CTS). More studies on medical thermography in the relation with CTS diagnostics were published. Jesensek Papez B. et al. in 2008 and 2009 improved outcome with classification success rates near to or over 80% in dorsal segments of hand. The background of this study is the skin physiological temperature distribution difference on the dorsal hands and pathophysiological temperature distribution on hands with CTS and non-invasiveness and painlessness of IRT. For presented study, the database of 268 thermal images of the dorsal side of 120 healthy (n= 120) and 14 pathological hands (n=14) with clinically diagnosed CTS of 8 patients were examined. Pre-surgical thermograms of the hands with CTS of each subject were taken and stored by using IRT (Thermocamera Fluke Ti55/20, FLUKE, USA). The new methodology of measurement and evaluation process of thermograms (SmartView 2.1, FLUKE, USA) was assessed. We observed the temperature distribution of the whole hand and the partial temperatures of the center point of carpals (D1), the center point of metacarpals (D2) and the finger tips of the third finger from proximal phalanges (D3), the intermediate phalanges (D4) to the distal phalanges (D5) and the Median Nerve Index (MI=(D1-D5)) were calculated [35]. Results obtained from measurements of the five defined points on the dorsal side of hands showed, that the temperature of CTS hands is characterized by a higher temperature in the phalanges unlike the wrist (MI<0, 71,4%), while the temperature is the lowest on distal phalanges (D5) of healthy hands (MI≥0, 85,8%). The results showed that the skin temperatures of median nerve distribution area on dorsal hands were significantly different between CTS and the control group. The sensitivity of IRT in diagnostic process of CTS is 0,714. Results will be confirmed by further screening of statistically significant group of patients.

INTRODUCTION
For many years temperature is the first measurement of a physical property for determination of diagnosis in the medicine. From electromagnetic theory it is a form of infrared energy being emitted from the first molecular surface of a body (skin). Infrared imaging is the detection and conversion of energy from a section of the infrared spectrum, into the visible spectrum. Surface energy levels are affected by the environment, operational conditions, heat transfer processes of a human body and skin characteristics. Because of thermograms interpretation is really important to know physiological characteristics and high skills with thermography measurement and picture analysis [9, 10, 15, 23, 35].

HEADLINE OF A SECTION
The goal of presented paper is to discuss the diagnostic role of medical thermography in neuro-vascular diseases of the human body such as Carpal Tunnel Syndrome (CTS). The main questions concern such problems as limitations in investigation of area of median nerve, diagnostic meaning of measurements, etc.
Medical thermography is a powerful tool for the study of surface temperature distribution of the human body. It is non-invasive, non-radiation, painless and non-contact imaging technique with numerous applications in medicine that include breast diseases (breast cancer) [5, 6, 8, 11, 13, 14], vascular diseases [19], skin diseases, [16, 20, 22, 27] studies of inflammatory responses [16, 21], Raynaud phenomenon [16, 18], sleep research [24], and painrelated thermal dysfunctions [2].
Jesensek Papez B. et al. (in 2008 and 2009) used a large database of 502 thermal images of the dorsal and palmar side of 132 healthy and 119 pathological hands. It confirmed the hypothesis that the dorsal side of the hand is of greater importance than the palmar side when diagnosing CTS thermographically. Using this method it was possible correctly to classify 72,2% of all hands (healthy and

pathological) based on dorsal images and > 80% of hands when only severely affected and healthy hands were considered. [1,3]

Ming, Z. at al. in 2007 used forty-one healthy hands (n=41) of 22 volunteers and 22 hands (n=22) with clinically diagnosed CTS of 16 patients were examined. A series of infrared photos of the hands of each subject were taken and stored by using digital infrared thermography (DIRT) before and 6 months after the CTR. The temperatures of the finger tips from digit 1 (D1) to digit 5 (D5), the center point of thenar (Th) and hypothenar (Ht) eminences were measured, the median nerve index (MI=(D1-D2)+(D1-D3)+(D2-D3)) and the temperature differences between the median and the ulnar nerve distribution area (MED.ULN=(D1-D5)+(D2-D5)+(D3-D5)+(Th-Ht)) were calculated. The results of DIRT measurements suggest that the blood flow regulation in CTS is abnormal possibly because of disturbed sympathetic vasomotor regulation and that the circulation gets normal together with the alleviation of the other symptoms of CTS as recorded 6 months after CTR operation [4].

CARPAL TUNNEL SYNDROME

Carpal tunnel syndrome (CTS), or median neuropathy at the wrist, is a medical condition in which the median nerve is compressed at the wrist (see Figure 1), leading to paresthesias, and numbness and muscle weakness in the hand. Night symptoms and waking up at night is a characteristic of established CTS. They can be managed effectively with night-time wrist splinting in most patients [1, 2, 3, 4, 35].

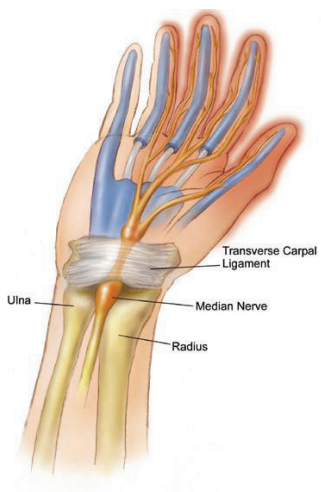


Fig. 1 *Pressured at carpal ligament*

In the case of CTS, what happens is that the finger flexor tendons get irritated enough so as to cause the Median Nerve to be compromised. This can happen for many reasons for example the finger flexor tendons are too thick, the Transverse Carpal Ligament is to thick or the carpal bones are too small [1, 3, 4, 35].

The result of these predisposing factors is that the finger flexor tendons cause friction as they move over one another and the heat generated results in local inflammation. This inflammation irritates the nerve and the pain that results is what one experiences when they have CTS. The reason there is so much pain associated with CTS is because of the pressure on the Median Nerve. That is why it is also known as a Median Neurapthy at the wrist. In severe cases, there can be sufficient compression on the Median Nerve causing muscle atrophy and motor weakness in turn.

In early stages of CTS individuals often mistakenly blame the tingling and numbness on restricted blood circulation. They may also be at ease and accepting of the symptoms and believe their hands are simply "falling asleep". In chronic cases, there may be wasting of the thenar muscles (the body of muscles connected to the thumb), weakness of palmar abduction of the thumb (difficulty bringing the thumb away from the hand) [1, 2, 3, 35].

The definitive treatment for CTS is carpal tunnel release surgery. This is effective at relieving symptoms and preventing further nerve damage, but established nerve dysfunction in the form of static (constant) numbness, atrophy, or weakness are usually permanent.

CTS is diagnostic with Special Test (physicians can use specific tests to try to produce the symptoms of CTS), The Tinel Test (the doctor taps on or presses on the median nerve in the patient's wrist, the test is positive when tingling in the fingers or a resultant shock-like sensation occurs), The Phalen Test (The Phalen, or wrist-flexion, test involves having the patient hold his or her forearms upright by pointing the fingers down and pressing the backs of the hands together) [30] and only EMG is one imaging diagnostic method. This method is based on the myodynamia, but results from EMG are not always clear. In addition, EMG is using electrodes either in contact with body or using invasive electrodes. Current medicine and seeks to be a non-

contact and noninvasive, also appears to thermography is suitable diagnostic method [35].
Problem with CTS is that it can be incorrectly diagnosed, and other syndromes can be diagnosed as CTS. A nerve conduction study, inflammation and temperature distribution may be of benefit in clarifying the diagnosis and this is the goal of this study.

METHODICS OF MEASUREMENT

Thermography is a temperature measurement technique used to produce a colored visualization of thermal energy emitted by the measured site at a temperature above absolute zero. Each pixel in the image depicts the radiance falling on the focal plane array/microbolometer - type detector used in an IR camera. [2, 7, 10, 19, 20, 23, 24]
Skin temperature on dorsal and palmar side of hands from our database (n= 268) was measured with a infrared thermograph (ThermaCam Fluke Ti55/20, Fluke, USA) infrared camera. This thermographic camera produces a matrix (representing image points) of temperature values. The thermal sensitivity of the thermograph is 0,05°C at 30°C. Camera works in the spectral range from 8 to 14 μm (human body infrared radiation is highest in the spectral range around 9,66 μm) [31] and the calibrated temperature range - 20 - 100°C. Resolution of the camera detector was 320×240 pixels (total 76,800 pixels). Data were obtained through a high-speed (60Hz) analysis.
Emissivity of the skin was set in the camera software to 0,98, the ambient temperature was measured by infrared (laser) thermometer (Pyrometer Testo 810) and for the control we used contact multimeter (Almemo Multimeter 2690, Ahlborn). Before each recording the camera was calibrated using the system's internal calibration process.
All thermograms (n=268) were processing with special software (SmartView 2.1, FLUKE, USA).

Conditions of Measurement

Our measurement was carried out under the same conditions, still in the same room about ambient temperature 20°C (±2°C). In this room were retracted blinds, to avoid the impact of solar radiation and the room was equipped with air conditioning, because of the condition of maintaining the same temperature at each measurement [7, 15, 19, 20, 33, 35]. Database is consist of reference thermograms (RT; nRT=240) and pathological (CTS) thermograms (PT; nPT=28). In the RT are male and female (RTF, nF=108). All group are divided into dorsal (dRT, ndRT=120; dPT, ndPT=14) and palmar (pRT; pPT) thermograms. PT is consists of female, therefore an RTF database for basic comparison of temperature was used. Current (thermographic) research focuses on the dorsal side of hand. And this is why we calculations focus on thermograms of female dorsal hands (dRTF, ndF=54).

Dorsal side	dRT_F [°C]	dPT [°C]	dPT-dRT_F [°C]
T_{MAX}	$32{,}244_{\pm 1{,}706}$	$34{,}479_{\pm 1{,}138}$	2,235
T_{AVG}	$27{,}611_{\pm 1{,}453}$	$31{,}8_{\pm 1{,}335}$	4,189
T_{MIN}	$22{,}785_{\pm 1{,}45}$	$24{,}093_{\pm 1{,}005}$	1,308
Parmar side	**pRT_F [°C]**	**pPT [°C]**	**pPT-pTR_F [°C]**
T_{MAX}	$33{,}267_{\pm 1{,}337}$	$34{,}757_{\pm 1{,}355}$	1,49
T_{AVG}	$27{,}783_{\pm 1{,}34}$	$32{,}186_{\pm 1{,}779}$	4,403
T_{MIN}	$22{,}217_{\pm 1{,}434}$	$24{,}271_{\pm 1{,}321}$	2,054

Tab. 1 *Comparison of thermal polygons, which route to contours hand from cca 1 cm supra-carpal to fingertips.*

Measured results clearly show that the influence of CTS is a hand warmer than a healthy hand by about cca 4°C (Tab. 1).

Median Nerve Index

Based on the knowledge, that symptoms of CTS are frequent burning, tingling, or itching numbness in the palm of the hand and the fingers. This is particularly typical for thumb or middle finger. Therefore, we identified five points in the lines of median nerve (on dorsal and palmar side of hand), on which we measured temperature. For dorsal side of hands it is the center point of carpals (D1), the center point of metacarpals (D2) and the finger tips of the third finger from proximal phalanges (D3), the intermediate phalanges (D4) to the distal phalanges (D5). (see Fig. 2)

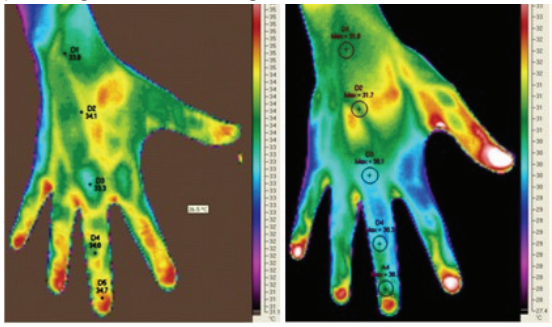
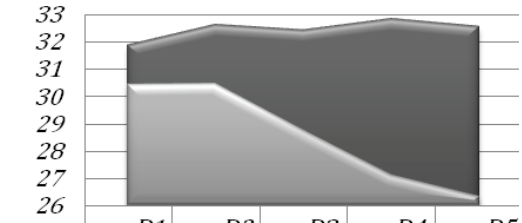


Fig. 2 *Location of points Di, on the left thermogram is hand of CTS (dPT) and on the right is hand from reference thermograms (dRT)*



	avg D1	avg D2	avg D3	avg D4	avg D5
CTS	31,871	32,629	32,429	32,843	32,557
RT	30,448	30,481	28,772	27,134	26,348

Graph 1 *Arithmetical average from temperature of hands on dorsal side of hand (line of median nerve)*

Graph 1 show relationship between points of line of median nerve from dRT_F (n_F= 54) and dPT (n_{PT}=14).
Cumulative average for physiological temperature distribution on female dorsal side of line of median nerve (D_{iF}= {D_{F1},…,D_{F5}}, see graph 1 and Fig. 2):

$$\overline{x_{DF}} = \frac{1}{n_{dF}} \sum_{i=1}^{n_{dF}} D_{Fi} = 28,638 \pm 3,189 \qquad (1)$$

Standard deviation for arithmetical average (1):

$$\sigma_{DF} = \sqrt{\frac{1}{n_{dF}} \sum_{i=1}^{n_{dF}} (D_i - \overline{x_{DF}})^2} = 3,188878 \qquad (2)$$

$$n_{dF} = 5.n_F = 270 \qquad (3)$$

Cumulative average for CTS temperature distribution on dorsal side of line of median nerve (D_{PT1}, D_{PT2},…,D_{PT5}, see Graph 1, Fig. 1):

$$\overline{x_{DCTS}} = \frac{1}{n_{dPT}} \sum_{i=1}^{n_{dPT}} D_{PTi} = 32,47 \pm 1,37 \qquad (4)$$

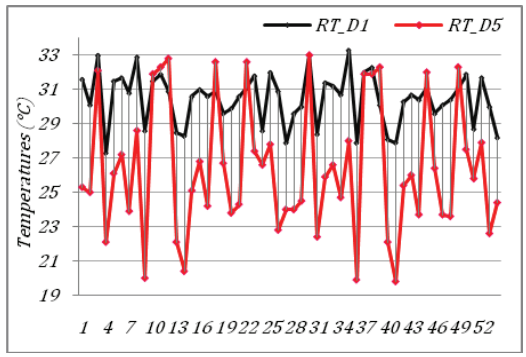
Standard deviation for arithmetical average (4):

$$\sigma_{DCTS} = \sqrt{\frac{1}{n_{dPT}} \sum_{i=1}^{n_{dPT}} (D_i - \overline{x_{DCTS}})^2} = 1,3706 \qquad (5)$$

$$n_{dPT} = 5.n_{PT} = 70 \qquad (6)$$

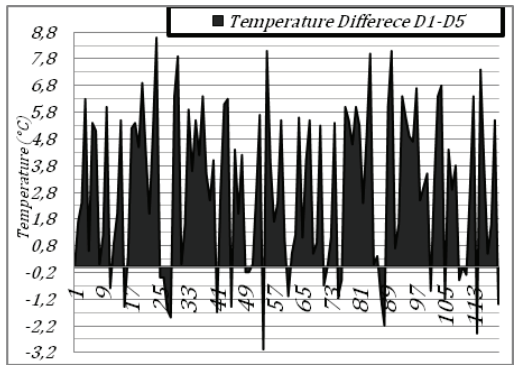
For account of Median Nerve Index (MI; Graph 2, 3, 4) [35]:

$$MI = D_1 - D_5 \qquad (7)$$



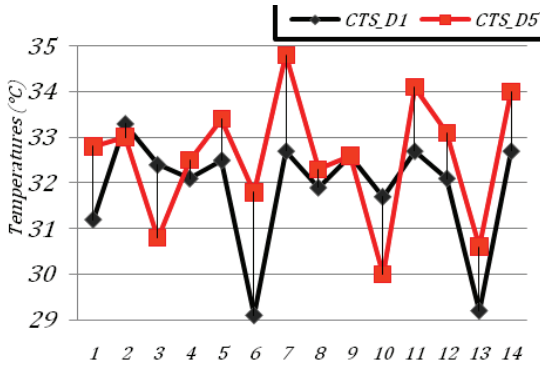
Graph 2 *Temperature difference between points D_1-D_5 (MI) from dRTF (n_{dF}=54)*

Negative difference D_1-D_5 (MI<0) from RT_F (n_{dF}=54) was detected in 8 healthy hands (that is 14,8% from dorsal side of hands from healthy female dRT_F), the arithmetical average from the eight hands was of course negative -1,275°C ± 2,947 but the arithmetical average from partial difference D_1-D_5 (MI) from dRTF (n_{dF}=54) was positive difference 4,1°C ± 2,927.



Graph 3 *Temperature difference between points D_1-D_5 from dRT (n_{dRT}=120)*

Negative difference D_1-D_5 (MI<0) from dRT (n_{dRT}=120, dorsal side of hands from healthy male and female) was detected in 23 hands (that is 19,2% from dRT) and the arithmetical average from the 23 hands was of course negative -1,165°C ± 2,944 but the arithmetical average from partial difference D1-D5 (MI) from dRT (ndRT=120) was positive difference 2,874°C ± 2,903.
Negative MI from dPT (n_{dPT}=14, dorsal side of hands from CTS patients) was detected in 10 hands (that is 71,4% from dPT), the arithmetical average from the 10 hands was -1,32°C±1,223 and the arithmetical average from partial MI from dPT was -1,165°C ± 2,944.



Graph 4 *Temperature difference between points D_1-D_5 from dPT (n_{dPT}=14)*

Median Nerve Index (MI)		
MI=D_1+D_5[°C] ± standard deviation		MI<0 [%]
dRT	2,874°C ±2,903	19,2
dRT_F	4,1°C ±2,927	14,8
dPT	-1,165°C ±2,944	71,4

Tab. 2 *Median Nerve Index (MI)*

Estimation of index test results

The diagnostic test performance includes consideration of validity and reliability of the test (infrared thermography). Specifically, sensitivity, specificity, and positive and negative predictive values were calculated when possible to assess the validity of infrared thermography testing. These measures were calculated based on presentation of results as shown in Tab. 3 below.

Based on Tab. 3 above, measures of validity and

		Reference test	
		Positive	Negative
Diagnostic test	Positive	**a=10**	**b=8**
	Negative	**c=4**	**d=46**
Total sample size		**n_1=14**	**n_2=54**

Tab. 3 *Assessment of validity of a diagnostic test*

95% confidence intervals were calculated using the following formulas:

Confidence interval for sensitivity: $p \pm 1{,}96(pq/n_1)^{1/2}$.

$$Sensitivity = \frac{a}{a+c} = \frac{a}{n_1} = 0{,}714 \qquad (8)$$

Confidence interval for sensitivity: 0,714±0,1207

$$p = \frac{a}{a+c} = \frac{10}{10+4} = 0{,}714 \qquad (9)$$

$$q = \frac{a}{a+c} = \frac{4}{10+4} = 0{,}714 \qquad (10)$$

Confidence interval for specificity: $p \pm 1{,}96(pq/n_2)^{1/2}$

$$Sensitivity = \frac{d}{b+d} = \frac{d}{n_2} = \frac{46}{54} = 0{,}8 \qquad (11)$$

Confidence interval for specificity: 0,852 ± 0,095

$$p = \frac{d}{b+d} = \frac{46}{8+46} = 0{,}852 \qquad (12)$$

$$q = \frac{d}{b+d} = \frac{8}{8+46} = 0{,}148 \qquad (13)$$

Positive predictive value (PPV):

Confidence interval for specificity: $p \pm 1{,}96(pq/n_2)^{1/2}$

$$PPV = \frac{a}{a+b} = \frac{10}{10+8} = 0{,}556 \qquad (14)$$

Confidence interval for specificity: 0,556 ± 0,077

$$p = \frac{a}{a+c} = 0{,}556 \qquad (15)$$

$$q = \frac{b}{b+d} = 0{,}148 \qquad (16)$$

CONCLUSION

Sensitivity and specificity of thermographic diagnostic test was realized in 54 healthy hands (ndF=54), where dorsal side of hands was scanned (dRTF) and 14 pathological hands (n_{dPT}=14) where also dorsal side of hands was scanned (dPT). As a referential test an EMG diagnostic method was applied. Sensitivity and specificity using formulas 6÷11 and argument MI=(D_1-D_5) from database of dorsal scans was calculated. The calculated sensitivity (0,714) with the confidence interval 0,714±0,1207 and specificity 0,852 with the confidence interval 0,852±0,095 showed, that thermography is the promising method in diagnostic process of CTS with the advantages of its non-invasiveness and contactlessness. More statistically significant measurements are required to confirm obtained results.

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